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Abstract Proceedings of the 5th Disaster Risk and Vulnerability Conference

K. R. Baiju, Karunakaran Akhildev, Joice K Joseph, Naveen Babu, Anithomas Idiculla,
Asha Rose, Shibu K Mani, Mahesh Mohan and A.P. Pradeepkumar
Editors

Disaster Risk and Vulnerability Conference

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Preface

The School of Environmental Sciences, Mahatma Gandhi University at Kottayam, Kerala, India is hosting the DRVC2023 from 19 to 21 January 2023, the fifth in a series that builds on the success of previous Disaster Risk and Vulnerability Conferences of 2011, 2014, 2017, and 2020. This series is a result of the frequent and severe disasters that have become the norm around the globe, particularly in light of climate change. After the initial DRVC, repeats were motivated by the interest that was created among the various stake holders. The conference is also a collaborative effort of the School of Environmental Sciences, Mahatma Gandhi University and the Department of Geology, University of Kerala.

Between the first conference and now, there have been numerous disasters around the world, and today's most devastating effects of disasters are displacement, migration, and humanitarian crises. Every catastrophe forces us to undertake the difficult task of conducting a postmortem, and inevitably, it becomes clear that there were no lessons learned. In this context, conferences like the DRVC become important as platforms for practitioners from various fields that deal with disasters to come together and learn from one another, share ideas and experiences, and discuss disaster management failures and successes. The papers in this volume are a result of such studies and cover a wide range of topics, including the use of technology to prevent or lessen the effects of disasters as well as post-disaster rehabilitation and recovery.

The enthusiastic sponsorships and participation of numerous agencies have helped to sustain the DRVC series. The conference has consistently been supported by both universities. The five conferences have all been faithfully funded by the Kerala State Disaster Management Authority (KSDMA). The conference has been supported over the years by the Atomic Energy Regulatory Board, the National Disaster Management Authority, the Department of Science and Technology, and the Kerala State Council for Science, Technology, and the Environment. The NGO 'Charitable Society for Humanitarian Assistance and Emergency Response Training', Christ University in Bangalore, Applied Geoinformatics for Society and Environment (AGSE) Germany, and Loyola College in Trivandrum have also provided assistance, which is gratefully acknowledged. We thank the entire faculty, staff, and students of the School of Environmental Sciences at MG University for their active participation and cooperation in the planning and execution of this event. Finally, we thank all of the delegates for coming from near and far, submitting their papers, and being here today. We hope to see you all again at the next DRVC and wish you all pleasant days of productive discussions and building collaborations, while at the conference.

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A COMPARATIVE STUDY OF AREAS AFFECTED BY FLOOD IN TWO DEVELOPING COUNTRIES

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Abstract:

Data was gathered from two nations, India and Namibia, and the study's main focus was on flood-affected areas. The study area in India is located in Kerala state, Kottayam district, in Maniyaparambu-West, Upper Kuttanad, and Mannanam. The study area in Namibia is found in Oshana region. Recurrent floods of differing sizes inundate both study regions every year. This study employed a non-structured questionnaire method and a field investigation to ethnographically analyse inhabitants perceptions of flood danger and coping mechanisms in the studied area. Desk research examined how much indigenous knowledge had been incorporated into disaster risk reduction strategies in both nations in connection to the Hyogo Framework for Action 2015–2030. Majority of the residents who were interviewed (80%) indicated that their houses are located in flood prone areas. An evaluation of Namibia's National Disaster Risk Management Policies identified flaws, particularly because modern disaster risk reduction is preferred over indigenous flood knowledge. Although flood in Kerala has become more frequent in recent years, the rebuild Kerala initiative guides the state to resilient recovery. In conclusion, majority of survey respondents are aware of their susceptibility and the risk of flooding they face. The respondents also indicated that the relief camps were well structured and met sphere standards. Recommendations include introduce DRR programmes in institutions of higher learning and translate awareness materials into local languages for risk communication to be effective which will help reduce the gap existing between the floodplain residents and policy makers.

Keywords:

Flood, Disaster, Coping Strategy, Risk, Awareness

INTRODUCTION

Namibia is a country in southwestern part of Africa. With 2.5 million inhabitants as of 2020, the nation is the second least densely inhabited nation in the world. The climate is generally hot and dry with sparse and erratic rainfall. 92% of the land area is defined as very-arid, arid, or semi-arid. With approximately 300 days of sunshine annually, and persistent, dry onshore winds provoked by the Benguela current, Namibia is quite dry for much of the year (NASA 2020). The dryness of the country is largely a function of the northward flowing Benguela current, which brings cold air to the western shores, driven by a high-pressure system, this combination generally suppresses rainfall. With a range of 650 mm in the northeast to less than 50 mm in the southwest and along the coast, the average annual rainfall is only 278 mm. This study focuses on flood in Oshana region which is located within the cuvelai basin. This region is one of the most affected regions in the past by floods.

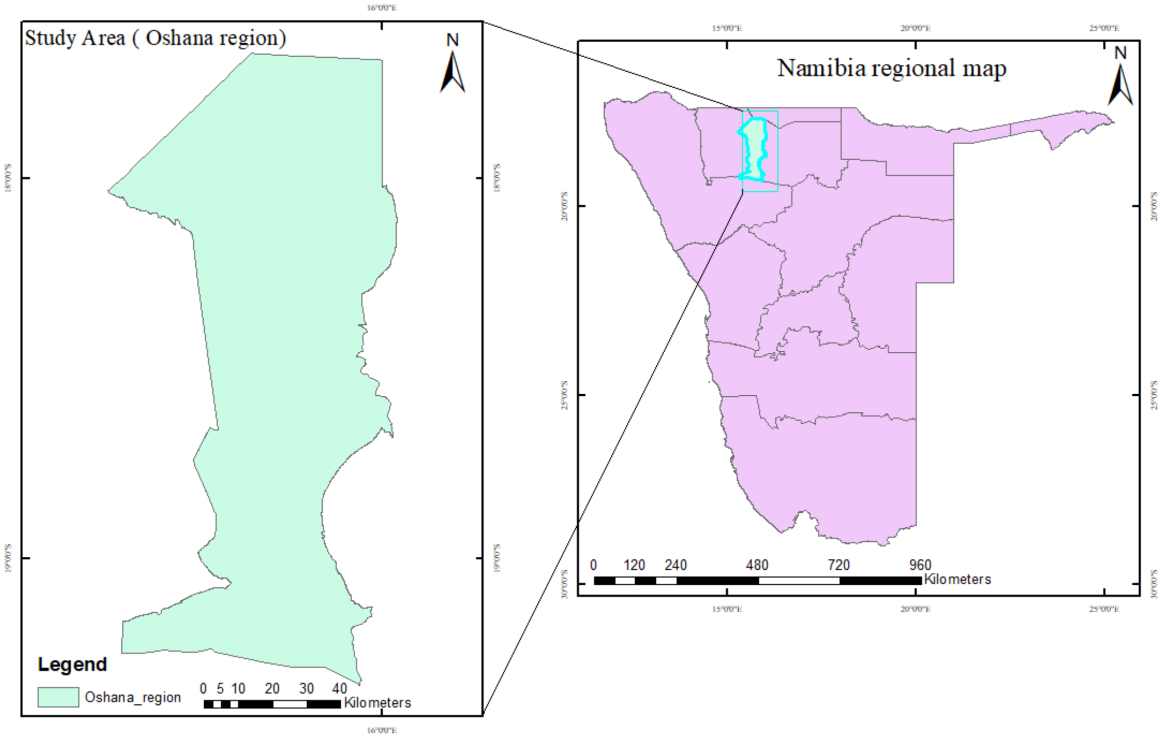


Figure 1: Map of study area in Namibia (Oshana region)

India is a country in South Asia. India receives major rainfall in only four months, June to September. Distribution of rain in India is not similar at every place, some areas receive higher rainfall and some receives lower (Prakish, 2015). The variation also fluctuates from time to time, and occasionally major flooding due to precipitation and cloud bursting occurs in locations that are not typically prone to flooding. According to the report by NIDM, heavy rains during periods of full river flow are the main causes of floods as well as the excessive rainfall in river catchments or concentrations of tributary runoff and river carrying flows that are higher than their design capacity. The study area is located in the state of Kerala. The State of Kerala is located in the southwestern part of Indian peninsula. It has a geographical area of 38,863 sq.km. The state belongs to one of the highest monsoon rainfall regions in India, along with the northeast India. The annual normal rainfall of the state is around 3000 mm with significant spatial variability across the state, and June and July months contribute the dominant share to the annual rainfall (Sudheer, 2018). The research was conducted in Mannanam and Maniyaparambu-West-Upper Kuttanad. Mannanam is a small Village in Ettumanoor Block in Kottayam District.

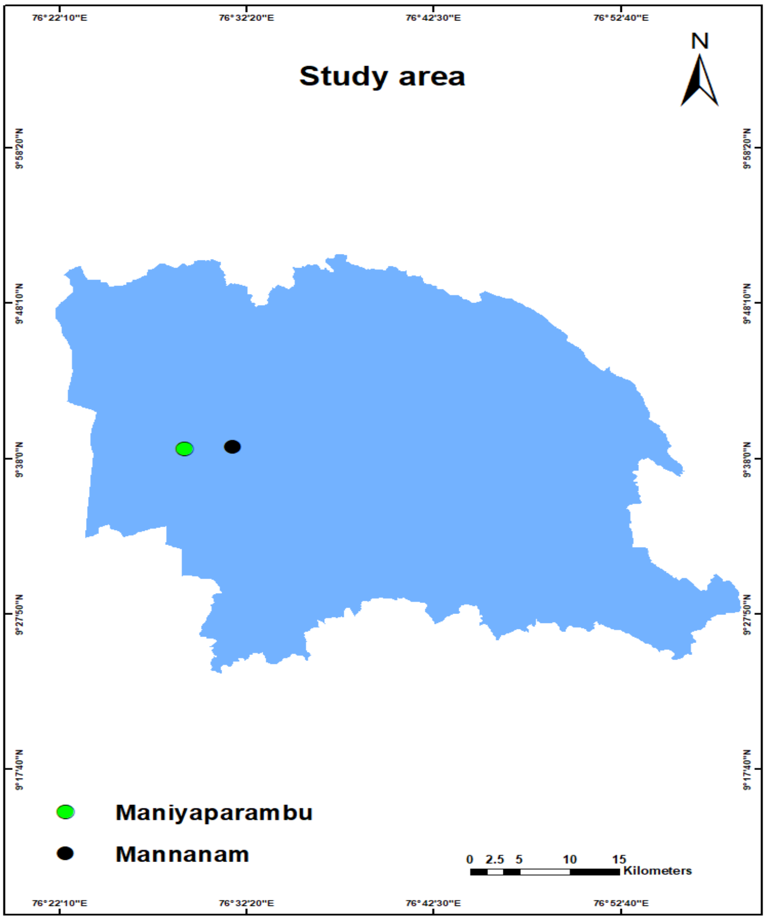


Figure 2: Map of Kottayam and study area

RESEARCH QUESTIONS

This research investigates the challenges that are faced in the floodplain, coping strategies, impacts of flood damage and conditions of relief camps of people in the northern Namibia and residents of Mannanam and Maniyaparambu-West-Upper Kutannad in Kottayam district in Kerala state. The research aimed at understanding and anticipating public responses to flood hazards in the study area to enhance the disaster risk reduction level through improved communication and policy. This research fills the gap existing in the lack of mitigations and coping strategies in the above-mentioned study areas by investigating risk perceptions and indigenous coping strategies.

What early warning system for flood is available in your area?

What strategies do floodplain residents use to cope with recurrent floods?

To what extent has the Government of both countries incorporated indigenous flood knowledge in disaster risk reduction (DRR) policies and programmes in relation to the Hyogo Framework for Action 2015-2030?

LITERATURE REVIEW

flood as a hazard

A hazard is a source of potential harm to a community, including its population, environment, private and public property, infrastructure, and businesses (Coppola, 2006). Flood is a natural hazard, natural hazards are the most common type of hazards worldwide because they affect more people than any other hazard (Twigg, 2004). In 2020, approximately 34.2 million people worldwide were impacted by flooding, including being injured or losing their homes (Alves,2022). Flood risk is near universal. Extreme flooding events are not relegated to the least developed nations, but can also devastate and ravage the most economically advanced and industrialized nations (UN, 2020). A vast number of people badly affected by flood are located in South and South east Asia. These regions are home to the majority of flood-exposed people, about 1.36 billion; with China (329 million) and India (225 million) alone accounting for over a third of the entire world population (Rentschler, 2020). In March of 2009, torrential rains across Angola, Namibia, and Zambia increased water levels in the Chobe, Kunene, Kavango and Zambezi rivers to such an extent that the North Central and North Eastern Namibia experienced the worst flooding in decades (GRN,2009). The causes of the flood disasters have been the above normal rainfall received in the northern central and eastern regions of Namibia, southern Angola and Zambia, the high inflows in the Cuvelai basin, Kwando and Kavango Rivers with flood waters from southern Angola (Octavi 2011). The damage affected an area that is home to sixty percent of the total population, destroying critical infrastructure, washing away crops and livestock, damaging homes, and causing widespread displacement. India is vulnerable, in varying degrees, to a large number of natural as well as man-made disasters, over 40 million hectares (12 per cent of land) is prone to floods and river erosion (NDMA, 2009)). The leading causes of floods in India are incessant monsoon rainfall, reduced river channel carrying capacity for high flows, riverbank erosion and the siltation of channel beds, poor natural drainage in flood-prone areas, cloudbursts and several other meteorological factors (Bhattachaiyya, 1997, Nandargi, 2003 and Sharma, 2012). In August 2018, the state of Kerala witnessed large-scale flooding, which affected millions of people and caused 400 or more death (Kaushik et al,2018). The flood was very unprecedented and rainfall in hilly districts were three times more, and the state was also not prepared for such mega scale, as it has not experienced a flood of this magnitude, except the recorded one in 1924. More than 1.75 lakh buildings were fully or partially damaged, affecting 7.5 lakh people. Apart from loss of lives and destruction of homes, the affected populace people grieved over the loss of jewellery, family photographs, and religious objects (NIDM, 2018).

Indigenous Knowledge (IK) and Coping Strategy

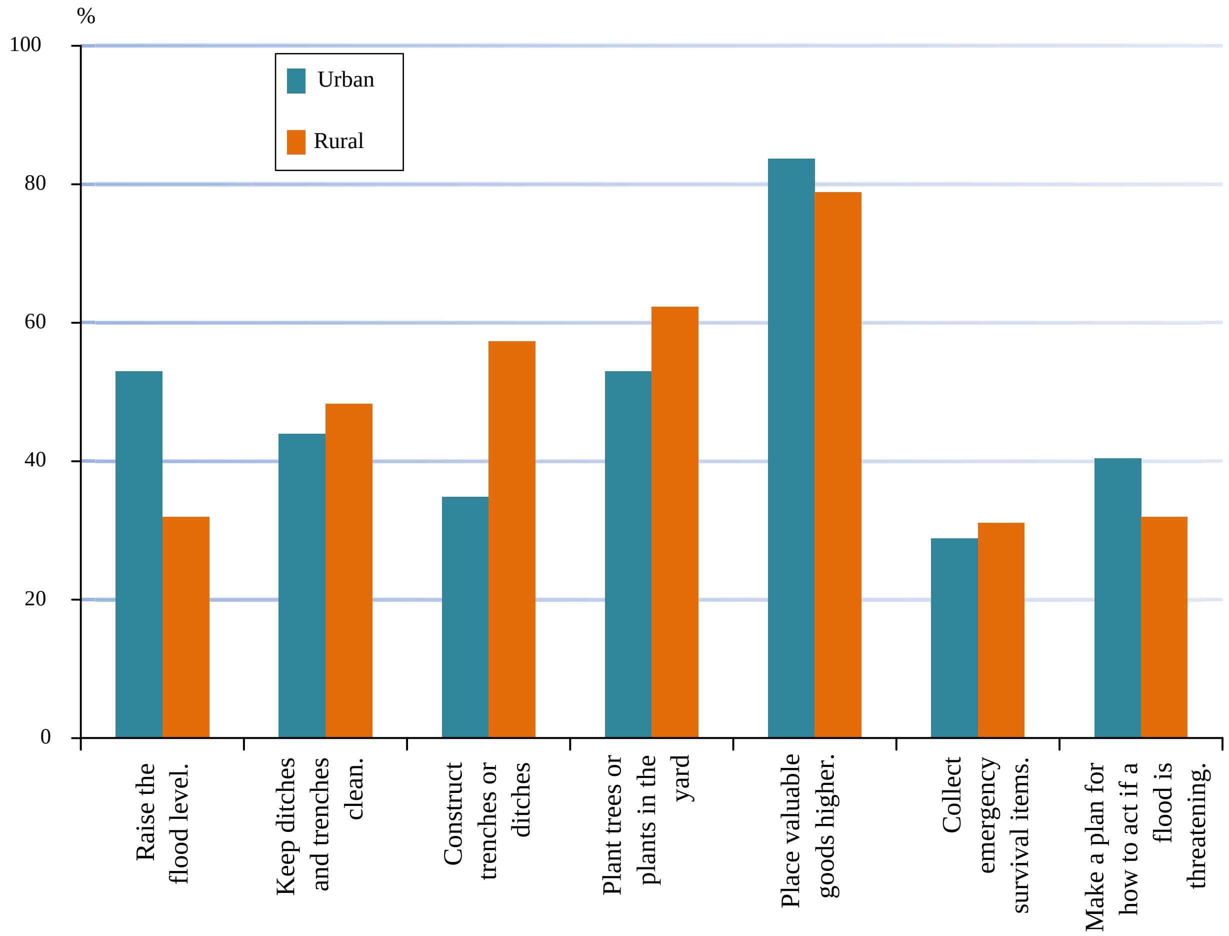
Indigenous knowledge refers to the methods and practices developed by a group of people from an advanced understanding of the local environment, which has formed over numerous generations of habitation (Shaw, et al, 2008). It is the basis for coping with hazard and is always executed first by the local people before any external support from the government, international community or humanitarian organisations like the Red Cross Society or the UN. It is most commonly transmitted orally or through demonstration and imitation from earlier eras, and it is generally learnt by repetition (Ellen and Harris 1996).

Repetition also helps in the reinforcement and retention of this knowledge (Sen 2005). Coping is an individual response to overcome a problem, the response is in accordance with what is felt and thought to control, tolerate and reduce the negative effects of the situation at hand (Baron et al, 2004). Finding new approaches to enhancing communities' and individuals' ability to adapt to these changes is necessary given the increased unpredictability surrounding global environmental changes. There are countless ways different groups of community's copes with hazards and resultant disasters (Mushabati, 2014). Coping strategies can be categorised as economic, technological, social and cultural strategies (Twigg, 2004). These strategies are applied before, during and after the disaster. Preventative strategies aimed at reducing the severity, are applied before disaster impacts (Wisner et al, 2004). During the disaster, communities at risk apply 'response strategies' that may include relocating some property and people from high-risk areas to more manageable risk areas. At the same time indigenous people might access stores of food or find alternative food from fields or forests, seek income from extended family and sell stocks (Wisner et al 2004). Floodplain dwellers may even take advantage of the floods through fishing, lily tuber harvesting or reed crafts. After disaster strategies, on the other hand, can be termed 'recovery' strategies. They include cleaning, renovations, developing new social networks, diversifying agricultural production, building food and saleable assets (Wisner et al,2004; Jabeen et al 2010; Twigg, 2004).

Coping strategy from India

The State of Kerala is striving to build flood-resistant houses (Rajendran, 2019). Kuttanad is an area in central Kerala that is 1.2 to 3.0 metres below sea level, the 2018 floods in Kerala, however, were the worst to ever occur here in modern times, flooding thousands of homes. Some elevated prefab homes being built in this area are bringing in new hope as shown in the figure below.

Figure 3: A house on stilts in Kuttanad area of Alappuzha district of Kerala
Sources:https://india.mongabay.com/2019/07/flood-resistant-housing-attracts-attention-in-kerala/



Coping strategy from Namibia

In Namibia, the household survey done by Hooli (2015) revealed that nearly all of the respondents (94%) had used at least a few coping mechanisms to strengthen their resilience to floods. Graph 1 below displays the most popular techniques and how they are used differently in urban and rural setting in Namibia. The most frequently used precautions were practical and short-term, such as elevating valuables higher in the home, gathering emergency supplies, creating a plan for what to do if the flood becomes a threat, and moving immediately in case of flood.

Figure 4: Most frequently applied coping measures in Namibia
Sources: Hooli (2015)

The role of indigenous knowledge in resilience building

The resilience notion emphasises the importance of communities to 'build back better (UNISDR, 2010), to bounce back if not bounce forward, and to bounce back from tragedies with little to no outside help. As evidenced by the Hyogo Framework for Action's 2005 demand for "raising the resilience of nations and communities to catastrophes," indigenous knowledge systems are becoming more and more involved in disaster resilience "thinking"(UNISDR, 2005). Disasters have demonstrated that the recovery, rehabilitation and reconstruction phase, which needs to be prepared ahead of a disaster, is a critical opportunity to "Build Back Better", including through integrating disaster risk reduction into development measures, making nations and communities resilient to disasters (SFDRR, 2015). In India context, BBB concepts were highlighted after the 2004 Indian

Ocean Tsunami and organisations such as the United Nations Office for Disaster Risk Reduction, United Nations Development Programme (Clinton, 2006; Mannakkara et al, 2013), Indian Red Cross Society and others considered BBB an obligatory concept. A Post Disaster Needs Assessment (PDNA) was created by the United Nations in the wake of the 2018 Kerala floods to evaluate the state's needs for damage, loss, and recovery (Neerja et al, 2020). Rebuild Kerala Initiative (RKI) was founded by the Kerala government to develop, organise, monitor, and evaluate the Rebuild Kerala Development Programme (RKDP), a strategic plan to create a resilient and environmentally friendly Kerala (RKDP, 2018).

International framework for disaster risk reduction

The Sendai Framework for Disaster Risk Reduction 2015-2030 (Sendai Framework) was the first major agreement of the post-2015 development agenda and provides Member States with concrete actions to protect development gains from the risk of disaster. It was endorsed by the UN General Assembly following the 2015 Third UN World Conference on Disaster Risk Reduction (WCDRR), and advocates for:

The substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries.

On 1st June 2016, the prime minister of India released national disaster management plan (NDMP**)** which is based on sendai framework for action**. The plan aims to make India disaster resilient and reduce loss of lives**. The NDMP serves as a document or guideline for the government agencies to act in all phases of disaster. It also identifies major activities such as early warning, information dissemination, medical care, fuel, transportation, search and rescue, evacuation, etc. to serve as a checklist for agencies responding to a disaster (PMINDIA, 2016). Namibia has also started to focus on sendai target number seven which is to increase accessibility: It target to substantially increase the availability and access to multi-hazard early warning systems and disaster risk information and assessments to the people by 2030.

METHODOLOGY

RESEARCH DESIGN

This study is qualitative in nature. The use of a qualitative study approach gave the researcher the chance to look into the impacted people's subjective perceptions, permitting a thorough understanding of victims' coping mechanisms and flood mitigation measures. A descriptive ethnographic study was chosen as a method for doing qualitative research. This approach concentrates on the social structures and cultural legacies of communities in their naturalistic environment. A key feature of qualitative ethnographic research is the naturalistic paradigm, “leaving natural phenomenon alone” (Maree, 2007). Despite being aware that research participants may have an impact on the researcher, the researcher subtly avoids tampering with the phenomenon.Documents and reports from Namibian National Disaster Risk Management (NDRM), Namibia Red Cross Society and all other available literature on DRR were examined to assess the degree to which coping and mitigation techniques had been incorporated into the disaster management policy. Literature review from India provided insights into best practices that the Namibian Government could adapt and modify to enhance their responses to flood hazards.

Field work and selection of the research subjects

Primary and secondary data were collected during this phase. The data were collected from September 2022 to October 2022. Primary data for India was gathered through in depth, one on one interviews conducted with each household. A total number of 21 households were interviewed in India. The population for this research, from which the sample was selected is located in Kottayam district and Oshana region in Namibia. Participant. These districts are located in close proximity to the channels that subsequently flood.

Sampling refers to the process of selecting a portion of the population for study (Maree et al, 2007). This study sampled forty (N=40) participants over from the age of 18- 72 years purposive sampling. Nineteen (19) participants from Namibia and twenty one (21) participants where from India. In **purposive sample,** a researcher selects participants from their sampling frame because they have characteristics that the researcher desires. Gender interviewed varied. Combining gender contributed greatly to the study, and the researcher could observe, how people communicate and gave their opinions.

Data collection instruments and procedures

This research contains secondary and primary data. The secondary data from Namibia was collected from newspapers, journals, government reports and news channel. Primary data were collected from Mannanam and Maniyaparambu-West-Upper Kuttanad using a disaster literacy questionnaire. Primary data Interviews were conducted in Malayalam language (n=21). All interviews were semi-structured to give an in-depth description of the residents' experiences in the floodplain. Later, analysis of both countries' s flood management strategies and programmes conducted on a desk-top enhanced the empirical field data.

Research ethics

The interviewer explained to the participants the length of the interview and the research made it clear that participation was voluntary and the information gathered remains confidential.

Limitation and scope of study

The data collected from Namibia was done through google form only, the researcher was not physically present to interact and ask respondents questions or to clear any doubts if respondents had any. Another limitation is that the researcher could not understand the Malayalam language, since data collection in India was done using an interpreter, the researcher also missed out on some important points which victims mentioned during the interview.

RESULTS AND DISCUSSION

A total number of forty (n=40) participants took part in the survey, twenty-one (21) participants from India and nineteen (19) participants from Namibia. The combination involved both male and females, ranging from the age of 18 years to 72 years old.

Table 1: Total number of participants in the survey

Country	No of participants
India	21
Namibia	19
Grand Total :40	

The majority of respondents, according to the research's findings, were female (see Graph 2). This is because many men leave the area in pursuit of work in other places. Since the females' ability to cope is constrained by social and economic restrictions, this eventually increases the community's susceptibility to flooding.

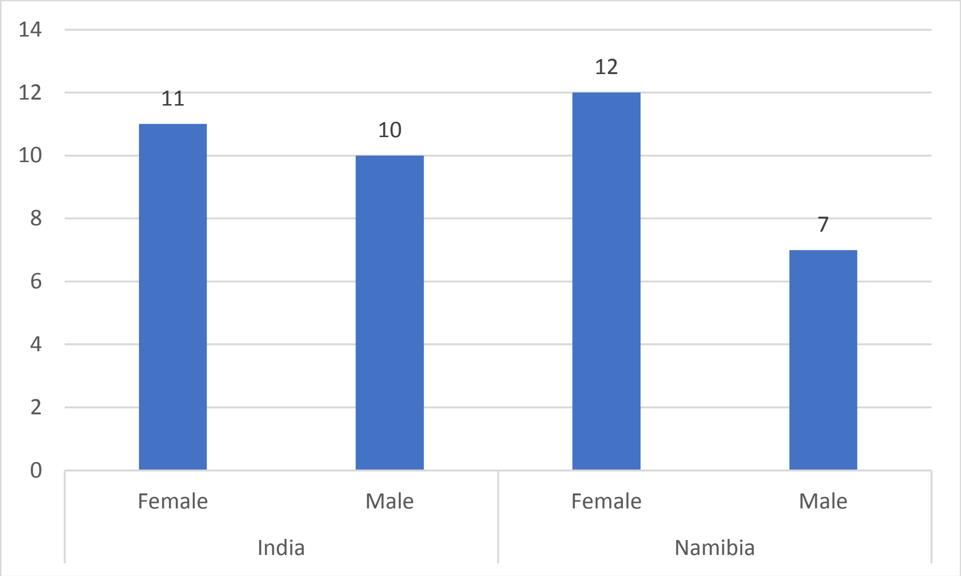


Figure 5: Number of participants by gender per country

In India, in terms of age, 18% of the respondents were aged between 18 and 28; 3% between 29 and 39, 13% between 40-50 while 66% were 51 and above (Graph 3). Majority of the responded in India (66%) were old age and have already retired.

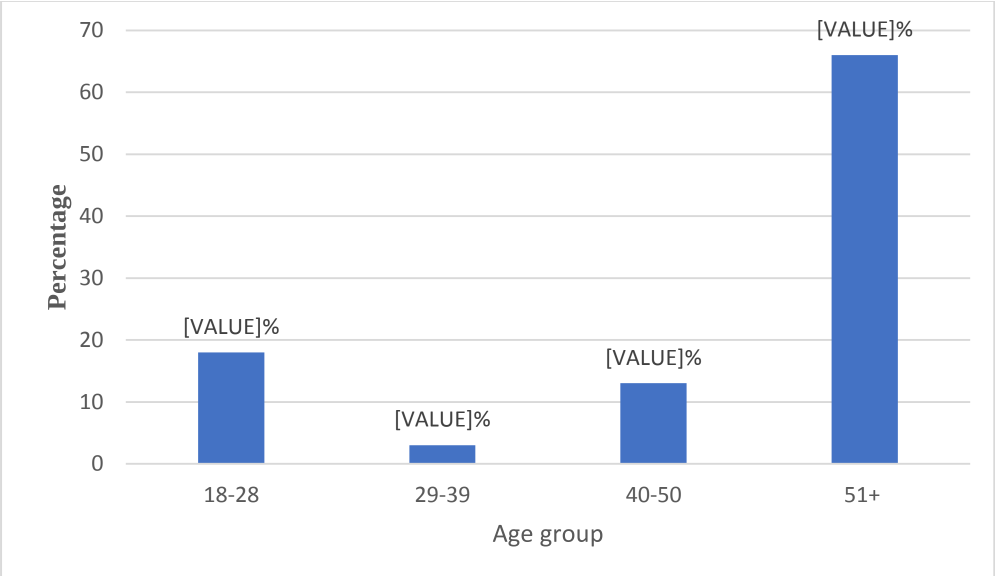


Figure 6: Percentage response by age group in India

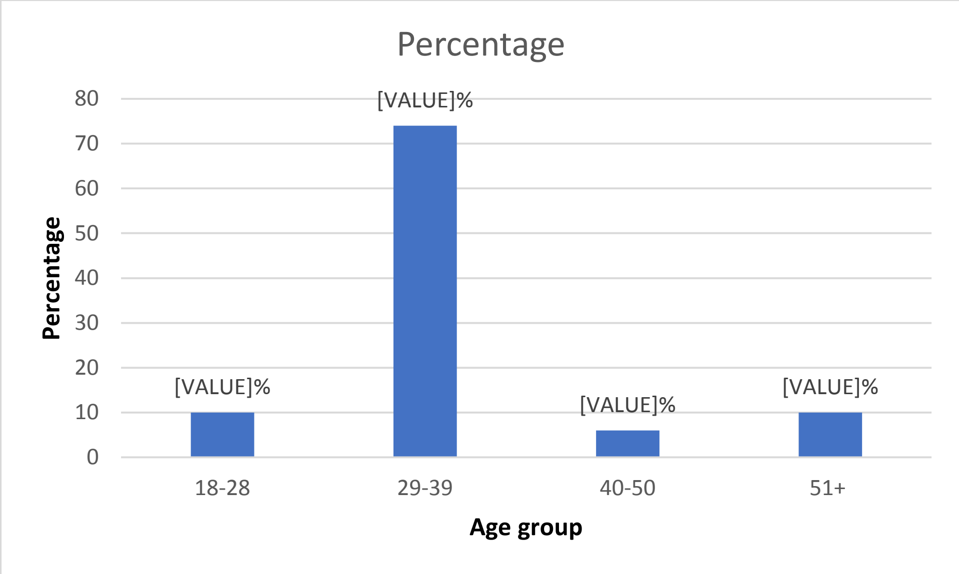


Figure 7: Percentage response by age group in Namibia

In Namibia, in terms of age, 10% of the respondents were aged between 18 and 28; 74% between 29 and 39, 6% between 40-50 while 10% were 51 and above (Graph 4).

Flood risk perception

Majority of the residents who were interviewed (80%) indicated that their houses are located in flood prone areas. All of them have indicated that flood occurrence in their area is likely and certain to happen (one or more occurrence per year). People who were interviewed stated to have lived in the flood plain for a long time and to have vivid memories of all the floods that had happened there. Some participants (39%) also indicated that their houses are flooded every year during rainy season as shown in table 7 below. Even though many of the respondents are farmers and depend on their crops for food and income when there is a sufficient harvest, many have stated that they do not want to relocate. Water and food is one of the key justifications for building and residing in the floodplain since they also need water for the watering of their crops, even if they are aware of the risks.

Table 2: Residents numbers of years affected by flood.

Chance of occurrence of flood	**Frequency (=n)**	**Percentage (%)**
Certain (1 or more occurrence per year)	13	34
Likely (1 occurrence every 1 to 2 years)	15	39
Possible (1 occurrence every 2 to 20 years)	6	16
Unlikely (1 occurrence every 20 to 5o years)	4	11
Grand Total	**38**	**100**

Causes and impacts of flood

The residents living in the flood plain indicated that the main cause of flood is rainfall. One elderly woman replied by saying that ‘’flood is an event out of human control therefore it is an act of God''. However,90% of the respondents indicated that climate change is also exacerbating flood as it now rains more often compared to the last 20 years. All of the people interviewed indicated that their houses get damaged every year a flood occur and for this they have to spend money to repair their houses. Some trees falls on their homes. One family has lost almost everything. A mechanic with a workshop at his house where he fixes motorbikes and cars in Maniyaparambu west indicated that during the 2018 flood in Kerala, he lost six cars of his client because it was washed away by the rain. All the respondent indicated that no one died from their households due to flood. The emergency that affected almost everyone was that their houses badly got damaged by the flood and some became homeless. The farmers have lost land, some people lost properties, pets and livestock as shown in the table below.

Table 3: Impacts of flood in India

The Kerala flood has destroyed properties

Impact	**Frequency (=n)**	**Percentage (%)**
Land degradation	5	24
Properties (Houses, Vehicles)	14	67
Pets (Cats, dogs)	2	9
Grand total	21	100

Substitute farming is the main economic activity in the flooded region of Namibia. In addition to raising small herds of cattle and goats, farmers also grow pearl millet (Mahangu), sorghum, beans, tiger nuts and pumpkins. The Mahangu field, on which residents of the study area relief, was particularly badly hit by the 2011 flood. Many people were left in poverty because prime source of livelihood Mahangu was destroyed. They eventually had to rely on the government for emergency help such as providing temporary housing, relocating to higher ground and providing bare essentials like food. The flood impact in Namibia is shown in the table below.

Table 4: Impacts of flood in Namibia

Impacts	**Frequency (=n)**	**Percentage**
Land degradation	6	32
Properties (House)	3	16
Pets (cats, dogs)	2	10
Livestock (Cow, Sheep, Goats)	8	42
Grand total	19	100

When it comes to receive immediate help during the 2018 Kerala flood, as shown in figure 13, 90% of the respondents have indicated that they received flood relief and were relocated to relief camps. However, 10% respondent that they did not receive anything.

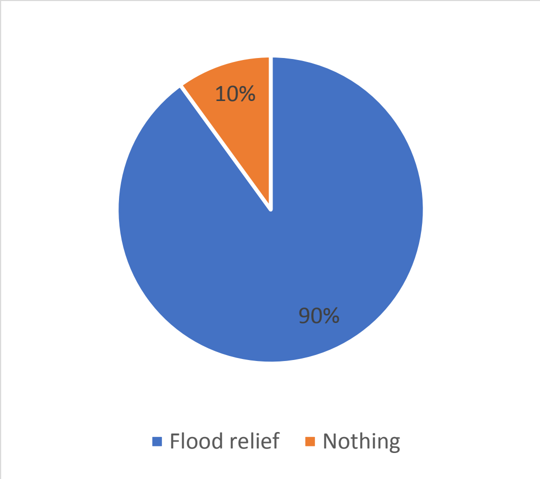


Figure 8: Immediate help offered by government in India

In Namibia, 94% of the respondents indicated that they have receive relief aid from the government, while 6% claim to have received nothing.

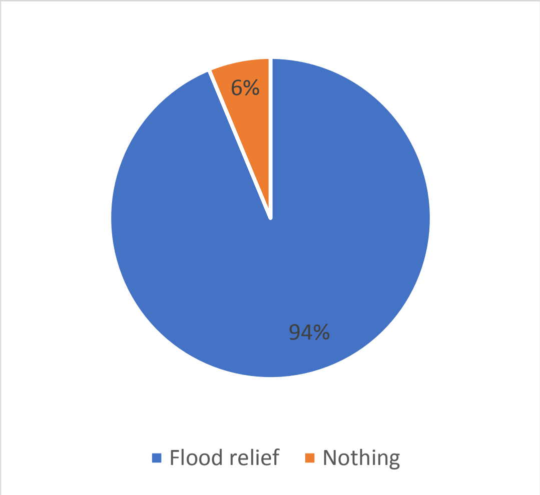


Figure 9: Immediate Help offered by government in Namibia

Majority of the residents indicated that their houses where damaged, the government of India provided money to these houses which were destroyed, however they indicated that they only got Rs 10000, which was not enough to reconstruct their homes.

Table 5: Number of those who got monetary fund from India

Received money from government	**Frequency (=n)**
Yes	18
No	2
Maybe	1
Grand total	**21**

Table 6: Number of those who got monetary fund from Namibia

Received money from government	**Frequency (=n)**
Yes	1
No	18
Grand Total	**19**

When residents where asked wether they think the local authority/ district cordinator are prepared to help flood victims, they respondent as follows:

Table 7 : Local authority state of readiness in India

Local authority prepared or not?	**Frequency**	**Percentage (%)**
Prepared	18	86
Unprepared	2	9
Not sure	1	5
Grand total	**21**	**100**

As can be seen in the above chart, 86% of the respondents in India said that district coordinators are ready to assist flood victims and that they do so by conducting rescue operations and assisting in the relocation of victims to high ground. 9% of respondents said they believed the district coordinator was unprepared, and 5% said they were unsure.

Table 8: Local authority state of readiness in Namibia

Local authority prepared or not?	**Frequency**	**Percentage (%)**
Prepared	10	53
Unprepared	4	21
Not sure	5	26
Grand total	**19**	**100**

According to the table above, 53% of Namibian respondents said their local government was ready to assist during a flood, while 21% said they were unprepared and 26% were unsure.

Early warning system

Early warning systems are a crucial part of methods for disaster risk reduction. The fundamental objective of early warning systems is to send out alerts when a flood is about to occur or is already happening. Early warning systems for floods comprise four inter-related elements: 1) assessments and knowledge of flood risks in the area, 2) local hazard monitoring (forecasts) and warning service, 3) flood risk dissemination and communication service, and 4) community response capabilities. This versatile system enhances community readiness for extreme weather events like floods, both in terms of warning and raising awareness of hazards and effective flood response.

The early warning system used is summarized in 14 table below. As a result of not having televisions in their homes, those who took part in the survey in Namibia stated that they mostly obtain information about floods through the radio. The respondents in India indicated that they get early warning from television such as Malayalam Manorama and Mathrubhumi news channel, as well as through radios. However, some have indicated that when it heavily rain, they are completely cut off as the electricity also switch off.

Table 9: Early warning systems

Early warning system	Frequency (=n)	Percentage
Dissemination and Communication (Radio, Tv)	26	65
Monitoring and Warning (Rainfall, River level)	3	8
Response Capability (Evacuation centers, search and rescue, relief goods)	3	8
Risk knowledge (Hazard, element at risks and vulnerability)	2	4
All of the above	6	15
Grand total	**40**	**100**

Relief camp

In the early stages of a disaster, shelter is a vital survival factor. Beyond just ensuring survival, a relief camp is essential for personal safety, climate protection, and the containment of epidemics. The relief camp is crucial for maintaining human dignity and family and community life as much as possible under difficult conditions. Each relief camp should have clean water and toilets.

During the period of flood, some schools and community halls are turned in relief halls to accommodate flood victims. SNDP LP school Arpookkara in Arpookora grama panchayat was used as relief camp in India. In Namibia tents are mostly set up because during the period of flood, most schools do not close during the period of flood. Although the relief distribution went well in most of the study area, transportation remained a challenge due to flooded roads. Some relief teams members were forced to walk long distances to deliver the necessary goods and this posed a further challenge to the operation in terms of effectiveness and efficiency in service delivery. Another challenge was the delay in the delivery of relief items from the regional warehouse due to some logistic regulations. Nevertheless, the red cross ensured prompt distribution upon arrival of the relief items.

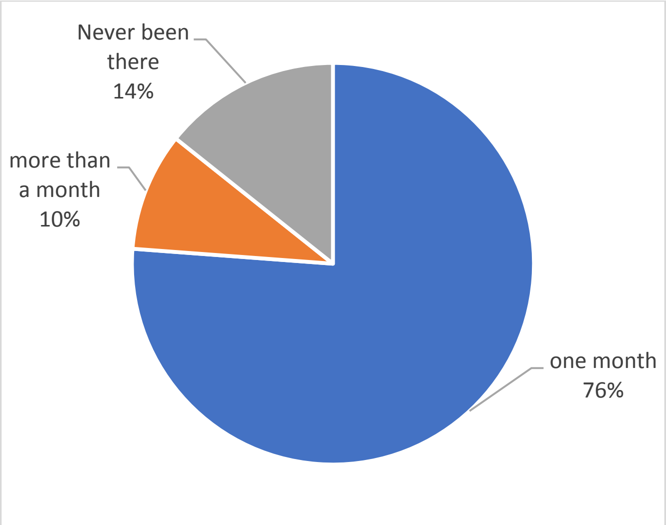


Figure 10: Percentage of those who went and did not go to relief camp in India

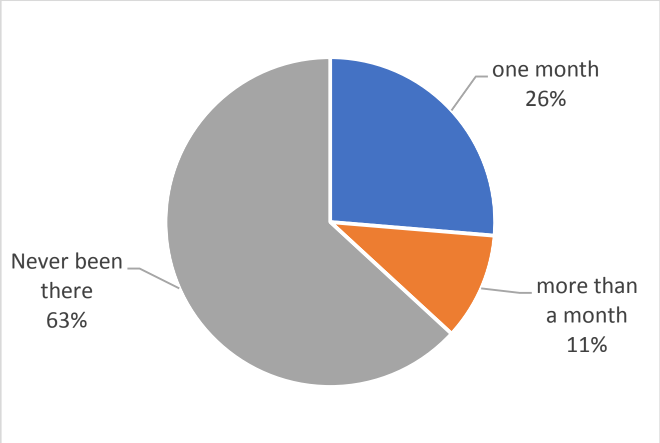


Figure 11: Percentage of those who went and did not go to relief camp in Namibia

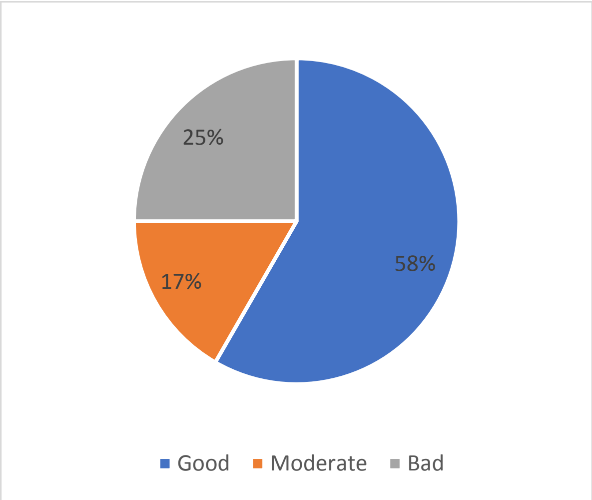


Figure 12: Condition of relief camp in India

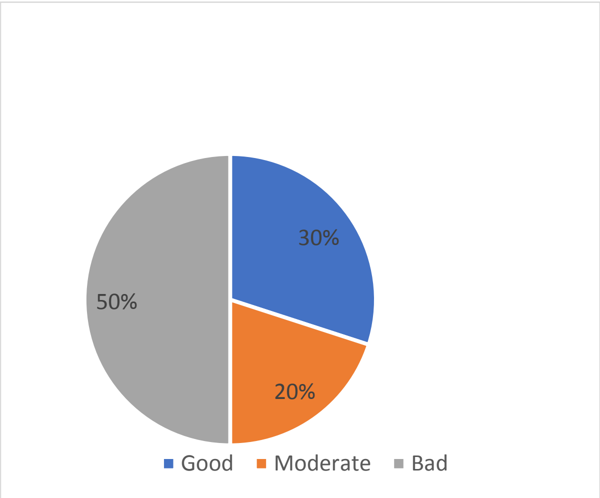


Figure 13: Condition of relief cam in Namibia

As shown in figure 21 above, 58% of the respondents in India said their stay in relief camp was good, while only 50% of respondents enjoyed their stay in relief camp. 30% of the respondents from Namibia rated their relief camp stay as bad, while 25% respondents from India did not enjoy their stay in relief camp.

CONCLUSION AND RECOMMENDATIONS

It can be said that the majority of survey respondents are aware of their susceptibility and the risk of flooding they face. This is explained by the fact that 39% of the participants said their locations frequently flood during the rainy season. They had a high perception of flooding because they understood that excessive rainfall was the primary cause of floods. However, other people hold the view that since the flood was an uncontrollable catastrophe, God must have caused it. The main adverse effect on the participants in this study is damage to their homes, land degradation and receiving little to no compensation from the government to repair their homes because they live in flood-prone areas.

Kerala flood destroyed infrastructure and houses, however the rebuild Kerala initiative guides the state to resilient recovery. Due to soil erosion brought on by floods, the few farmers in the state who had paddy fields and also farmed other crops now have unproductive land. Additionally, this will worsen the state's food insecurity. The vast majority of respondents in Namibia often do not prefer to leave their homes to stay in relief camps during times of flooding since the benefits they receive from the floods outweigh the risks. This is due to the fact that locals depend on floodwater to cultivate crops including tiger nuts, pumpkins, beans, sorghum, and maize. Additionally, flood delivers cat fish, a delicacy of northern Namibia. The respondents also indicated that their stay in relief camp was good and all the camps have met sphere standards for relief camps during a disaster. In conclusion, this are the authors contribution to this research:

1. Introduce DRR programmes in institutions of higher learning
2. Educate the community on preparedness and mitigation since they are first responders, in their local language so they can understand better.
3. Translate awareness materials into local languages for risk communication to be effective will help reduce the gap existing between the floodplain residents and policy makers
4. An EIA should be conducted to establish whether a region is at risk of flooding and whether settling there is safe before land is allotted for human habitation.
5. Dam construction and reforestation in Northern Namibia
6. Construction of an underground drainage system to direct water to a river or the sea
7. Build flood control channels so that when it rains, the excess flood water can accumulate there and eventually flow into the river.
8. For the purpose of determining if the water level is rising, a stream gauge network should be set up to monitor water level and stream flow in rivers.
9. The number of fatalities each year may be decreased by having ambulances and hospitals prepared, warning people to migrate in advance, and providing accommodation for the thousands who will be displaced.

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CHALLENGES OF POST-DISASTER HOUSING RECONSTRUCTION AND THE IMPORTANCE OF DECISION-MAKING

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Abstract:

Extreme climate change has resulted in intensified impacts of disaster events in recent years. Resilience and risk reduction of affected infrastructure are obtained through efficient planning and accurate decisions taken at crucial phases of reconstruction. Studies of the 2004 Tsunami and recent Kerala floods state the importance of formulating reconstruction strategies and efficient planning for housing infrastructure. The lack of organized systems for decision-making has caused delays in post-disaster housing reconstruction projects. Though numerous studies have attempted to identify challenges in PDHR, studies which have focused on the decision-making aspects of the project are lacking. One of the crucial technological advancements in decision-making includes incorporating the Decision support system (DSS). DSSs are a new concept in the domain of PDHR that requires a substantial focus and development for further integration into decision-making processes. To understand the relevant usage of DSS in PDHR, it is vital to identify the challenges encountered by decision-makers during the various phases of reconstruction. This study has attempted to identify the critical challenges of decision-making in PDHR through a comprehensive literature review. Additionally, the paper has also tried identifying the strategies used to develop DSSs in the published literature on PDHR. The study identified significant gaps in decision-making in the planning and design stages of the PDHR process and established critical success factors from the recognized challenges of the reconstruction process. Future research directions are obtained through the summarized study of various DSS strategies, which will help develop a holistic decision system for strengthening risk reduction governance according to the Sendai Framework for Disaster Risk Reduction 2015-2030

Keywords:

Post-disaster housing reconstruction; decision-making; Decision support system; PDHR challenges; planning.

INTRODUCTION

When a disaster strikes, infrastructure sector is the most affected with multiplier effects on the concomitant sectors resulting in vast damage. Housing is an essential infrastructure sector to well-being and development of the associated communities (Barakat, 2003). Housing and related infrastructure are significantly damaged by disasters and are identified to contribute the majority of loss, necessitating high recovery costs (Chang-Richards et al., 2013; Comerio, 1997). Housing restoration and infrastructure reconstruction are given the highest priority in recovery process, with maximum resources allocated to ensure future resilience (Lang, 2008). Post-disaster housing reconstruction (PDHR) is one of the most crucial parts of disaster management cycle. The reconstruction phase of disaster management is one of the most crucial stages. Reconstruction efforts aim to improve the quality of life for affected communities by restoring infrastructure and residential buildings that have been destroyed or damaged. The successful reconstruction of damaged infrastructures, particularly housing, is required for the long-term recovery of the disaster-affected community (Anilkumar & Banerji, 2021). Housing reconstruction after a disaster is a complex process that entails a number of interconnected activities. Future disaster vulnerability reduction and ensuring resilience for affected communities and infrastructure is achieved through successful management of post-disaster reconstruction and delivery of quality outputs. The process of PDHR involves coordination and communication between various stakeholders at every level of projects. However, previous studies highlight that housing reconstruction after a disaster recurrently encounters a variety of difficulties both in the planning phase and during long-term occupancy (Anilkumar & Banerji, 2019). The challenges in PDHR arise mainly due to the inefficient decision-making process by the stakeholders in the initial planning stages of reconstruction which causes delays in delivery of new housing units to the affected community. It is seen that even though many studies have attempted to identify the critical challenges of planning PDHR process, a summarized understanding of the advancement of literature in the domain is not yet attempted. This study thus tried to analyze the published research works to document the key findings of the literature highlighting the challenges encountered in the planning stage of PDHR.

OBJECTIVES

This study has attempted to identify the critical challenges faced by stakeholders and decision-makers during the process of PDHR. The study has also tried to analyze the role of decision-making tools such as decision-support systems (DSS) in the planning process of PDHR by identifying the key strategies and approaches of the previous studies aiming for developing DSS.

- To find the major challenges of planning PDHR
- To analyze selected decision-making tools and approaches for PDHR from published literature

The first section of the paper highlighted the need and importance of the paper through a brief introduction. Section two of the paper underlines the aim and main objectives of the study. Section three discusses on the various methods and materials used in the study to achieve the required results. The fourth section presents the literature review to identify the key challenges of PDHR as mentioned by previously published papers. The results of the study are represented in the fifth section of the paper with detailed analysis. The final section of the paper provides the key discussions and conclusions of the study along with future scope.

MATERIALS AND METHODS

The study attempted to identify the key challenges of PDHR and importance of decision-making in the process from published literature works over the years. A systematic review is adopted in the paper to understand the various approaches and tools developed for decision-making in the previous studies in the field. Literature for analysis is selected form online database of Scopus and Web of Science. The primary objective of the study was identified and a search code was developed with appropriate domains for the selection process. The selected literature was examined using content analysis and a set of challenges in the planning stage of PDHR is identified. Further, the study also attempted to analyze the various decision-making approaches and tools for post-disaster housing developed by previous literature works. Literature was selected from Scopus and WoS databases using search codes and was analyzed in detail to find the common methods and techniques adopted.

LITERATURE REVIEW

Housing is a multidimensional asset with connections to family and social stability, livelihoods, health, and education (Barakat, 2003). According to a research by the United Nations Economic Commission for Latin America and the Caribbean, the housing sector in Indonesia sustained the most damage from the tsunami and earthquake that struck in 2004 (Zapata Martí, 2005). The continuation of work and other sources of income, as well as the restoration of a private and secure place to reside, are essential to the risk reduction and future resilience of affected communities. When a disaster strikes, prompt decisions must be taken regarding the location, method, and financing of any necessary housing reconstruction (C Johnson & Lizarralde, 2012). Post disaster housing reconstruction (PDHR) is a complicated process that involves several associated tasks (Silva, 2010). Due to this complexity of the PDHR process, reconstruction efforts following disasters are not always successful and have had various degrees of failure caused by multiple challenges (Karunasena & Rameezdeen, 2010). Numerous housing reconstruction projects, especially in developing nations, have exacerbated or even made pre-disaster vulnerabilities more severe in the long run. Programs to reconstruct houses after disasters have frequently fallen short of their declared goals. (Abdulquadri Ade Bilau & Witt, 2016; Andrew et al., 2013).

Barakat (2003) identified the key issue of PDHR as poor planning and inefficient coordination between the concerned agencies and stakeholders. He also highlighted the issues arising due to time constraints for PDHR projects which lead to rapid planning and implementation with no regard to the socio-economic preferences of the community. Delaney and Shrader (2000) identified challenges such as lack of community participation, communication between stakeholders and lack of cultural and resettlement appropriateness. The lack of commitment from planning and implementing organizations to take into account community needs and requirements for the reconstruction process results in the community openly rejecting homes or, in certain circumstances, reselling the homes that were allocated. These challenges cause housing reconstruction projects to fail with low post-occupancy satisfaction from beneficiaries.

Shyni and Haimenti (2019) suggested that the lack of knowledge about the complicated and dynamic project management environment of the housing reconstruction process is one of the primary challenges of PDHR. Ahmed (2011) identified the lack of institutional coordination, lack of planning policies, corruption, ineffective finance management, and delays in the implementation and project delivery procedures of PDHR as major challenges. Additionally, Biswas and Puriya (2018) emphasized the significance of having a dual system to promote advanced technology and scientific knowledge among experts, as well as a suitable institutional platform for disseminating insights amongst the community and to develop a legislative and policy framework for PDHR. Meding et.al (2008) highlighted that large-scale reconstruction is carried out without proper planning and coordination. He identified that planning phase of the PDHR process is the most poorly executed stage. The project fails in the later stages as a result of the ineffective management of the planning. Yi and Yang (2014) identified the key issues in PDHR such as governance issues, sustainability and future vulnerability, resourcing, stakeholder analysis, reconstruction approach and waste management. Ophiyandri et al. (2013) found that in the long run, government actions and efforts from decision-makers and stakeholders to rebuild damaged infrastructure is insufficient. PDHR faces a number of different difficulties, but one of the primary causes of these problems is the unstructured and ineffective decision-making at the planning stage of the reconstruction process (Platt & Drinkwater, 2016). Platt and Drinkwater also advocated the application of evidence-based reasoning to support professionals in difficult assessment tasks and to guarantee long-term resilience.

To generate sufficient outcomes in post-disaster housing, it is imperative to take long-term planning into account and include all stakeholders in decision-making (Kennedy et al., 2008). Although PDHR comprises many stages, decision-making in the planning stage is the most important for determining the best course of action for the project as a whole (Sofberi & Zainal, 2018). The inadequacy of multi-stakeholder coordination and planning is one of many challenges related to PDHR that have been recognized in the literature. A major gap identified through the challenges of PDHR is the inefficiency of decision making in the initial stages of PDHR which in turn affects the subsequent stages of reconstruction and recovery process of housing.

Challenges of Planning PDHR

Li et al (2019) attempted to systematically review planning as well as policy implementation in PDHR of Dujiangyan City to identify specific challenges that were successfully resolved in the process. The main challenges in reconstruction stage were the high demand of housing in limited time, complex land and property issues, issues of reconstruction planning, lack of community participation, lack of government support and expert knowledge, lack of legal frameworks, not considering local preferences, lack of funds and vulnerability of specific groups. Roosli et al. (2018) focused on issues of ineffective policy implementation in planning PDHR and identified the main challenges as lack of community involvement, lack of understanding of regulations by the affected community, need for capacity building and knowledge development, and lack of local resources and skilled labor. Barraqué et al (2017) analyzed the challenges restricting the involvement of non-profit sector from active participation in disaster reconstruction policy implementation in Puerto Rico. He identified three important challenges as the exclusionary nature of federal financial policies, weakness of industrial environment and the lack of skilled professional with adequate knowledge regarding PDHR. Abe et al (2018) assessed the long-term changes in the level of community engagement in PDHR and the differences in the perception of disaster vulnerabilities amongst the communities affected by Tsunami 2004 in Indonesia. The study highlighted the issues such as lack of community participation and challenges arising due to top-down approach as well lack of knowledge and awareness amongst beneficiaries regarding what to expect in the process of PDHR. Kondo (2018) discussed on the lack of reconstruction process to restore the built environment to ensure sustainable recovery and risk reduction. The haphazard planning, inefficient use of land, lack of proper policies and ignorance of the needs of affected communities are identified as key issues for housing recovery after the Great Japan Earthquake. In the same year, Sadiqi et al (2017) identified the five important challenges for community involvement in PDHR , which were, low capacity of the affected community, gender-based issues, lack of experiences professionals in implementing agencies and NGOs, inefficient government practices and policies, and insecurities of the community. He developed a logical framework matrix for planning PDHR based on surveys conducted in communities living in PDHR projects in Afghanistan. Adding on, Smith (2016) identified that lack of involvement of local government agencies, lack of community participation, the issues in planning PDHR in a process-oriented approach to ensure proper formulation of policies by stakeholders. Patel and Hastak (2013) proposed a strategic framework to help decision-makers to assign houses to beneficiaries in reduced timespan of reconstruction. The study focused on temporary housing reconstruction and its issues in planning such as lack of resources and funding, issues with coordination amongst various stakeholders, limitations of existing regulations and contracts, logistics and supply chain issues, as well as issues with lack of supporting infrastructure. C Johnson and Lizarralde (2012) suggested the importance for decision-making in PDHR and highlighted the necessity for systems-approach for management of PDHR as well as the need for interdisciplinary planning. They identified key challenges of PDHR as centralized decision- making, lack of legal, financial and administrative framework, issues with land acquisition and planning policies, lack of community involvement, coordination and commitment issues of various stakeholders and also the lack of sustainable methods to ensure future resilience. Sarkar (2006) attempted to review housing planning and development to identify the failures and success factors of housing reconstruction. He mentioned the key failure factors of PDHR as poor selection of site location, lack of community involvement and understanding of community needs, social factors, housing design and quality issues, lack of sustainability. Mukherji (2015) examined the PDHR policy for renter households after 2001 Gujarat Earthquake in India through qualitative case-study method. She found the major issues pertaining to rental housing tenants after disaster were the lack of funding frameworks and mechanism, lack of suitable policies and lack of knowledge and awareness of the community. Tas et al.(2010) studied the various challenges of PDHR in Turkey after 1999 Marmara earthquake. He analyzed the permanent housing provisions and identified the key challenges as limited time and resources, administrative restrictions, difficulty in choosing relocation site, lack of consideration of local needs during planning, deficiency in supervision and coordination, and low quality construction. These issues delayed the process and the beneficiaries were unsatisfied. Tafti and Tomlinson (2015) focused on 2001 Earthquake in Bhuj, Gujarat and 2003 Earthquake in Bam to comprehend the issues in knowledge transfer on PDHR. They described the issues with lack of expertise and communication causing issues with knowledge sharing amongst stakeholders, and especially focused on the issue of not considering the needs of the community during the planning process of PDHR. Hendriks and Opdyke (2020) analyzed the barriers in knowledge adoption in PDHR process in the context of Typoon affected communities of Philippines. The inhibitors of effective knowledge adoption are the disputed roles of knowledge sources, lack of coordination and communication, lack of administrative framework, lack of appropriate policies. Wang et al.(2022) introduced an agent-based simulation framework to identify the demand of workforce and needs of community and contractors. The framework is also used to analyze challenges of the PDHR process. The study identified a major challenge as shortage of experienced labor and contractors.

ARTICLE	IDENTIFIED CHALLENGES OF PLANNING PDHR
(Li et al., 2019).	High demand of housing in limited time, complex land and property issues, issues of reconstruction planning, lack of community participation, lack of government support and expert knowledge, lack of legal frameworks, not considering local preferences, lack of funds and vulnerability of specific groups
(Roosli et al., 2018)	lack of community involvement, lack of understanding of regulations by the affected community, need for capacity building and knowledge development, and lack of local resources and skilled labor
(Barraqué et al., 2017)	exclusionary nature of federal financial policies, weakness of industrial environment and the lack of skilled professional with adequate knowledge
.(Abe et al., 2018)	lack of community participation and challenges arising due to top-down approach as well lack of knowledge and awareness amongst beneficiaries
(Kondo, 2018)	haphazard planning, inefficient use of land, lack of proper policies and ignorance of the needs of affected communities
(Sadiqi et al., 2017)	low capacity of the affected community, gender-based issues, lack of experiences professionals in implementing agencies and NGOs, inefficient government practices and policies, and insecurities of the community
(Smith, 2016)	Lack of involvement of local government agencies, lack of community participation, the issues in planning PDHR in a process-oriented approach to ensure proper formulation of policies by stakeholders.
(Patel & Hastak, 2013)	lack of resources and funding, issues with coordination amongst various stakeholders, limitations of existing regulations and contracts, logistics and supply chain issues, as well as issues with lack of supporting infrastructure
(C Johnson & Lizarralde, 2012)	centralized decision- making, lack of legal, financial and administrative framework, issues with land acquisition and planning policies, lack of community involvement, coordination and commitment issues of various stakeholders and also the lack of sustainable methods to ensure future resilience
(Barraqué et al., 2017)	Lack of coordination, expertise and knowledge transfer between stakeholders, lack of community participation and consideration of their needs, lack of funding

(Hayles, 2010)	Limited access to information, Lack of expertise and knowledge transfer between stakeholders, lack of community participation, lack of commitment of implementing agency, lack of legislative and regulatory framework , limited resources, time and funds, no sustainability.
(Sarkar, 2006)	poor selection of site location, lack of community involvement and understanding of community needs, social factors, housing design and quality issues, lack of sustainability
(Mukherji, 2015)	lack of funding frameworks and mechanism, lack of suitable policies and lack of knowledge and awareness of the community
(Pezzica et al., 2021)	Lack of planning policy and its flexibility, top-down approach, limited access of information and lack of expertise, knowledge transfer and communication of stakeholders, lack of considering community needs and lack of framework for beneficiary selection, lack of community participation and lack of funding mechanisms as well as time and resource constraints,
(Tas et al., 2010)	limited time and resources, administrative restrictions, difficulty in choosing relocation site, lack of consideration of local needs during planning, deficiency in supervision and coordination, and low quality construction
(Tafti & Tomlinson, 2015)	lack of expertise and communication causing issues with knowledge sharing amongst stakeholders, and especially focused on the issue of not considering the needs of the community
(Hendriks & Opdyke, 2020)	disputed roles of knowledge sources, lack of coordination and communication, lack of administrative framework, lack of appropriate policies
(Wang et al., 2022)	Shortage of experienced labor and contractors

The detailed analysis establishes the major bottlenecks of PDHR for planning PDHR, especially contributing to the need for appropriate decision-making tools in the planning stages of the process. The main challenges of are highlighted as lack of community involvement in decision-making process of PDHR as well as lack of appropriate legal and regulatory frameworks for funding and other management processes.

Various Decision-Making Approaches and Tools in PDHR

In this section, the study has attempted to comprehensively review the published research works focusing on various decision-making aspects of PDHR. The main aim of the analysis is to identify the various tools, methods and approaches to aid decision-making presented in the previous literature works.

Davidson et al. (2007) emphasized the role of community participation in decision-making process of PDHR through case studies of Colombia, El Salvador, and Turkey. He used systems approach to highlight the importance of community involvement in decision-making at planning and design stages of the reconstruction process. Johnson (2007) identified the key challenges of decision-making for planning PDHR as excessive cost, poor planning of relocation and inefficient design of housing. An analysis of six temporary housing programs after disasters from 1979-1999 were studied to develop a strategic planning framework to aid in decision-making by integrating the data of available resources and organizational design in planning stage. (El-Anwar et al., 2008) presented a multi-objective optimization model to identify temporary accommodations in the most optimal manner. The model used a weighted linear programming and focused on reducing negative socio-economic and environmental impacts, minimizing expenses and increasing safety of displaced beneficiaries. Eid et al. (2014) introduced a Decision-support framework to ease the transition of beneficiaries form current housing to reconstructed units. Rakes et al (2014) developed a decision-support framework for assigning beneficiary families to reconstructed housing units using benchmark developed by integer programming model and evaluated the three identified heuristics. Amin Hosseini et al (2016) presented a new model for selecting temporary housing units based on concepts of sustainability. The model is developed as Multi-criteria decision making (MCDM) system and is called integrated value model for sustainable assessment (MIVES). A.Ade Bilau & Witt (2016) identified issues of management of PDHR programs through systematic literature review method and developed a conceptual decision-aiding framework to correlate contextual factors with management strategies. Pezzica et al (2021) proposed a computational analytical method to ensure optimal delivery of temporary housing units and people-centric design.

CONCLUSION

The study attempted to review key developments and findings of previous literature works to identify the various challenges and barriers of PDHR planning phase in particular. The analysis of several literature works highlighted the lack of focus on the planning phase of PDHR projects which has caused severe challenges later on in the projects. Majority of the challenges identified was a result of inefficient decision-making by responsible stakeholders at various levels of PDR process. Comprehensive content analysis of literature identified the key issues of planning PDHR as lack of coordination and expertise amongst decision-makers and stakeholders, the lack of community involvement and the inability of implementing agencies to consider community needs, lack of resources and funding and lack of suitable policies and regulations. These issues needs to be further researched and understood in detail to find the sub-factors and dichotomies obstructing the efficient PDHR management process. Future research is required to develop on the identified challenges to establish critical success factors for successful planning and decision-making in PDHR. The study also identified the importance of decision-making in the process of reconstruction. Improper decisions affect the consequent stages of reconstruction and pave path to multiple challenges in the projects. Various decision-making related approaches developed and analyzed by published literature were studied to understand the general methods and progress over the years. Technological advancements like decision-support systems aid in efficient outcomes at various stages of PDHR. The most commonly used methods include Multi-criteria decision-making model (MCDM), multi-objective optimization models, Machine learning (ML) and artificial intelligence (AI) methods. The studies mainly focused on developing strategies and conceptual frameworks as an initial step towards developing future decision making tools and DSSs. Future research is required in developing a comprehensive decision-making tool to address the various challenges of planning stage addressed in this study.

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DECLARATION OF COMPETING INTEREST

No Conflict of Interest between authors, affiliated organizations and any of the funding agencies/ Organization and other matters, corresponding author should state for no copyrights involved or published elsewhere in any journals/conferences or any publication agencies/Universities.

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CLIMATE CHANGE RISK ANALYSIS TO ASSESS VULNERABILITY TO APPLE YIELD IN HIMACHAL PRADESH (INDIA)

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Abstract:

Climate change has become a major global as well as regional challenge because of its adverse effects on biodiversity and agriculture. Himachal Pradesh (India) falls in the western Indian Himalayan region which is predominantly an agricultural economy and apple is the major cash crop of the region. This paper presents the trend analysis of climate parameters in the region so as to establish the effect of climate change and its impact on the apple yield. The temperature and rainfall data were obtained from the Indian metrological department, while snowfall was estimated with the MEERA-2 and the chill unit was calculated using the UTAH model. The climate change trend was compared with the changes in the apple yield of the region to identify the influence of climate change parameters on the crop yield. The risk and vulnerability were assessed in accordance with IPCC AR5. The trend analysis indicated that there was a decrease in temperature in monsoon months and an increase in temperature of the winter months. The decreased snowfall and increased rainfall observed during the spring season, between mid - February to mid-April, affected the apple crop yield. The chill units and apple production showed a positive correlation. Based on the study, some strategies for adaptation and improving resilience to climate change are proposed for sustainable apple production in the region.

Keywords:

Climate Change Risk; Vulnerability; Extreme Climate Events; Apple Yield; Adaptation and Resilience

INTRODUCTION

The regional, as well as the global impact of climate change (CC), is well established. Studies have indicated an effect of change in climate on the annual production of soya bean, rice, wheat (Deng et al., 2010) and apple (Li et al. 2018). In India, the vulnerable regions identified to face the impact of CC are the west coast, north, and north-west Himalayas (Dash et al., 2007). The irregular and extreme metrological events as a consequence of CC have already started playing a significant role in micro-climatic variation in northern India (Tamaddun et al., 2019). The apple tree growth and yield largely depend on meteorological dynamics. The changed micro-climatic conditions like temperature, rainfall, and snowfall are found to affect apple production (Li et al., 2018).

In Himachal Pradesh (India), 90% of the population depends upon agriculture and it provides 62% of occupation to workers (Economy Survey, 2017). The area under apple cultivation is continuously growing in Himachal Pradesh with an average increase of 1.5 per cent every year (Wani, 2018; Kumari and John 2019).

Since Himachal Pradesh falls under the vulnerable areas to the effects of climate change, there is a great need to understand the CC scenario in the region, especially of winter and spring seasons, as these two seasons play a dominant role in apple production. The chill units accumulated during the winter season is important for apple crop to break potential and start flowering and fruiting in spring. During the spring season, especially the flowering time, temperatures above 26°C and below 15°C may harm apple yield (Li et al., 2018). Rainfall during spring, which is also the flowering period for apple crop, is catastrophic for apple production, as it washes away the pollen and retards the pollen tube growth and also reduces the bee activity which leads to a poor set of fruits. In response to the possible CC and its effects, the Himachal Pradesh government has already developed a CC resilience strategy (ICLEI, 2013). However, the proposed strategies in the compilation do not cover the CC impact on agriculture.

This paper is an attempt to understand the climate change risk in the district Shimla of Himachal Pradesh (India) and to assess the vulnerability due to CC in the region especially in the agricultural yield.

MATERIALS AND METHODS

Study Area

District Shimla of the state Himachal Pradesh (India) was selected as the study area which lies on the south-western ranges of the Himalayas. It is one of the predominant apple cultivation districts of Himachal Pradesh. Fig. 1 shows the geographical setting of the study area. The area falls in 31.1231°N (latitude) and 77.6536°E (longitude). Jubbal, Kotkhai, and Rohru were selected for the study which are major apple producing areas of Shimla district, and the locations are shown in Fig 1. The regional climate is classified as subtropical highland climate under the Koppen climate classification (Raju et al., 2013).

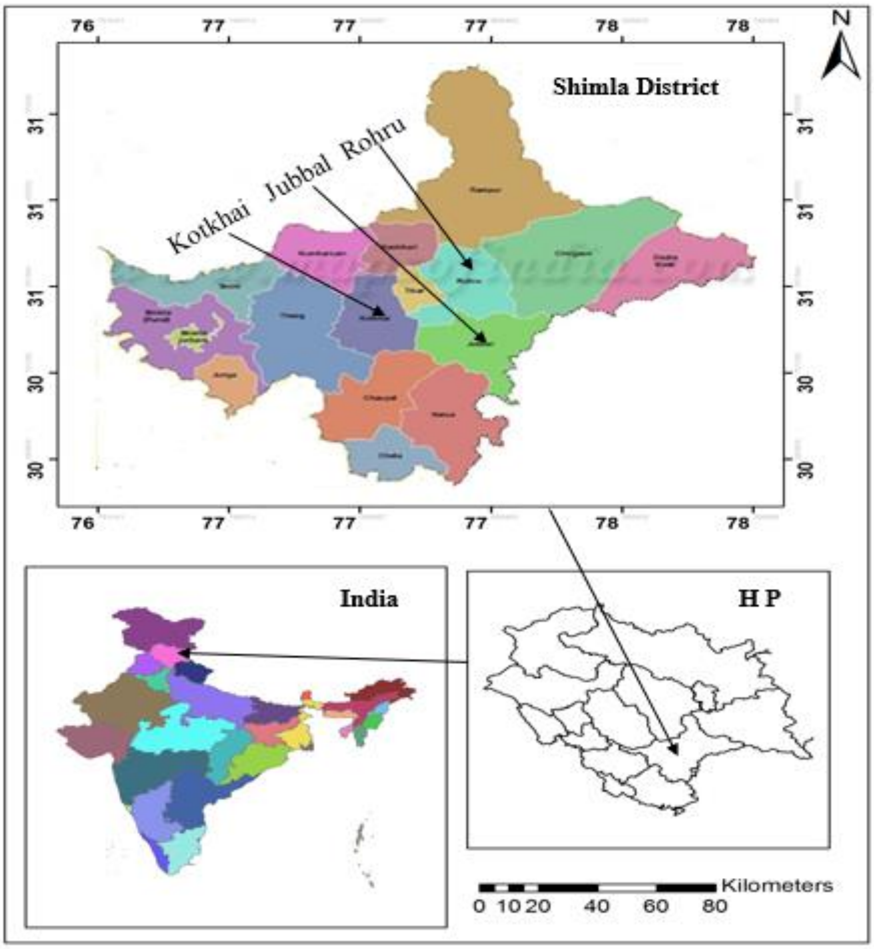

Fig. 1. Study area

Data Collection and Tools Used

In this study, the historical data related to temperature, rainfall, and snowfall, the major climate variables which affect the apple crop production, were analyzed to establish the trend of CC in the region. This trend was corroborated with the trend in the ambient air concentration of greenhouse gases (GHGs). The chill unit, a major contributor to the apple crop production, was also estimated from the analysis.

The monthly maximum, minimum, average temperature from 1901 to 2020 was collected from Indian Metrological Department, Shimla (IMD, 2021). The snowfall data from 1985 to 2020 of each winter month starting from November to February was obtained using the model "modern-era retrospective analysis for research and application" (MERRA-2) which estimates the snow cover. The MEERA-2 is developed by the National Aeronautics and Space Administration (NASA) using GEOS-5.12.4 system (Bosilovich et al., 2015, 2016). The hourly chill unit was calculated using the UTAH model inputting the temperature data (Byrne and Bacon, 1992). To assess the impact of change in climatic parameters on the apple crop yield, crop yield data from 1991 to 2018 obtained from the Department of Horticulture regional office, Shimla was used (Horticulture Department, 2019). CO and CO_2 concentrations were obtained from MEERA-2 and ARIS, respectively. The data of NO_x was adapted from Himachal Pradesh State Pollution Control Board (HPSPC, 2021).

The Mann Kendall (M. K) test was applied for the statistical trend analysis (Arora et al., 2005). For M. K test, R studio (version 3.5.1) software was used. The criterion $p \leq 5\%$ was taken as the significance limit.

Chill Units Calculation

Apple trees need a definite period of cool hours in the winter season so that dormancy could break and flowering get started during springs. Lack of sufficient amount of chill hours leads to uneven and delayed leaf development and flowering, which results in a drop in crop yield and poor quality fruits (small and uneven size). The effective chill units during the study period were calculated using the historic temperature data adopting the UTAH model (Byrne and Bacon, 1992).

Yield Reduction Risk

Yield Reduction Risk (Xi) is used to measure the risk that crop yield will fall from the expected yield trend. The expected yield trend is calculated by using five years weighted average. Equations (i) to (iv) were used to calculate the Yield Reduction Risk (Guo et al., 2019).

$$Y = Y_t + Y_w + \mathcal{E} \quad \text{(i)}$$

$$Si = \frac{Y_i - Y_{it}}{Y_{it}} \times 100\ \% \quad i, t = 1, 2, 3...n \quad \text{(ii)}$$

$$V \quad X_i = | S_i |, S_i < 0 \quad \text{(iii)}$$

$$X_i = 0, S_i > 0 \quad \text{(iv)}$$

Where, Y represents the actual production, Y_t the trend output, and Y_w the weather output, Ɛ is the random error. S_i is relative weather output, X_i is the yield reduction rate.

RESULTS AND DISCUSSION

Temperature Trend Analysis

Monthly minimum, maximum, and average temperature trend analysis is presented in Table 1. A significant increase in minimum temperature could be seen in the months of February, March, April, and November by 1.55°C, 1.08°C, 0.87°C, 0.87°C and 1.10°C, respectively. Also, the maximum temperature in February, March, April, November, and December showed a significant increase by 0.85°C, 0.42°C, 0.67°C, 0.44°C and 0.42 °C, respectively. Moreover, the average temperature in January, February, March, November, December increased 0.34°C, 0.81°C, 1.10°C, 0.74°C and 0.80°C, respectively and decreased in the months of June, July and September by 0.85° C, 0.54°C and 0.23°C, respectively. The temperature trend analysis during the study period indicated a rise in winter temperature and a reduction in the temperature of pre-monsoon, monsoon, and post-monsoon months.

The changes in temperature have different impacts; in case of very high temperatures, the crop development or reproductive phase will disturb pollen and fruit generation and development (Hatfield et al., 2008, 2011). Several studies revealed the impact of temperature on flowering, plant growth, and crop yield of the different types of crops (Sheehy et al., 2005; 2006b; Oh-e et al., 2007; Wiebbecke et al., 2012). The minimum temperature significantly affects the growth of plants (Hatfield et al., 2011) and maximum temperature affects the water content in soil and plant (Alfaro et al., 2006). Several studies reported that the rise in temperature caused a decrease in the crop yield and the decline in the yield varied from 2.5% to 10% (Hatfield et al., 2011; Lobell et al., 2011).

Table 1. Temperature trend analysis

	Maximum Temperature					Minimum Temperature					Average Temperature				
Month	Mean	SD	Sens Slope	p %	Change	Mean	SD	Sens Slope	p %	Change	Mean	SD	Sens Slope	p %	Change
Jan	16.5	1.3	0.003	50.59	0.31	4.6	1.4	0.006	14.1	0.66	10.56	1.25	0.008	2.4	0.94
Feb	18.8	1.5	0.007	4.32	0.85	6.6	1.5	0.013	0.12	1.55	12.59	1.46	0.007	5.77	0.81
Mar	23.8	1.6	0.004	3.45	0.42	11	1.5	0.009	4.21	1.08	17.4	1.52	0.009	3.1	1.1
Apr	30	1.6	0.006	2.11	0.67	16.2	1.6	0.007	0.08	0.87	23.04	1.54	0.006	15.41	0.72
May	33.9	1.6	0.002	71.85	0.19	20.2	1.4	0.007	7.44	0.8	26.97	1.47	0.004	34.2	0.49
Jun	34.2	1.2	-0.009	0.81	-1	22.7	1.1	-0.004	0.17	-0.52	28.44	1.09	-0.007	3.26	-0.85
Jul	30.6	0.8	-0.008	0.15	-0.89	22.4	0.8	-0.004	3.72	-0.43	26.49	0.72	-0.004	3.76	-0.54
Aug	29.5	0.6	-0.005	3.72	-0.62	21.9	0.7	-0.004	3.7	-0.41	25.68	0.58	-0.002	6.1	-0.32
Sep	29.5	0.7	-0.006	0.45	-0.65	20.2	0.7	-0.002	19.34	-0.27	24.84	0.61	-0.002	2.4	-0.23
Oct	28.1	0.9	-0.006	2.23	-0.66	15.4	0.9	-0.002	41.53	-0.26	21.7	0.85	-0.004	13.84	-0.45
Nov	23.4	1	0.004	1.72	0.44	9.6	1	0.007	0.05	0.87	16.51	0.9	0.006	1.38	0.74
Dec	18.9	1.1	0.004	0.26	0.42	6.1	1.1	0.01	0.36	1.1	12.45	1.08	0.007	2.27	0.8

Rainfall Trend Analysis

Rainfall data from 1901 to 2020 was used for the trend analysis. Table 2 shows the statistical parameters indicating the significance in the rainfall trend variation. From the trend analysis, a significant rise in the rainfall of 4 months viz, February, March, April, and May was seen and the magnitude of increase was 23.2 mm, 19.6 mm, 10.4 mm, and 13.4 mm, respectively. The increased spring season rainfall (February to April) destroys pollens and leads to a reduction in the apple yield.

Table 2. Rainfall trend analysis

Month	Mean	SD	Sens Slope	Change in Rainfall (mm)	p (%)
Jan	37.44	27.59	0.032	3.7	59.9
Feb	39.88	31.73	0.2	23.2	0.5
Mar	32	26.93	0.17	19.6	0.468
Apr	23.44	16.51	0.09	10.4	3.6
May	29.48	18.69	0.12	13.9	1.7
Jun	106.3	64.69	-0.04	-5.1	78.29
Jul	258	108.21	-0.24	-27.8	36.4
Aug	242.9	86.38	-0.23	-26.7	30.54
Sep	138.2	78.16	-0.07	-7.7	78.85
Oct	16.04	16.29	0.08	1	64.43
Nov	9.079	12.71	0	0	37.18
Dec	14.83	14.87	0.02	2.7	36.19

Snowfall Trend Analysis

Figure 2 shows the trend of total snowfall during the winter months (from November to March) of the last 35 years in Shimla district. The relevant statistical parameters of the analysis are shown in Table 3.

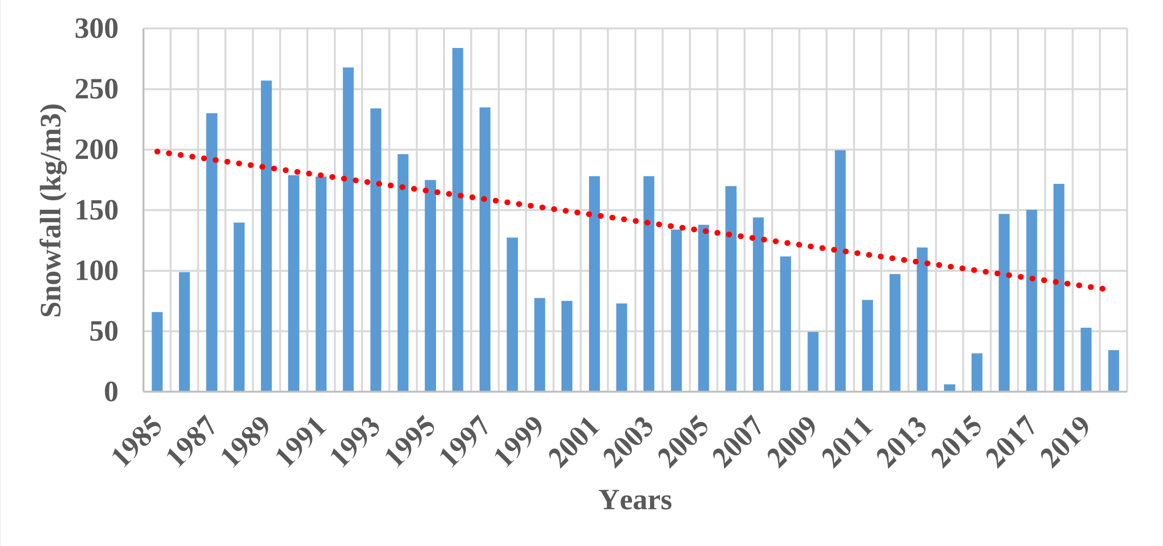

Fig. 2. Total snowfall trend form 1985 to 2020

The snowfall showed a clear decreasing trend. Over the past 35 years, the annual total snowfall during the winter months decreased by 0.375 kg/m^2. The least amount of snowfall was encountered in the year 2009. A Similar, decline in the snowfall was observed in the other districts of Himachal Pradesh (Rana et al., 2012). The drop in the snowfall compared with the trend of temperature observed corroborates the increase in the minimum temperature as evidence of CC in the region.

Table 3 Snowfall trends analysis in winters

S.No	Month	Sens slope	Snow fall Decline (kg/m^2)	P value (%)
1	November	-0.025	0.375	3.2
2	December	-0.084	1.26	2.1
3	January	-0.378	5.67	4.3
4	February	-0.18	2.70	3.1
5	March	-0.34	5.10	2.3
	Total	-1.35	15.11	4.7

Greenhouse Gases Emission Trend

Fig. 3 shows the trend of GHGs (CO, CO_2, and NO_x) from 2004 to 2020. It indicates a drastic increasing trend for CO_2 concentration in the region. Similar observations were reported by ICLEI (2013) in the study area and Anderson et al. (2016) have reported the global increase of CO_2.

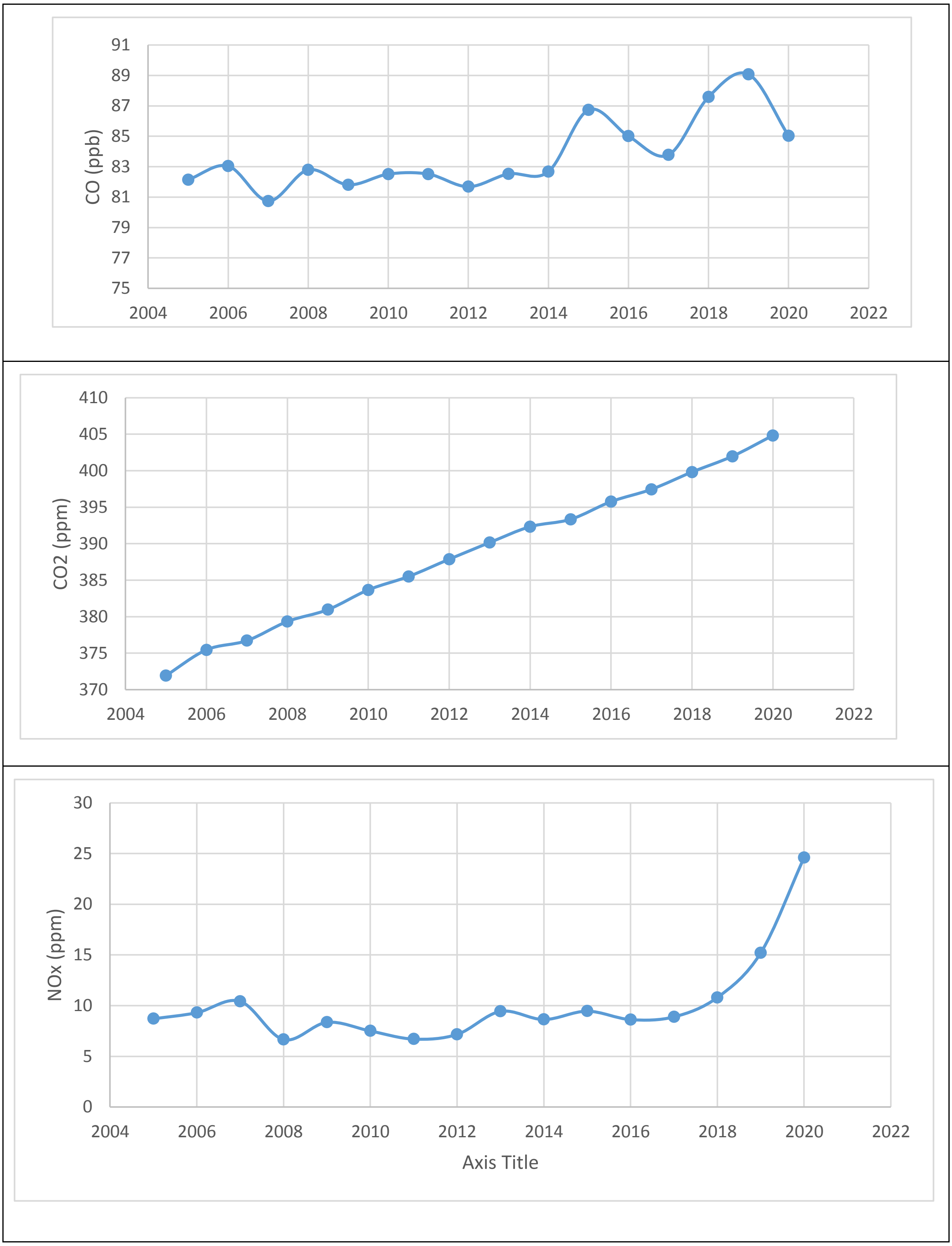

Fig 3. Trend of Green House gases (CO, CO_2, and NO_x)

Chill Units vs Apple Yield

The chill units calculated using the UTAH model was subjected to trend analysis. Fig. 4 shows the trend of chill units for the period from 1991 to 2018. The analysis yielded Sen's slope '-7.5' and p-value 4.23%, which shows a significant decline in chill units over the past

28 years in the apple cultivation areas of Shimla. Similar observations of a decrease in the chill units in the other districts of Himachal Pradesh (Rana et al., 2012; Chand et al., 2016). The decline in the snowfall is a major reason for the drop in chill units. Reduction in chill units due to CC (the rising trend in temperature) was also reported by Chand et al. (2016). Fig 4 also depicts a similar declining trend in the apple crop yield throughout the study. Thus, the CC, especially the trend change in temperature is largely affecting the chill units and accordingly, the apple yield.

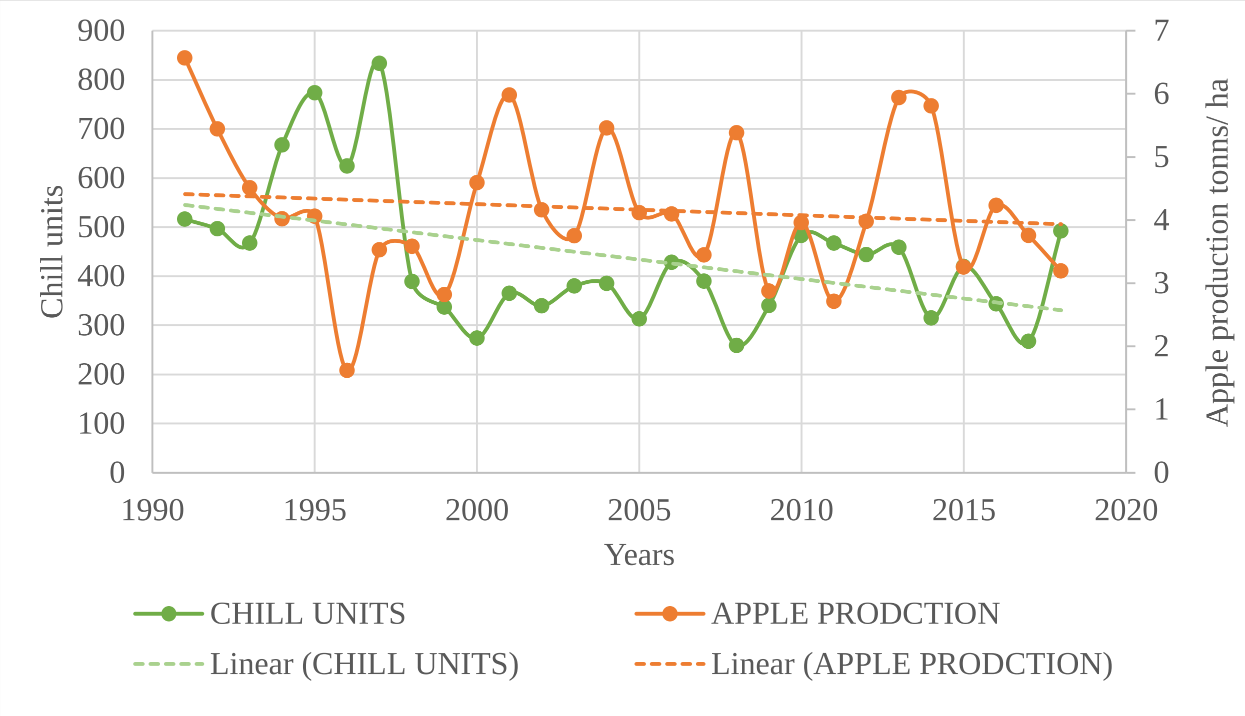

Fig. 4. Time series analysis of chill unit and apple yield

Apple crop is reported to require the standard chilling hours of 800 h – 1100 h and temperature 21°C (Byrne and Bacon,1992)

Relationship between chill units and apple yield in the study area was also analyzed. Fig. 5 shows the trend in chill units vs. apple yield. A cross plot of the chill units and the corresponding apple yield indicted a significant positive correlation between chill unit and apple yield with the R^2 value of 0.6175.

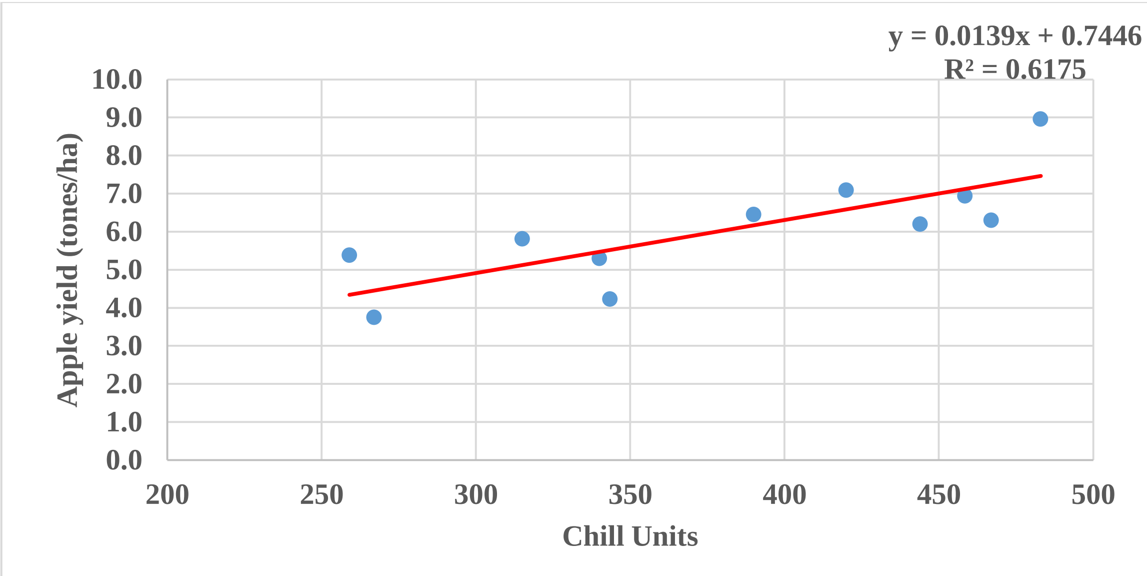

Fig. 5. Cross plot of chill units vs apple yield

Thus, it could be inferred that the chill unit's variation in the study area is significantly affecting the apple yield.

Table 4. Correlation matrix

	CO	CO_2	NO_X	Snow fall	CU	AY	Temp	Rainfall
CO	1	0.340	0.184	-0.663	-0.52	-0.334	0.525	0.291
CO_2		1	0.476	-0.664	-0.158	-0.377	0.664	0.390
NO_x			1	-0.138	0.194	0.062	0.041	0.091
Snow fall				1	0.481	0.564	-0.007	-0.581
CU					1	0.604	0.218	-0.157
AY						1	0.189	-0.185
Temp							1	0.19
Rainfall								1

CU: chill units, AY: apple yield

The correlation among the CO, CO_2, NO_x, snowfall, chill units (CU), apple yield (AY), temperature, rainfall were analyzed in a statistical tool SPSS version 20 in Table 4. CO and CO_2 were positively correlated with temperature with R^2 values 0.525 and 0.664 respectively and negatively correlated with snowfall with R^2 value -0.663 and – 0.664, respectively. While no direct correlation was observed between GHGs and apple yields but the snowfall and chill units have a positive correlation with apple yield with R^2 values 0.564 and 0.604, respectively. Previous studies also documented the influence of CC on apple crops (Fujisawa and Kobayashi, 2011; Pu et al., 2008). Climatic conditions not only impact on the yield of the crop but also the quality of apple (Wei et al., 2003). Li et al. (2018) reported a positive correlation between the various metrological parameters and the apple yield. In this study, the chill units as a comprehensive parameter representing the CC were correlated with the apple yield.

Yield Reduction Risk

Yield reduction risk was calculated by the equations mentioned in the section of materials and methods. Figure 6 shows the results of yield reduction risk calculated for the apple yield of the Shimla district. It indicated that apple production may decrease by 11.48% in upcoming years, if this trend of CC continues.

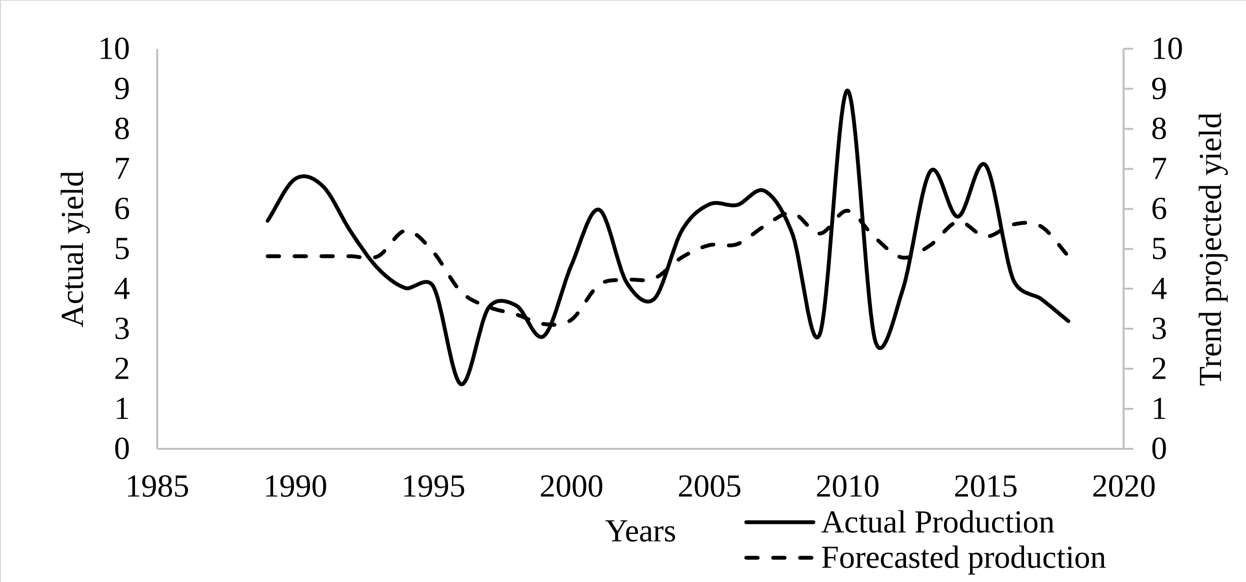

Fig. 6 Time series plot of actual yield and projected yield

CONCLUSIONS

The study evidenced indications of climate change through a trend analysis in respect of temperature, rainfall, snowfall in Shimla district. An increase in winter temperature and reduction in snowfall resulted in decreasing chill units. The apple yield of the region showed a declining trend vis-a-vis the chill units. Therefore, it could be concluded that the apple yield in the study area was affected by climate change. Hence, climate change adaptation and mitigation strategies need to be evolved for sustainable apple production in the region.

DECLARATION

It is declared that there is no conflict of interest between authors, affiliated organizations and any of the funding agencies/organization. Also, this publication has no copyrights involved or published elsewhere in any journals/conferences or any publication agencies/Universities.

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COASTAL EROSION IN INDIA- FROM A SOCIOLOGICAL PERSPECTIVE

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Abstract:

Coastal erosion occurs when there is removal of sediments from the shoreline. The coastal areas are dynamic and often subjected to challenging circumstances like tidal surge, sea level rise, cyclones, and tsunamis-related wave action. Anthropogenic activities like the construction of groins, jetties, ports, sea walls, etc., also contribute significantly towards erosion processes. Coastal erosion assumes serious proportion when lands of ecological and economic importance are lost and in the process becoming a disasters. India has a vast coastline of about 8000kms which is subjected to varying levels of erosion and accretion process. According to a report by the Space application center, 3829 km, or 45.5% of the Indian coast, is subjected to erosion, whereas 2004 km, i.e., 35.7%, is getting accreted, and the remaining 1581 km, i.e., 18% is considered stable coast. Lakshadweep islands face the maximum erosion, particularly after the 2004 tsunami, whereas 66.4% of Tamil Nadu's coast is facing accretion, while Goa carries the most stable shoreline (Rajawat et al., 2015). Various structural and non-structural measures are taken to deal with the risk of coastal hazards but most often done on an ad-hoc basis, leading to unintended consequences. The study aims to examine the coastal erosion phenomenon from an integrated perspective of disaster risk reduction, climate change, and sustainable development. Its specific objectives are; to identify the extent of erosion through secondary sources, examine relevant policies and regulations that are being considered to deal with the hazard, and evaluate different mitigation and rehabilitation strategies in operation.

Keywords:

Coastal erosion, India, Adaptation, Risk Reduction.

INTRODUCTION

The border between ocean and shore is very dynamic which has a substantial societal impact. The net removal of sediments from the coasts leads to erosion. Wave actions, tidal forces, tsunamis, and storm surges are the primary factors that cause coastal erosion. Excessive of it allows the waves to attack landforms that are usually out of their reach. Apart from this, human activities are also responsible for it. Rapid modernization has contributed to the erosion process and increasing hazard risk. Local sea level rise leads amplification of effects of coastal storms, and facilitating increased coastal erosion (Plag & Plag, 2013).

The vulnerability of the coasts depends upon various factors, i.e., the topography, human interference, the tidal ranges, coastal protection measures, and sediment supply and demand. Coastal regions are of great importance for a variety of reasons. There has been an increasing migration rate in these areas as it provides ample livelihood opportunities. It further puts pressure on the area. To better understand sediment behaviour, it is essential to know the erosion and accretion behaviour of the coast. (Rijn, 2011)

Coastal erosion is an indirect cause of climate change. The increase in relative sea level demands more sediment supply which, when not provided, leads to a coastal retreat. Higher sea levels will increase the low tide line as well. The current estimation of Sea level rise is up to 0.6m by 2100. (IPCC, 2007). Adaptation to such climate change impacts has been problematic and increases vulnerability as people need more resources and direction to deal with it. The government also plays an important role here (Chouinard et al., 2008). The erosion process operates at various spatial and temporal scales. Even though certain mitigation measures are taken, the erosion continues to occur and has far-reaching consequences in the coasts and communities.

Adaptation strategies, according to IPCC, fall into three categories "retreat, accommodate and protect" (IPCC, 2001). A retreat displaces residents, properties, and other valuable assets to avoid potential impacts. Accommodation is an act of compensation to some extent in the changing environment. Protection refers to using complex structures like sea walls to protect assets situated on the coasts and prevent regional erosion. Techniques like planting vegetation and beach nourishment are other ways to protect the shore naturally.

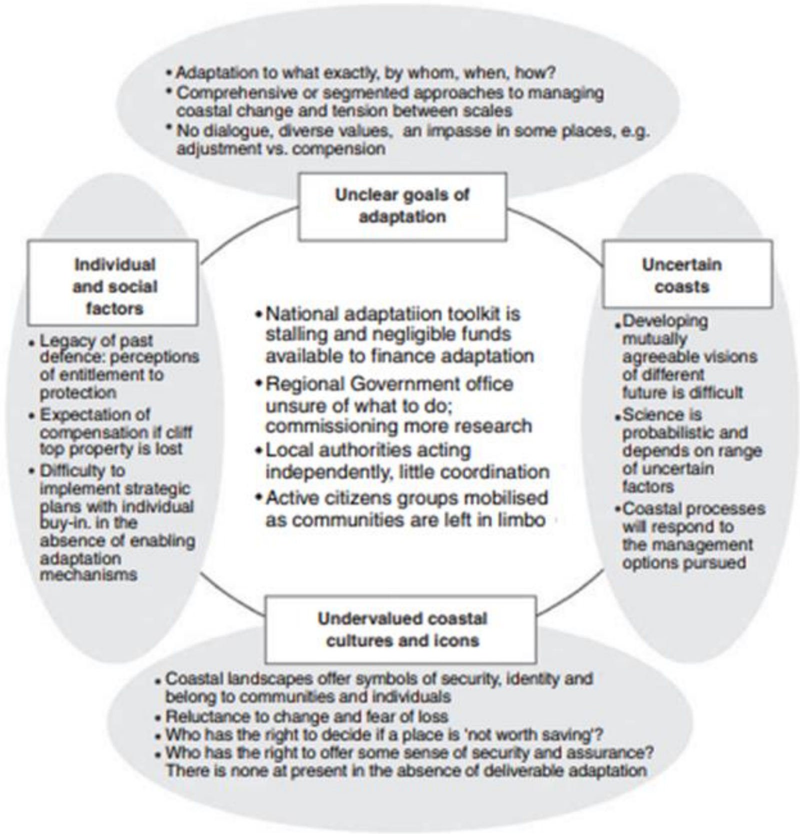

Fig 1. Problems faced while implementing adaptation options. (Nicholson & Ri' Ordain, 2019)

Coastal erosion problems should be addressed at their source, i.e., the sediment budget imbalance on the shore. The loss of sediments in the deep waters is undoubtedly the leading cause of coastal erosion and land loss. The question of who is responsible for coastal erosion often arises. The public authorities often take protective measures, but the parties responsible for erosion are often not held accountable. Approaches taken to reduce or prevent coastal erosion are primarily through ad hoc arrangements. Most countries need coordination or take it as a general problem. Adaptation measures should be substantially robust to withstand sudden changes cost-effective manner. Long term sustainable measures for adaptation often fails due to functional scale mismatches. Climate change adaptation measures are mostly handled in ministry levels whose tenures are of a limited period. With the change in tenure there is a difference in mandates, programmes and agendas (Birkman & Teichman, 2010), due to which proactive measures often fail. Catalytic effects like tsunamis, storms also affect decision-making processes and changes in policies thus adaptive governance plays an essential role in reducing the vulnerability of the people. It refers to a coordinated and integrated approach. Careful preparation, collective responsibility, effective public participation, shared visions, and appropriate scientific knowledge collectively are the building blocks of adaptive governance (Nicholson & Riordian, 2019). Implementing adaptation measures requires a better understanding of the shoreline dynamics by the decision makers helping select appropriate mitigation measures. There has been significant progress in understanding the shoreline dynamics. Gaps still remain regarding what type of adaptation measures, when it is beneficial, and how much sustainable it is. All adaptation has trade-offs. The dynamics of the coastal environment makes win-win situations rare. (Johnston et.al, 2018).

Use of engineering structures do have a positive effect on preventing erosion, but these are short-term solutions that exacerbate erosion in adjacent areas. The construction of such structures is necessary but comes with additional repercussions. The construction of harbours and ports again modifies the coasts and forms artificial coasts. This situation is often undesirable, resulting in the conflict between conservation and rigid structures. Similarly, the construction of ports has a significant impact on sediment transportation, for which the planning of ports should be conducted with the appropriate study of the beach profile and their impact on sediment dynamics.

Coastal erosion becomes a concern until there are no visible losses. The scientific community has adequately assessed the problem of coastal erosion. However, the ultimate sufferers of this process are the communities depending primarily on the coast and its resources. The sociological approaches to the exhaustion of natural resources by anthropogenic activities and increasing risk has often been neglected. According to Ulrich Beck's "Risk Society" political and individual incompetence increases the uncertainties of risks and an undeterminable future of the society. These areas hold much aesthetic value but are cared for significantly less. Developing countries still need help managing the coastal zones strategically. These areas ideally should be development free, but they see the maximum growth due to increasing demand in the tourism industry. The rural areas' low degree of technical development, along with social, economic, and gender disparities, exacerbates the vulnerability of mostly illiterate, untrained, and resource-poor populations. The population's and the government's difficulties are further triggered by coastal zone erosion. If welfare is to be provided, a detailed structural design of the region is required; otherwise, other welfare systems will be ineffective.

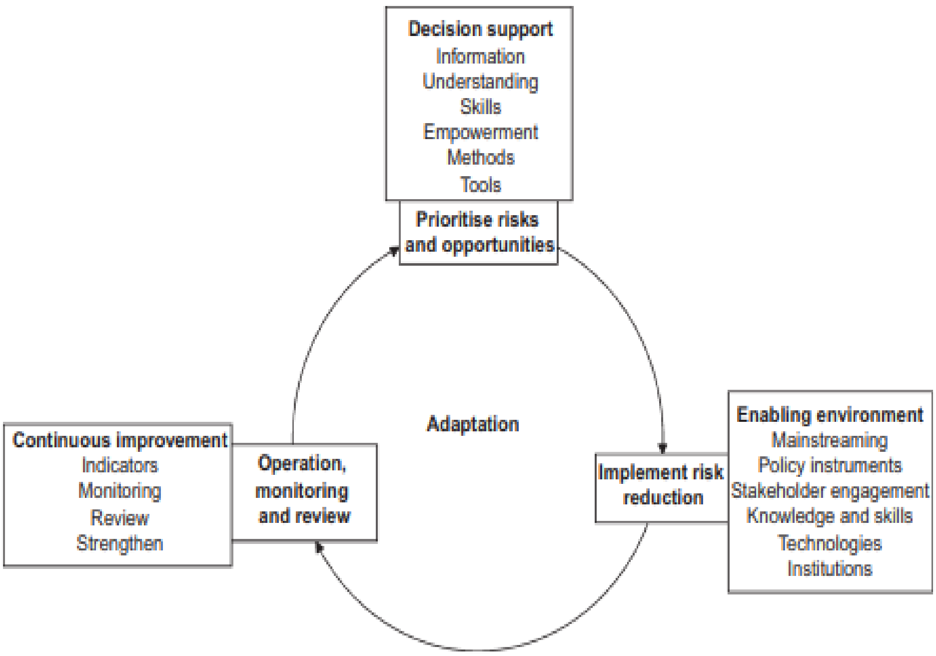

Fig: 2 The adaptation cycle as a conceptual framework (Hay, 2009)

Figure 2 above illustrates adaptation as a process rather than a terminus with proper review and monitoring by the decision makers (Linham & Nicholson, 2012).

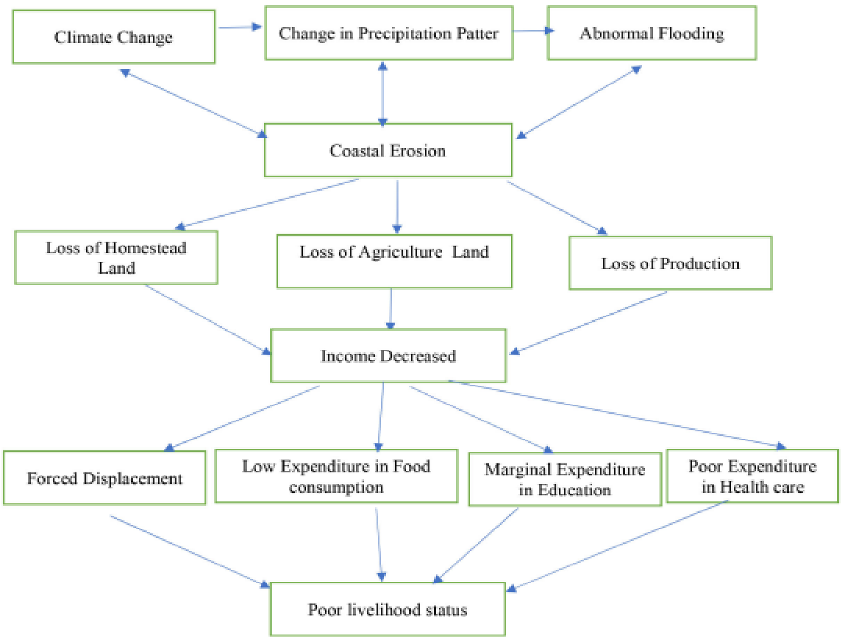

Fig 3. Coastal erosion and its relation to livelihood (Barua et al., 2020)

General belief and opinion about coastal erosion.

Understanding public opinions and ideas about coastal erosion are very important for the effective management of coasts. Opinions on coastal erosion usually form through observing the behaviour of the oceans and its impacts on the environment, culture, and society. Knowledge about such phenomena helps in policy-making decisions as people can influence decisions regarding the environment. Balancing competing demands of the environment, like coastal erosion, from an economic and social perspective is necessary for proper coastal zone management. Understanding the phenomena also facilitates the willingness to pay for the prevention and protection of Coastal erosion (Tourlioti et al., 2021). The perception of people living on the coast also determines whether they want to stay or leave the risk zone.

India's coastal erosion.

The east coast of India, which borders the Bay of Bengal, is made up of four states: West Bengal (which contains a portion of the Ganga Delta), Odisha (which contains the Mahanadi-Brahmani-Baitarani composite deltas), Andhra Pradesh (which contains the Krishna-Godavari and Penner River deltas), and Tamil Nadu (Cauvery Delta). The east coast of India consists of landforms like wide beaches, barrier spits, mangroves, and tidal inlets. Erosional features, like wave-cut beaches, and cliffs, are also seen on the eastern coast, particularly on the Vishakhapatnam coast. The western coast is narrow and non-deltaic, with more numbers of estuaries, spits, mudflats, and mangroves (Ramkumar et al., 2016). The east coast's deltaic parts are highly low-lying and heavily inhabited, with considerable commercial activity. From north to south, Gujarat, Maharashtra, Goa, Karnataka, and Kerala are India's west coast, the region that is the most dwelled and demanded. The important economic centers like Vishakhapatnam, Mumbai, Paradip, Chennai, Kolkata, and many others. Indian coast is approximately 8000 km. It carries a variety of coastal dynamics. For example, the Northwest part of the West coast is mostly tide dominated whereas, whereas the South western part of the south coast are coasted with high wave energy. Long shore solid sediment transport is seen along the south western parts of the east coast and a coast heavily influenced by river discharges along the north western parts of the east coast (Rajawat et al., 2015). The coastal zone in India is subjected to multiple uses, thereby leading to conflicting demands for the exploitation of various resources by different interest groups. The eastern coast of India faces a lot of tropical cyclones every year; with the increasing climate change, the intensity and frequency of storms are also increasing every year. The Sundarban and Ganga delta is the most affected region due to coastal erosion, where 5kms of land is lost (SAPCC, WB).

Table 1: Percentage of erosion and accretion on the Indian coast 1990-2016 (NCCR, MoES 2018**)**

Sl. No.	**State**	**Erosion (%)**	**Accretion (%)**	**Stable (%)**
1	Gujarat	31	43	26
2	Maharashtra	24	64	12
3	Goa	12	68	20
4	Karnataka	22	48	30
5	Kerala	45	34	21
6	Tamil Nadu	41	36	23
7	Pondicherry	57	35	8
8	Andhra Pradesh	27	31	42
9	Odisha	28	21	51
10	West Bengal	63	13	24

Resettlement or Relocation strategies.

The protection of vulnerable citizens is a key responsibility of the states. Proper spatial planning is said to be carried out to prevent populations from identifiable risks. Planned relocation (also known as resettlement) is considered a necessary and effective intervention. Resettlement is usually considered a climate change adaptation. (IPCC, 2001; Barnett and O'Neill, 2012). Direct engagement and proper involvement of communities is an essential pre-requisite to carry forward any relocation activity. (Sipe&Vela, 2014). Resettlement has many negative consequences when not appropriately implemented, leading to the risks of destitution and lost livelihoods (Barua et al., 2020).

People who relocated in an unplanned manner suffer from various social, economic, cultural, and political problems. Social stratification, identity crisis, oppression by local and political musclemen, paying illegal money, loss of cultural harmony, and so on are other problems faced due to relocation. Due to such long history of a breach in human rights, international guidelines and protocols have emerged with development-related forces/planned locations. (UNHCR, 2014; Warner et al, 2013; Baird and Shoemaker, 2007). Retreat and relocation often gives rise to “buffer zones” and significantly reduce the cost of maintaining and installation of protective measures. However this process requires surrendering the lands to natural processes leading to social and political controversies (Linham & Nicholls, 2012). Adaptation requires knowledge of multiple scenarios of extreme weather related events. Uncertain scenarios need proper adaptation technologies and continuous monitoring of the coasts.

The Bengal Delta

The people from the submerged island of Lochara and Ghoramara were relocated to the neighboring island of Sagar due to the large-scale erosion of the lands by the west Bengal government through the local Panchayat. The island of Ghoramara had a total area of 8.51 sq. km, which decreased to 4.43 sq. km in 2012 (Samling et al., 2015). The islands of Lohachara, the villages of Khasimara, Khasimara Char, Suparibhanga, Bagpara and Bedford Islands, Lakshmi Narayanpur, and Baishnabpara of Ghoramara. (Ghosh, T et al., 2014). The displaced population has been resettled (not all) in the neighboring Sagar island in five 'Colonies,' namely Phuldubi Colony, South Haradhanpur Colony, Bankimnagar Colony, Gangasagar Colony, and Jibantala-Kamalpur Colony, by the state government of West Bengal, via the local administrative bodies, the Panchayat (Harms, 2013; Chakma, 2014). A survey has also recorded dissatisfaction due to diminishing landforms, change of occupation leading to low income, and lack of health facilities. Conflicts between residents and settlers have also been observed (Samling et al., 2015). Sagar Island is currently vulnerable to erosion as well. (Roy & Sen, 2013)

The Odisha Coast

The Department of Relief and Rehabilitation carried out relocation and rehabilitation, Government of Odisha, from the villages of Satabhaya and Kanhupur in Kendrapada district to Bagapatia under Rajnagar Tehsil of the same district. (R&DM, 2011) The 17km stretch of the Satabhaya coast is the fastest eroding beach along the Odisha coast. Satabhaya (meaning seven brothers) is one of the remaining villages facing the wrath of erosion. In the neighboring village, the refugees were relocated to Bagapatia. Ten decimal lands were provided to each family. Bagapatia initially used to be a low-lying land as it had shrimp gherries, and the land had to be refilled, which took up additional costs. (MyCitylinks, 2019)

Mangrove Restoration and plantation in India.

Wetlands are lands of high ecological and economic value as well. Many traditional communities depend on mangroves. Mangroves are estimated to "functionally disappear" within 100 years (Duke et al., 2007), which can be controlled through a practical and refined plantation. Bangladesh has carried out a massive mangrove plantation and restoration since 1960 (Ahmad, 2012). In India, the plantation gained further priority after the 2004 Tsunami. There are various ways in which the mangrove plantation is carried out, for example- using cut bamboo, coconut shells, earthen pots, and officially constructed canals (Thivakaran, 2017).

Mangrove plantation is extensively carried out in the Gulf of Kacchh with the proper involvement of stakeholders like fishermen, farmers, and other people dependent on the coast. The areas of the Gulf of Khambat are erosion-prone erosion-prone areas. (Kumar et al, 2006; Rajawat et al, 2015). The eroded area in Gujarat is more than that of the accreted area. (Rajawat et al, 2015). 99.4% of the mangroves are found in three areas, i.e., Kori Creek, Gulf Of Kachh, and Gulf of Khambhat (Pandey & Pandey, 2011). The mangrove plantation drive, however, showed varied types of results at different tehsils as studied (Das, 2019). The Kori creek showed a positive effect. Mangroves that are planted over mudflats generally do not survive (Pandey &Pandey, 2011) due to their existence in discontinuous patches.

Five coastal districts are highly vulnerable in Odisha; Jagatsighpur, Kendrapada, Puri are among the high erosion zones. A similar type of mangrove plantation and restoration activity was carried out in Odisha by Integrated Coastal Zone Management Project

(ICZMP) in over 228 ha of land in the forest divisions of Puri and Rajnagar during 2016-2018. Tidal trenches and channels were constructed for the smooth flow of tidal water, which facilitates appropriate needs for mangroves that were not appropriately maintained. This reduced the survival chances of the mangroves from 0 to 35% (4th Audit Report, Comptroller and Auditor General of India, 2022).

Though mangrove plantation seems to be a very effective and sustainable way to mitigate coastal erosion, specific unresolved issues still cripple the mangrove plantations. Poor survival of the plantations acts to be a considerable barrier (Thivakaran, 2017). Carrying out plantations in unsuitable sites primarily contributes to such mortality. Engaging a skilled workforce and skilled labourers can prevent damage as well. Through both scenarios, we can see that post-plantation management needs to be addressed more. Full participation of the stakeholders and adequate funds can make such drives successful. Such programs should be given social and economic attention rather than just seeing them as scientific activities (Thivakaran, 2017).

Wetlands and mangroves act as a buffer in protecting the shores by controlling erosion rates. They hold the soil in place with their roots, and their net-like structure helps reduce the tide and wave energy. It acts as a buffer to damaging storm surges, thus preventing excessive water from traveling inland. However, this is only location specific and depends highly upon the quality of the mangroves (Das, 2020). Mangroves only colonize and stabilize existing lands and thus should be called "land stabilizers", "not land builders" (Alongi, 2008; Kathiresan, 2003).

Use of hard structures

Coastal erosion is an inevitable phenomenon, and reducing its impacts technically often comes as the responsibility of coastal engineers. Using complicated structures is considered a practical measure and an immediate solution when it comes to protecting the shore. Nevertheless, using complicated structures has undesirable outcomes and often promotes erosion activities elsewhere.

A study conducted by (Sundar et al., 2021) reviews specific hard and soft measures taken on the Indian coast and their sustainability. Various structures like sea walls, groins, breakwaters, and gabions were studied. The coast of Chennai has a sea wall that helped reduce the effects of the 2004 Tsunami and is still standing. Sea walls may be an effective and immediate way to mitigate erosion, but the sustainability of such structures is still a question. These may prevent erosion in one place but cause changes in other unprotected shore (Linham & Nicholls, 2012)

Groins are vertical structures constructed perpendicular to the shore. In India, groins are constructed along the Puducherry coast, Paradip and Gopalpur coast (Odisha), and Alappuzha (Kerala) coastal areas. These promote erosion in the updrift and cause scouring in the downdrift. The main problem with such structures is that they trap the sediments which travel to the adjacent beach resulting in downdrift beach loss (Bush, 2001; McLachlan, 2006). The installation of geotubes has been another form of protection measure, a very prominent case study for this is the geotube and gabion boxes installed at Pentha, Kendrapada, and Odisha. Pentha is among the first villages to face the wrath of climate change through coastal erosion. The erosion process at Pentha was first recorded in 1978 (Water Department, Government of Odisha). The locals and scientific experts believe that the construction of embankment activities at Paradip port and Jagatsighpur have accelerated the erosion rates in Pentha (DownToEarth, 2019). Under

ICZMP funded by the World Bank, the government of Odisha deployed geo-synthetic tubes along the coast to arrest the erosion, which was 505 meters long, 24 meters wide, and 8 meters in height. Two hundred forty-one geosynthetic tubes were laid (ICZMP 2017; Swain, 2018). This too came with repercussions. It was observed that the space which served as a nesting ground for olive ridley turtles was lost. Sea waves have gnawed away the large volume of rocks and stones packed inside gabion nets, which have been torn (OrissaPost, 2019). It was observed that the space which served as a nesting ground for olive ridley turtles was lost. Sea waves have gnawed away the large volume of rocks and stones packed inside gabion nets and the gabion nets have been torn (OrissaPost, 2019)

DISCUSSION

A more detailed understanding of the coasts needs to be assessed to implement proper structural and non-structural mitigation measures that can efficiently reduce coast erosion rates. Proper analysis of policies and proper monitoring of measures post-implementation should be conducted. Impacts of other anthropogenic activities such as urbanization, and population pressure, on coastal erosion needs to be understood.

CONCLUSION

Coastal erosion is an inevitable phenomenon that requires special attention in recent times. Though much scientific research has been carried out to mitigate the risks, looking into it through a social lens gives better clarity of the nature of the problem at the grassroots level. The population depending upon the coast and its resources are the ultimate sufferers of this process, and fair and unbiased involvement in the decision-making process is a vital action that should be taken care of. The use of hard/soft structures for coastal erosion protection has its drawbacks. It is the collective responsibility of the stakeholders to understand the cost and choose appropriate and sustainable measure which causes less negative consequences in the longer run.

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DELINEATION OF GROUNDWATER POTENTIAL ZONES USING REMOTE SENSING, GIS AND AHP METHODS: A CASE STUDY IN KORAYAR RIVER BASIN IN PALAKKAD GAP.

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Abstract:

The Korayar River is one of the significant tributaries of Kalpathypuzha. Kalpathypuzha is a tributary of Bharatapuzha It is actually a part of a rain shadow region in Palakkad gap. The region receives comparatively low rainfall and the Korayar and its tributaries are non- perennial in nature. All of these factors lead them to rely on groundwater for their cultivation and household needs. Therefore, groundwater is the main source of water for irrigation and domestic purposes. As a result, the identification and delineation of the potential groundwater zone is a major requirement. The study is an integration of RS and GIS with the AHP Approach to delineate areas of groundwater potential. While GIS and remote helped to create thematic layers and ground water potential mapping, AHP method used to calculate different factors according to the weightage. The various parameters used in the study include lithology, geomorphology, drainage density, land use and coverage, soil and slope. The groundwater potential zones are classified as five major classes, namely very high, high, moderate, low, and very low. Similar studies would be beneficial to water resource planning and may avoid field surveys.

Keywords:

Korayar river basin, groundwater potential zone, Remote sensing

INTRODUCTION

It is unsure whether there is another resource on earth like water that has this much-influenced humans and even helped to shape their civilization. The importance of water never diminishes as new uses are emerging and there are many things that connect humans with water such as agriculture, Industry, domestic needs, and recreation. Water scarcity is a common term in tropical countries, especially in arid and semi-arid regions. Reduced rainfall and increased evaporations pose problems in these areas with limited water resources. Another thing that needs to be read along with this is human overuse and misuse of water resources. It is commonly accepted that there is a correlation between human behavior and environmental changes(Pallathadka Arun and Pallathadka Harikumar).Likewise It has been recognized that human behavior can have an impact both on water, and on the global ecosystem and that there is a need to regulate that behavior in order to stabilize and sustain our future (WCED, 1987).It is not possible to propose a solution to water scarcity in an area unless the real causes are found. Since water is seen as one of the most critically stressed resources and much attention is now being paid to global water stress and the water needs of the poorest people. (Sullivan, C.A et al.2003).

Ground water is a main source of irrigation in rain shadow region due to the uncertainty of the surface water resources. Beside that the rain shadow effect is a distinctive phenomenon in mountain climates the variability in annual rainfall between the upslope and the downslope areas of the rain shadow region is enormous, leading to significant climatic, hydrological and ecological differences (Thomas, 2012, Thomas Jobin 2018). The Situations in rain shadow region is more intensive than surrounding region. In developing countries, the mapping of water resources requires additional efforts and time because of the lack of proper financing and human resources. (Al-Djazouli et al.2020). The study area, Korayar river basin in Palakkad gap area, is actually a part of rain shadow region, the region receives comparatively low rainfall and the Korayar and its tributaries are non- perennial in nature. All these factors lead them to depend on groundwater for their cultivation. So, the identification groundwater potential zone is very much crucial for this area. The status of ground water plays very important role in socio- economic development of a region. Thus, a generalised classification of groundwater potential zones is evaluated for a quick assessment of the occurrence of ground water resources on regional scale. (Subba rao,2006).

The ground water potential mapping combining various elements like geomorphology, slope , lithology, soil , rainfall, land use etc. the traditional methods for delineating water potential zone is somewhat expensive, time consuming and complex.at the same time The incorporation of Remote sensing and GIS is a paradigm shift for ground water research which supports the evaluation, monitoring and preservation of ground water resources(Silwal and Pathak, 2018,Shao et al. 2020).The AHP and GIS are commonly used for delineating groundwater potential zone. The AHP is an effective tool for dealing with complex decision making in ground water related fields which is introduced by Thomas Saaty in the year 1980. The tool is useful for reducing complex decision to a series of pair wise comparison and then synthesizing the results (ArulBalaji.,P et al,2019). In the present study combining both GIS and AHP for delineating Ground water potential zones of Korayar watershed in Palakkad gap region.

Study area

The Korayar river basin in Palakkad gap region covering an area of 222.423km2. Korayar Puzha is one of the significant tributaries of Kalpathy Puzha and Kalpathy Puzha is one of the major tributaries of Bharathapuzha. Bharathapuzha is the second longest river which flows through the Palghat Gap region. Korayar river is a non- perennial river almost dry during summer season. Korayar basin area extent in two states Coimbatore of Tamil Nadu and Palakkad district of Kerala. But the present study only focusing the Korayar river basin in Palakkad gap region. According to central ground water board, major part of the of the study area comes under rain shadow region. Though the region receives both Southwest and Northeast monsoon rainfall, the SW monsoon is almost scantly in this region. Thus, the density of cropping is comparatively low in the rain shadow region of the Palakkad gap. The rainfall availability is comparatively low in this part, it is also affecting agriculture. So, people living in the rural area mainly depends groundwater for their purposes. The condition of ground water resources is not healthy. Central Ground Water Board included the whole Chittur block as over exploited block in Palakkad district. The elevation of the watershed between 140 to 230 meters from west to east. The main geomorphological units covered in this area are floodplains, Pedi plains and pediments, moderately and highly dissected valley and hills. The land use of the Korayar basin has classified into five categories built- up area, Agriculture, barren land, forest and water bodies.

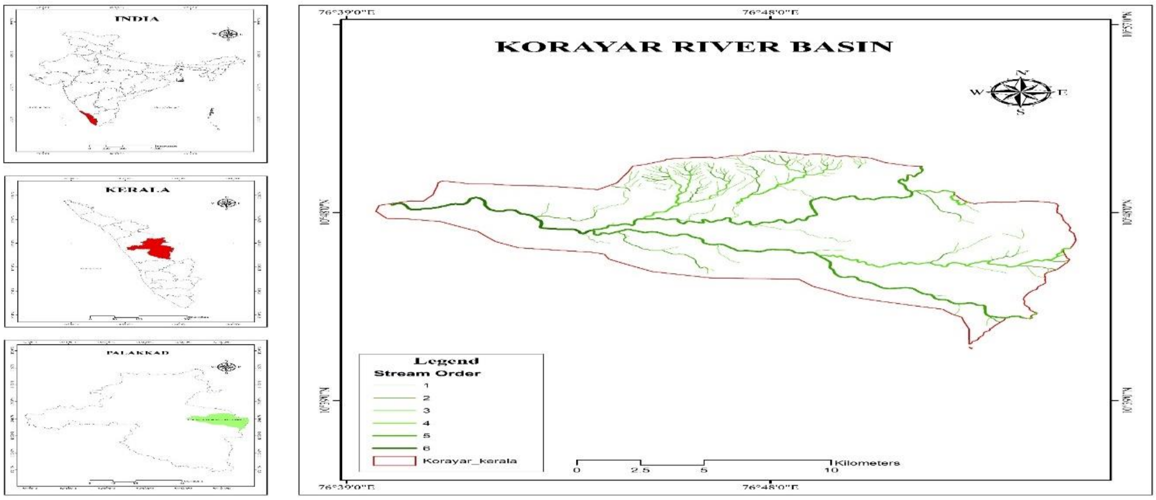

Fig .1 Location map of Korayar river basin

OBJECTIVES

To identify groundwater potential zones in Korayar river in Palakkad gap region.

LITERATURE REVIEW

The study of Groundwater potential zone based on remote sensing and GIS has been conducted by different scholars around the world. There is no universal definition for groundwater potential zone. But most of the groundwater potential studies have been conducted in recent years.Among them Kabetto et al.(2022),Abhijith et al.(2020),Shao et al.(2020)Saranya & Saravanan (2020) used remote sensing and GIS with AHP method to delineate the groundwater potential zones. These studies also conducted in different geographical environments like hard rock region(Prasad et al, 2008,Rajaveni et al,2005),Deccan lava plateau(Das et al.2017, Ajay Kumar et al.2020),river basin(Bera et al 2020. Kaewdum et al,2021) etc. the important thing is there is no defined methodology to assign weight to thematic layers. Each scholars used their own previous experience to assign weights to the thematic layers.(Ifediegwu,2022, Shao et al.2020)

MATERIALS AND METHODS

Groundwater potentiality modelling can be accomplished by looking at the elements that govern groundwater flow, storage, and occurrence (Yıldırım 2021; Ifediegwu 2021)Stanley 2022). To produce water potential map of the study area, The different thematic layers should prepare. The preparing these thematic layers are mainly based on various types of secondary data sources. The selection of these thematic layers determined by the availability of the data and relevance of the data. Geomorphology and Lithology maps of the research area were extracted from Geological survey of India website. Slope, Curvature and Drainage density of the region created using Digital Elevation Model (DEM) of Cartosat version 3R1 having spatial resolution 2.5m. The Soil map extracted from Map prepared by Land use Board, Kerala. The Land use map was digitised from google satellite map. AHP is a type of multi criteria decision analysis widely using along with GIS to delineate groundwater potential mapping of a region. The study analyse the influence of the each thematic layers on groundwater potential of the study area. A parameter with high weights shows high impact on water potential and low weights shows low impacts. all these weightages are based on Saaty's Scale (1990) (1-9) of relative importance value. Previous similar studies are considered to give other weights.

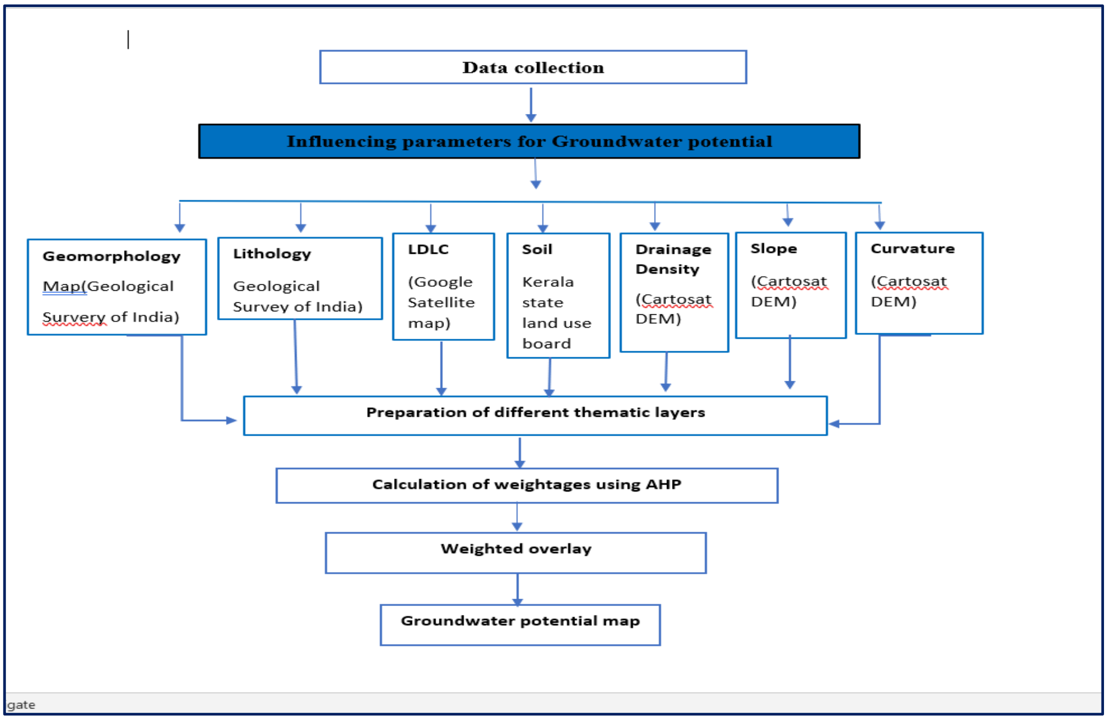

Figure 2. Methodology chart

Determination of rank and weights using AHP

Multi criteria decision analysis using analytical Hierachical process(AHP) is the most common and well known GIS, based method for delineating groundwater potential zones(Arulbalaji et al.2019). the method was developed by L.Saaty in 1970's.According to this method try to integrate various thematic layers. Selection of these thematic layers based on the availability and reliability of the study. A total of 6 parameters used in the study. These selected thematic layers give weightages according to its influence on groundwater potential. The weightage was gave based on the Saaty scale (1-9) of relative importance value. Assigning ranks and weightages to each parameter depends upon the field experience and previous studies. Table 1 indicates the Saaty scale of relative importance values. These thematic layers compared according to its relative importance in the pair wise comparison Metrix(table 2). It is for comparing assigned values in the layers. Though all these thematic layers influence groundwater of the area, its degree of influence may different (Table 3) shows categorization of factors influencing of groundwater potential zones. The result of the table considered for groundwater potential mapping.

Table 1. Saaty's scale

Intensity of importance on an absolute scale	Numerical evaluation
1	Equal importance
3	Moderate importance one over the another
5	Essential or strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8 intermediate values between the two adjacent judgements (Source: Saaty 1987)	

Table 2. Pair-wise comparison Metrix

factors	geomor phology	litholog y	curvatur e	slope	Soil	LDL C	Drainag e density	Weigh t
Geomorphology	7	6	5	4	3	2	1	0.38
Lithology	7/2	6/2	5/2	4/2	3/2	2/2	½	0.19
Curvature	7/3	6/3	5/3	4/3	3/3	2/3	1/3	0.12
Slope	7/4	6/4	5/4	4/4	¾	2/4	¼	0.10
Soil	7/5	6/5	5/5	4/5	3/5	2/5	1/5	0.08
LDLC	7/6	6/6	5/6	4/6	3/6	2/6	1/6	0.066
Drainge Density	7/7	7/7	5/7	4/7	3/7	2/7	1/7	0.064
Total								1

Table 3. categorisation of factors influencing of groundwater potential zones

factors	Assigned weight	Rank	Overall
Geomorphology			
Flood plains	38	9	342
Pediments and pediplains		8	304
Moderately dissected hills and valley		5	190
Highly dissected hills and valley		3	114

Lithology			
Hornblende biotite gnessis	19	6	114
Meta pyroxene		6	114
Pyroxene granulate		6	114
Curvature			
Concave	12	8	96
Flat		5	60
Convex		3	36
Slope			
Steep Slope(0-10^0)	10	3	30
Moderate slope(10-30^0)		5	50
Gentle slope (30-60^0)		7	70
Soil			
Sandy loam	8	7	56
Sandy clay loam soil		5	40
Clay soil		3	24
Landuse and landcover			
Waterbodies	6	9	54
Agriculture		7	42
Forests and natual vegetation		8	48
Built up area		2	12
Barren land		5	30
Drainage density			
Very high density(1300-1500)	6	2	12
High density(890-1200)		3	18
Moderate density(600-880)		4	24
Low(300-590)		6	36
Very low(0-200)		8	48

RESULTS AND DISCUSSIONS

Drainage density

Dd is directly related to components such as lithology, infiltration, runoff, rivers, vegetation cover and climate (Moglen et al.1998, Al-Djazouli et al.,2020). It can be calculated by total stream length divided by total basin area. In the study area drainage density map has prepared by using Cartosat DEM images by using ARC GIS. The Korayar river flowing in this region, where water flows only SW monsoon and NE monsoon season. The drainage density of the study area has classified as Very high (1300-1500), high (890-1200), medium (600-880), low(300-590), very low(0-200).The higher rank assigned to 1.3 to 1.5 Km/ km2 and lower rank given to 0-0.29 km/Km2.Lower drainage density (0-0.29 Km/Km2) occupies the most part of the region, Followed by moderate density (0.66-0.88 Km/KM2). A higher density region found here and there in the region. It is evident that surface runoff and infiltration directly linked to drainage density. The high-density regions have high percolation level which means low runoff (Nasir et al., 2018, Abijith,D. et al 2020) Low drainage density can help enhance the groundwater, since this area is usually flat and has slow surface runoff which facilitates more recharge (Anbarasu *et al.* 2019).Figure 3 shows the drainage density of Korayar river basin. The high drainage density assigns lower rank and lower drainage density assign higher rank.

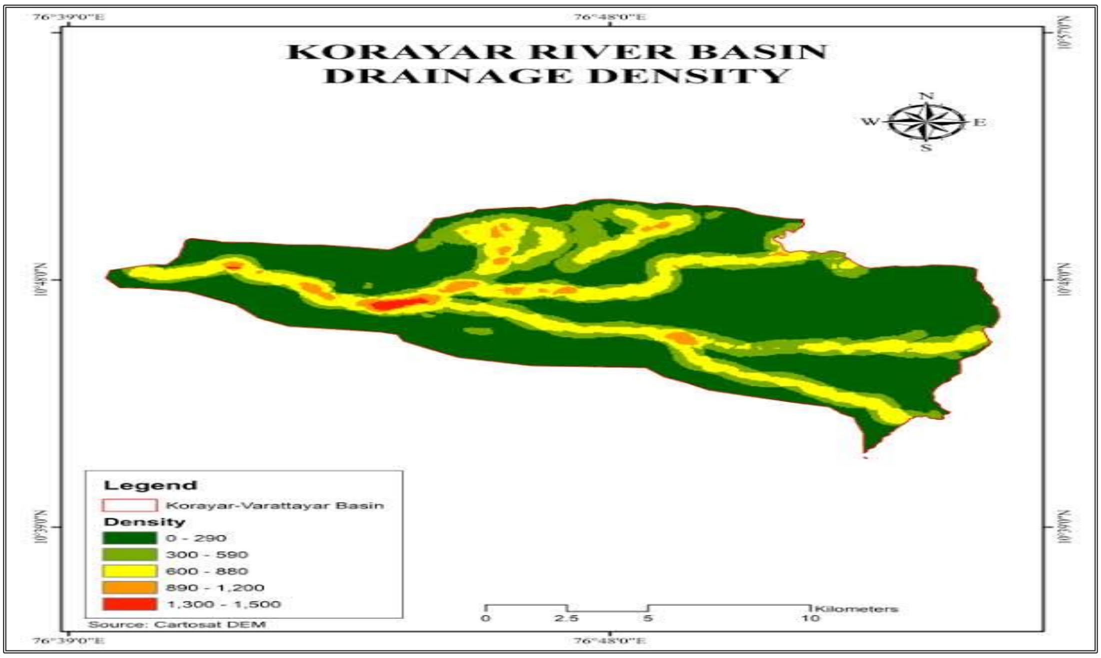

Figure 3. Drainage density of Korayar river basin

Lithology

Lithology is a very important factor to determine the ground water potentiality of the area. The lithology maps have downloaded from the Geological Survey of India websites and digitised by using ARC GIS. The above 90 percentage of the study area covered by hornblende biotite gneiss. It is a type of metamorphic or igneous rock; thus, permeability and infiltration of the region is comparatively less, it simply means ground water recharge is also very low. Another two lithological unit occur in this region is Meta- pyroxenite and Pyroxene Granulite. All these are either igneous or metamorphic rocks therefore have very little infiltration and groundwater recharge, so they are given a low weightage.

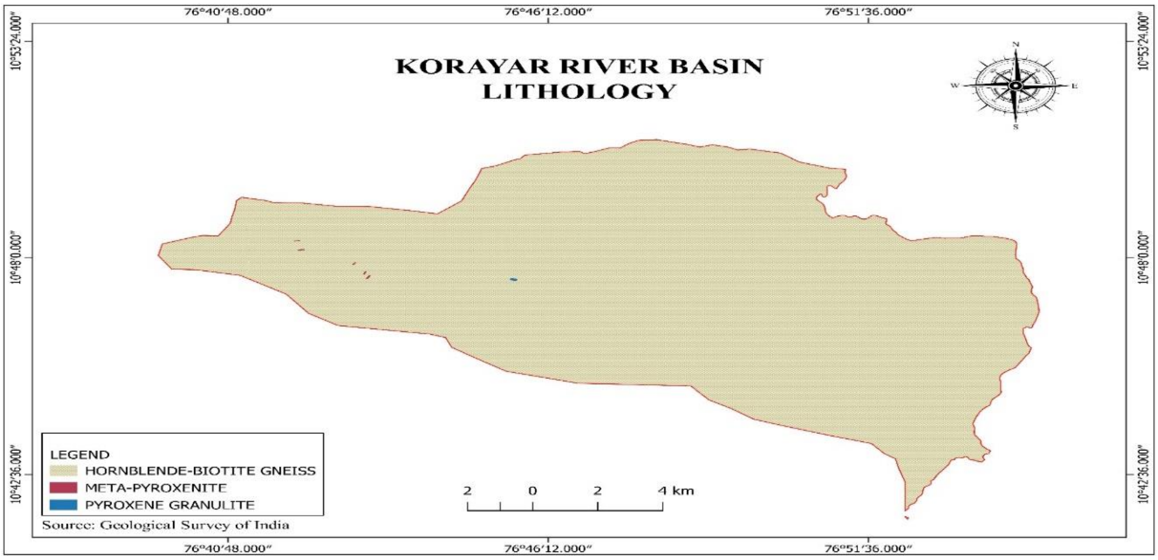

Figure 4 Lithology of Korayar river basin

Soil

The water-conserving capability of a place relies upon the soil sorts and their permeability. The infiltration rate of a soil depends upon the availability of the rainfall and water holding capacity and water holding capacity of the soil. Thus, the soil properties will determine the runoff percentage and infiltration percentage of an area, it also affects the groundwater potential of an area. Soil found in this region can be broadly categorised into three categories clay soil, Sandy loam and sandy clay. Figure.5. the details of the soil categories identified in the study area based on the report of the Land use survey board, Kerala.1.92 percentage of the study area contained clay soil and 2.59 percentage covered by sandy clay loam and 94.84 the percentage has found to have sandy loam. Among these groups, the sandy loam received a higher score than the clay loam and clay soil. The two soils contain clay which has lower or slower infiltration rates. The sandy loam has a thicker soil base, lighter soil texture and better soil nutrient quality. Consequently, it was assigned the maximum weight (Zhenfeng Shao, et al. 2020). Meanwhile clay loam soil is considered to be moderately suitable for groundwater storage. The infiltration rate of Clay soil is very low; thus, it owes only small weightage value.

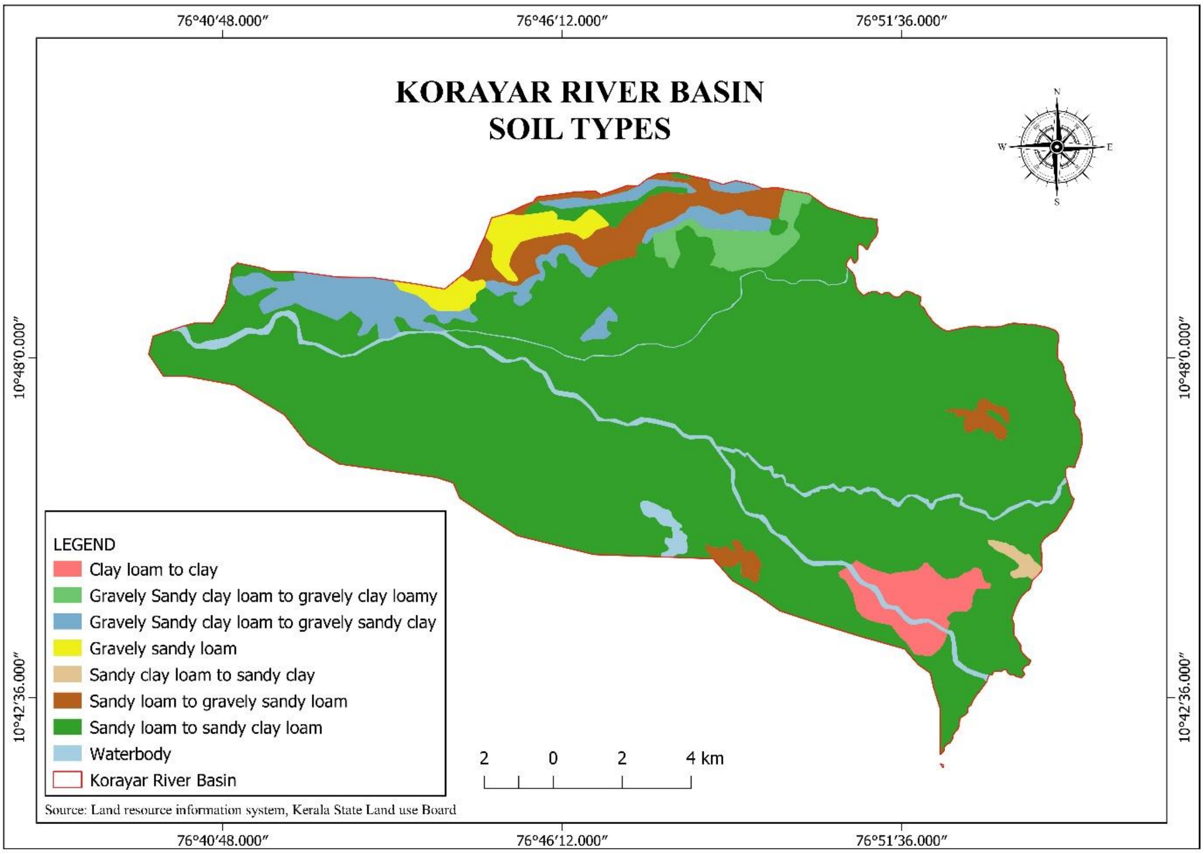

Figure 5. Soil types -Korayar river basin

Land use

The LULC of the area provides important indications of the extent of groundwater requirements and utilization (Gupta &Srivastava, 2010). Its situations have an effect on the hydrologic cycle and hydrologic manner by changing the evapotranspiration, transpiration, infiltration, interception, and surface runoff, and thereby the groundwater potential distribution conduct in lots of ways. Figure 6. Shows that land use in the study area comprises 5 classes like Agricultural land, Barren land, built up area, Forest and natural vegetation and water bodies. Which identified and digitised on the basis of google satellite map. According to the Land use map of the study area around 48% of the land area is covered by Agriculture land. Barren lands and Natural vegetation cover 20 and 17% of area respectively. While the built-up area covers 10.50 % area water bodies covers only 2. 84% of the study area. Water bodies and agricultural lands are most favourable for groundwater recharge. Thus, both classes owe good rank than others. Apart from the forest, natural vegetation also almost favourable sites for groundwater. But built-up areas and barren lands are not much conducive to groundwater seepage and storage.Figure 5 Shows the land use of the Korayar river basin.

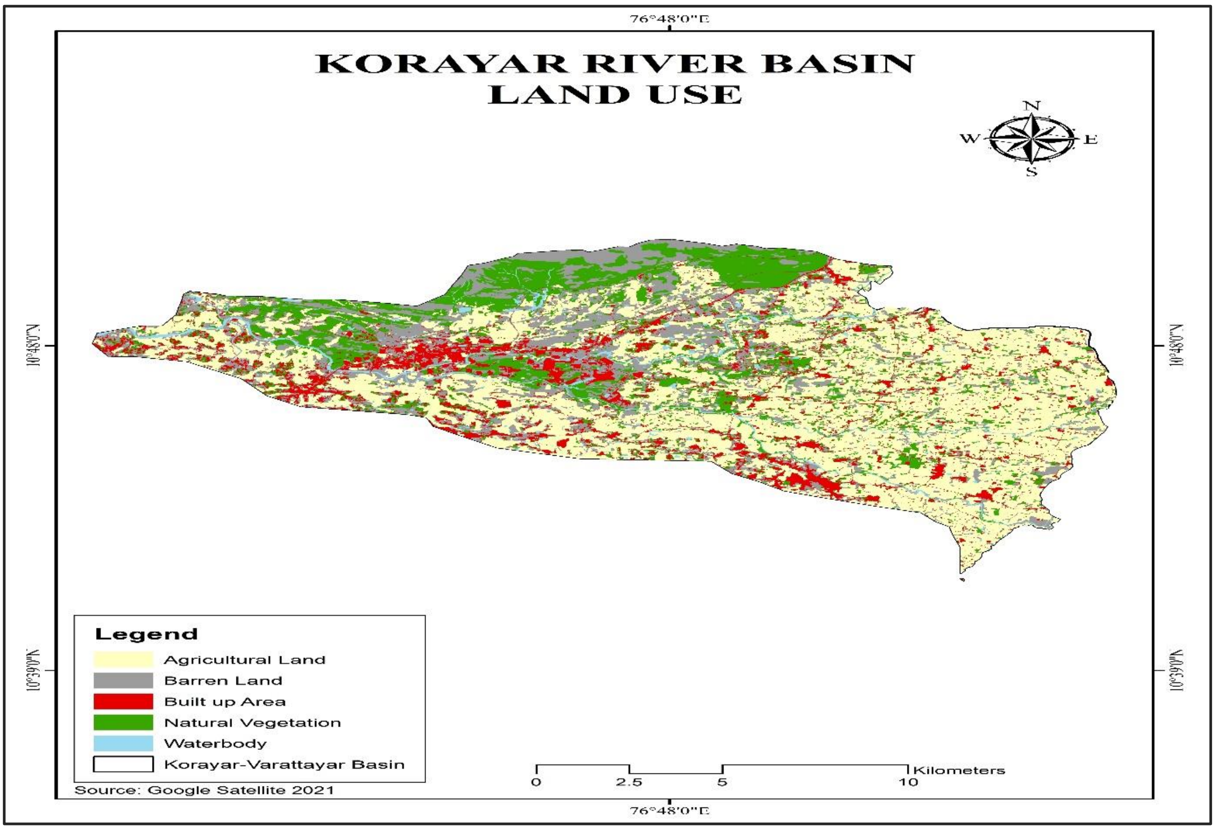

Figure.5 Landuse-Korayar river basin

Geomorphology

Geomorphological units are the important aspects of the physical feature of the earth's surface, evaluation of the topography, hydrogeological investigations and identification of groundwater resources (Krishnamurthy and Srinivas 1995, Ajay Kumar et al 2020).Highly and moderately Dissected hills and Valley, Flood plains, Pedi-Plaines and Pediments are the major geomorphic features found in the study area (Fig 6). Pediments is the gentle sloping surface formed between hill and plain surface (Rajaveni et al.2015). Pediments and Pedi Plaines cover major part of the area. The highly and moderately dissected hills and valleys occur extreme north portion of the study area. The flood plains are deployed in areas adjacent to or on both sides of the river. The area occupied by different geomorphic features are given the table (4). About 85% of the total area was found to have pediplain.It is good for the groundwater flow and storage. Like pediments flood plains are also good in case of groundwater prospects. Flood plains cover only 3.34% of the study area. Both Geomorphic features yield higher rank. Structurally dissected hills and valleys are considered as low groundwater recharge zones due to their high elevation, steep topography, faster runoff and subsequently low infiltration rate (Anbarasu et al. 2019). Thus, both the features have assigned lower rank as compared to others.

Table 4. Geomorphic feature -Korayar river basin

Name of the geomorphic feature	Area in sq. km
Flood plains	7.4
Highly dissected valleys and hills	12.88
Moderately dissected hills and valley	9.75
Pediments and Pediplains	40.08

Source: Geological survey of India

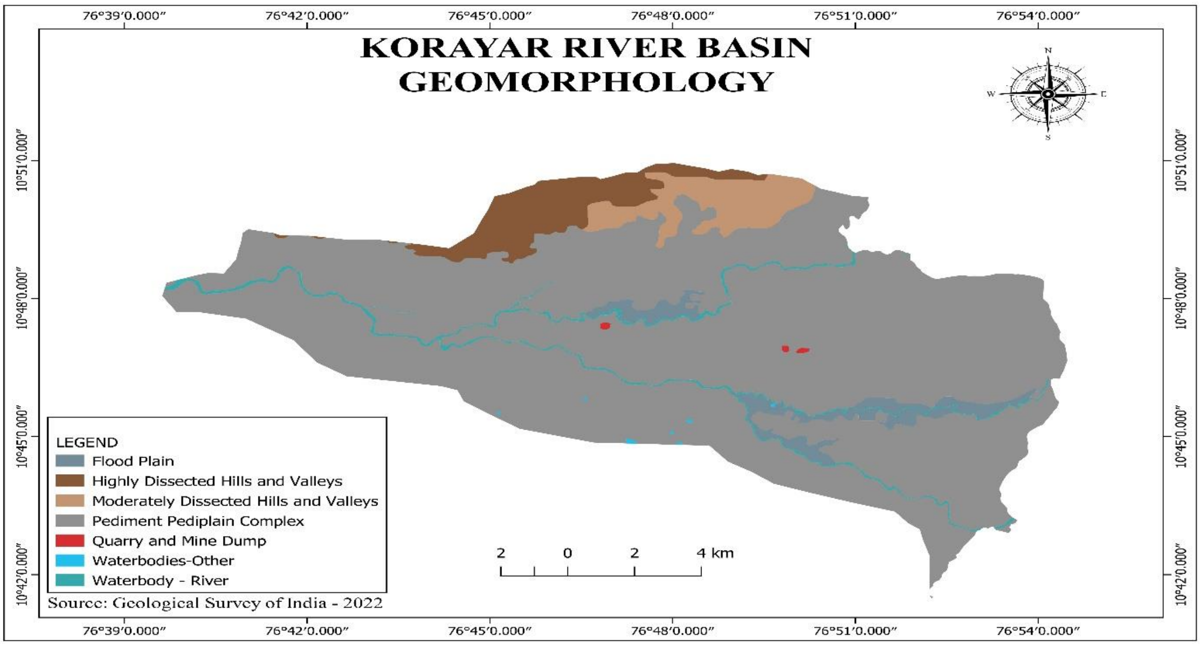

Figure 6. Geomorphology of Korayar river basin

Slope

The slope is an important determining factor in determining the groundwater potential of an area. Sites with flatter or lower slopes are good indicators of groundwater potential zones, since they provide more excellent rates of water renewal compared with regions of higher slope (Mumtaz et al., 2019; Nayyer et al., 2019, Shao et al, 2020). The slope map has been prepared by using Cartosat DEM version3R1 with defined class interval very gentle (0-100), Moderate (10-300), Steep (30-600) (Fig.7). The gentle slope cover in most part of the study area. It indicates good groundwater storage potential and medium slope (10-300) and steep Slope found in the Northern part of the study area. The groundwater storage capacity of this region is comparatively low. Because Larger slopes produce smaller recharge because the water received from precipitation flows rapidly down a steep slope during rainfall. (Arul Balaji et al.2019). Therefore, higher rank was giving lower slope region.

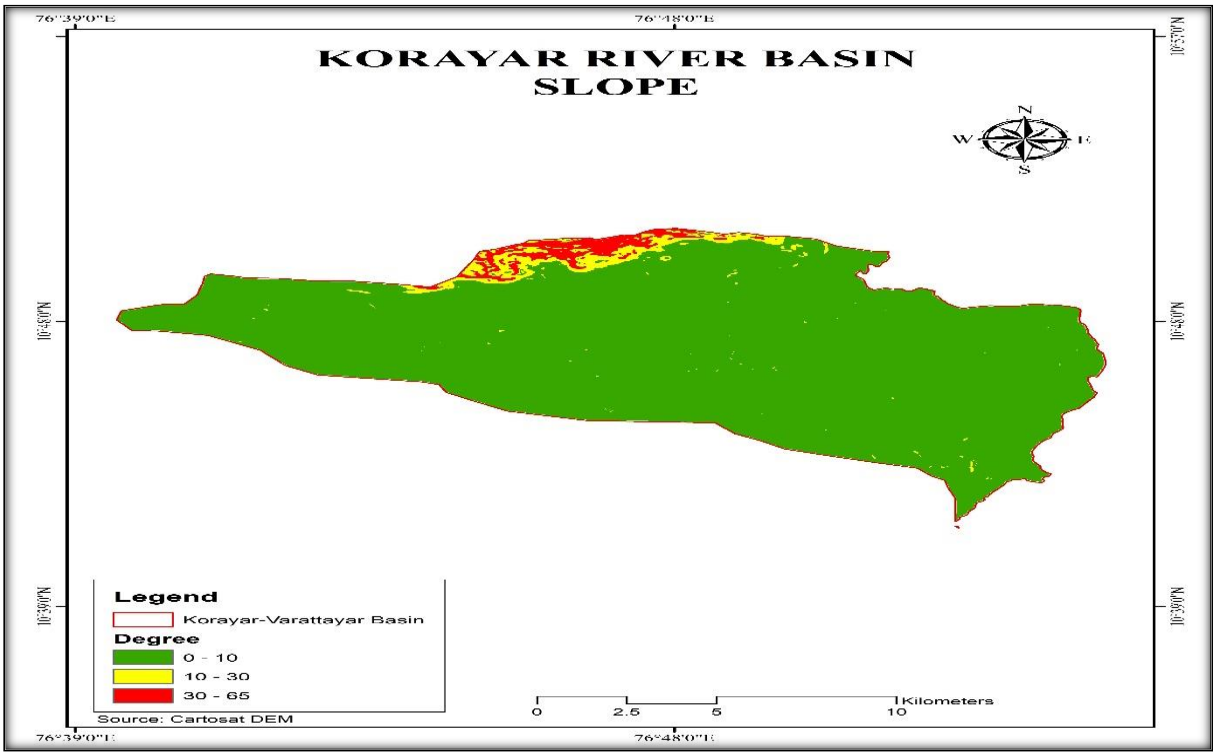

Figure 7. Korayar river basin-slope

Curvature

Curvature of an area quantitatively measure the concaveness and convexness of the terrain.It plays an important role in soil moisture and ground water potential. The value zero denotes a flat surface. Because soil thickness is relatively higher in areas with concave slopes, soils in these areas continue to gather more water than soils in areas with convex slopes (Ghosh et al.2022). The curvature of the study area ranges from -1.7 to19.0. Based on slope curvature the study area was divided into three main categories. Such as Concave (-1.70—6.8) flat (-6.8-5.8) convex (5-19).Korayar river basin is mostly flat.

Figure 8. curvature of Korayar river basin

Delineation of groundwater potential zones

Groundwater potential zones (GWPZs) are a dimensionless amount that predicts the groundwater potential zones in a region (Rahmati et al. 2015, Ajay Kumar et al. 2020). There are several factors influence groundwater potential of an area.The present study focused only six factors. These thematic layers were prepared by Remote sensing and GIS. These thematic layers have g according to its priority (table 2). The overall weightage of each element used to prepare groundwater potential map (Table 3). These weightages are derived by AHP method. The groundwater potential zone map (Figure.9.) ranging 0 to550.It can further classified as low (0-104), medium (104-376) and high (376-474) and very high (474-550) groundwater potential zones. Among these0.177 sq. kms area covered by high groundwater potential zones and 28.08 sq. km area covered by medium groundwater potential zones low and very low groundwater potential zone cover 16.18 and 0.35 sq. kms respectively. Geomorphic features like Flood plains, Pediplains and pediments associated with high ground water potential, while highly or moderately dissected valleys and hills associated with low or moderate groundwater potential. Beside that there is sandy loam soil is more favourable for groundwater storage and potential. High groundwater potential zones connected with the soil type. Steep slope areas associated fall into low ground water potential zone.

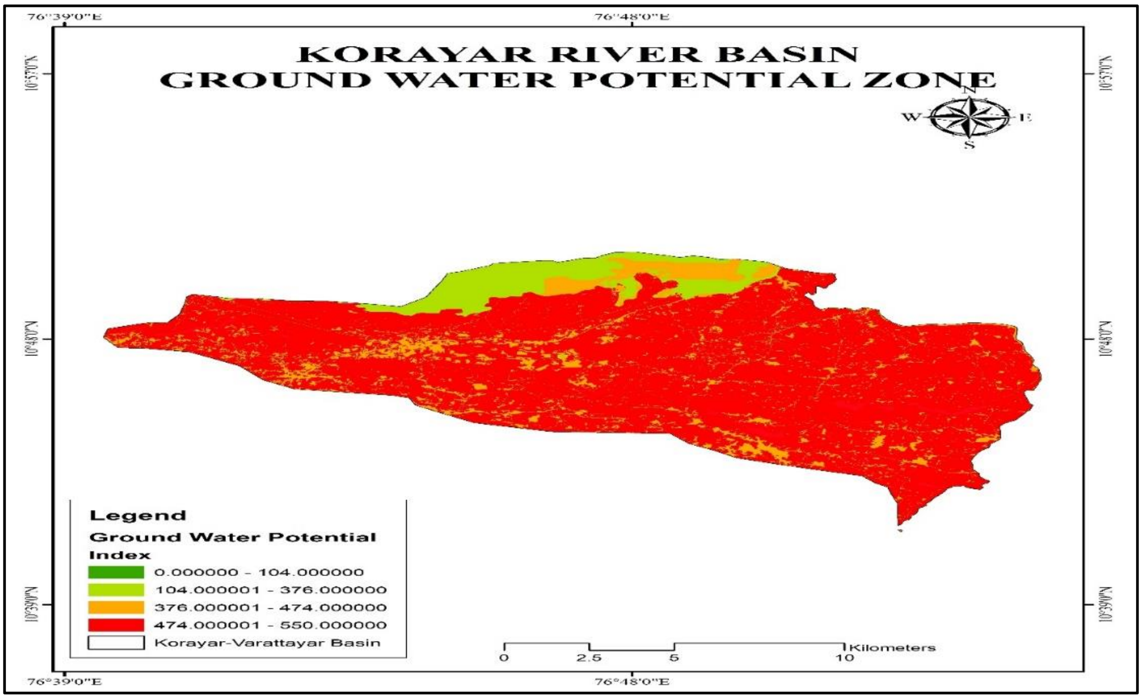

Figure 9. Groundwater potential zone map of Korayar river basin

CONCLUSION

GIS and Remote sensing are the one of the most easiest method to delineate groundwater potential zone.Groundwater potential zone mapping is crucial for sustainable management of water in a region where agriculture is a major source of income. In addition to that Groundwater is the major source of water in Korayar river basin. Here the groundwater potential zone was identified on the basis of seven thematic layers. According to the groundwater potential map most part of the study area has high groundwater potential especially the regions with Flood plains, Pediplains and minimal slope. The decision makers in the Korayar river basin would benefit from the groundwater potential zone mapping for their water related planning.

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AUTHORS CONTRIBUTION

RESHMA M,Research scholar,Govt Collage Chittur,Palakkad , who done an important role in identification of problem,selecting this topic,reviewing and writing the paper.

MUHSIN M C, M. Sc sudent,Govt College Nilambur,Malappuram,contributed in data collection and mapping.

RICHARD SCARIA, Assisstant Professor,Department of Geography,Govt College Chittur,contributed in methodology, organising the paper and rectifying errors and providing valuable suggestion

DECLARATION OF NO CONFLICT OF INTERESTS

The authors declared that there is no conflict of interest between authors,Affliated organisation and any funding agencies in this paper and this work is not published elsewhere.

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DEVELOPMENT OF ISOPLUVIAL MAPS OF KERALA USING GRIDDED RAINFALL DATA

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Abstract:

Rainfall characteristics are an essential input for the design of water management infrastructures such as dams, reservoirs, culverts, drains, etc. Engineers often make use of isopluvial maps to estimate design floods for the planning and design of such hydraulic structures. However, intensification of the hydrologic cycle in changing climate has perturbed the frequency and intensity of rainfall events, and are expected to increase in the future. The recent occurrence of frequent extreme rainfall events (EREs) in changing climate have hampered the stability of hydraulic structures, warranting a timely review of the rainfall characteristics considered in hydraulic designs. An overestimated/underestimated design flood will lead to uneconomical or unsafe designs. The Indian Meteorological Department (IMD) provides the isopluvial maps of Kerala using station rainfall data, but the latest report was released in 2009. Although the probability for the occurrence of EREs over Kerala is very low, the recent years (2018, 2019, and 2020) witnessed the occurrence of multiple EREs across Kerala. In this context, the present study aims to prepare isopluvial maps of Kerala, and evaluate its evolution under the influence of the recent EREs. Isopluvial maps of return periods of 2, 5, 10, 25, 50, and 100 years are developed using 120 years of IMD gridded rainfall data (1901 – 2020) at a spatial resolution of 0.25^0. The results show an increase in rainfall for all the return periods except 2 years. This is a typical characteristic of the impact of climate change, whereby an increase in rainfall intensity is observed with a decrease in rainy days. In other words, rainfall events of larger return periods are more intense. The recent decade with EREs shows an increase by nearly 20 mm at certain grids for rainfall of 25, 50, and 100 years return period. Finally, the impact of the updated isopluvial maps on the design of drains are examined using the guidelines of Indian Road Congress.

Keywords:

climate change; isopluvial map; extreme rainfall events; design flood

INTRODUCTION

Water is the most valuable and limiting resource for humans, with rainfall being the major source (Venkata et al. 2018). However, it is not distributed evenly; certain areas may receive abundant rainfall while others may experience a shortage. Water must be distributed consistently to multiple demand sites, which requires the construction of man-made structures. In order to hold excess water during the rainy season, barriers like dams are placed across the river on the upstream side and are cautiously withdrawn during the dry season to various demand sites located in the downstream side. Rainfall is a key component in the construction of many engineering projects, like dams, aqueducts, canals, sewers, and drainage systems (Arvind et al., 2017, Powell et al, 2006). In recent decades climate change has altered every phase of the global water cycle. Because of global warming, South Asia will experience an increase in the danger of floods and drought (Mishra et al. 2020). Numerous records from meteorological stations, satellites, and radar amply demonstrate that global precipitation patterns have changed (IPCC AR6 WG 2, 2021). One of the most significant effects of climate change is the intensification of the hydrological cycle. At both global and local level, this intensification increases the intensity and frequency of precipitation (Sarkar et al., 2020, Mukherjee et al.2018), which results in flash floods, landslides and will have a negative impact on society, economy and environment (Mishra et al. 2018, Mukherjee et al. 2018, Goswami et al. 2006). In the month of August 2018 Kerala witnessed some of the worst EREs leading to widespread flooding and landslides in majority of the state's districts, seriously harming both the built environment and the natural ecosystem (Kieran et al. 2020). The prolonged rainfall episodes and the EREs occurring throughout the Indian Summer Monsoon Rainfall season were the main causes of flooding in Kerala (KSCSTE Report, 2019).

Since rainfall characteristics are often used to design water management infrastructures, reviewing and updating rainfall characteristics is necessary for future designs of structures, as unexpected climate change have hampered the stability of hydraulic structures. An overestimated design flood or underestimated design flood will lead to uneconomical and unsafe designs. Therefore, utmost care needs to be taken to estimate the design rainfall. The knowledge about the frequency and magnitude of EREs is important for adapting to the extreme weather, designing engineering structures, managing reservoirs etc. Engineers requires design rainfalls in order to design stable hydraulic structures (Johnson et al. 2019). Though probability distribution models are appropriate, they are rigorous. In comparison, the isopluvial maps are often used as a quick tool to estimate the rainfall intensity at any place with fairly good accuracy (Parvez et al. 2019). Isopluvial are lines on a map connecting points having the same amount of rainfall for a return period. The return period is a statistical parameter used in frequency analysis and is a measure of the probable time interval between the occurrence of a given event and that of an equal or greater event (SOP for Hydromet services, 2021)

IMD provides the isopluvial maps of Kerala using station rainfall data, but the latest report was released in 2009. Although the probability for the occurrence of EREs over Kerala is very low, the recent years (2018, 2019, and 2020) witnessed the occurrence of multiple EREs across Kerala. In this context, the present study aims to prepare isopluvial maps of Kerala, and evaluate its evolution under the influence of the recent EREs. Isopluvial maps of return periods of 2, 5, 10, 25, 50, and 100 years are developed using 120 years of IMD gridded rainfall data (1901 – 2020) at a spatial resolution of 0.25^0. Finally, the impact of the updated isopluvial maps on the design of drains are examined using the guidelines of Indian Road Congress.

STUDY AREA

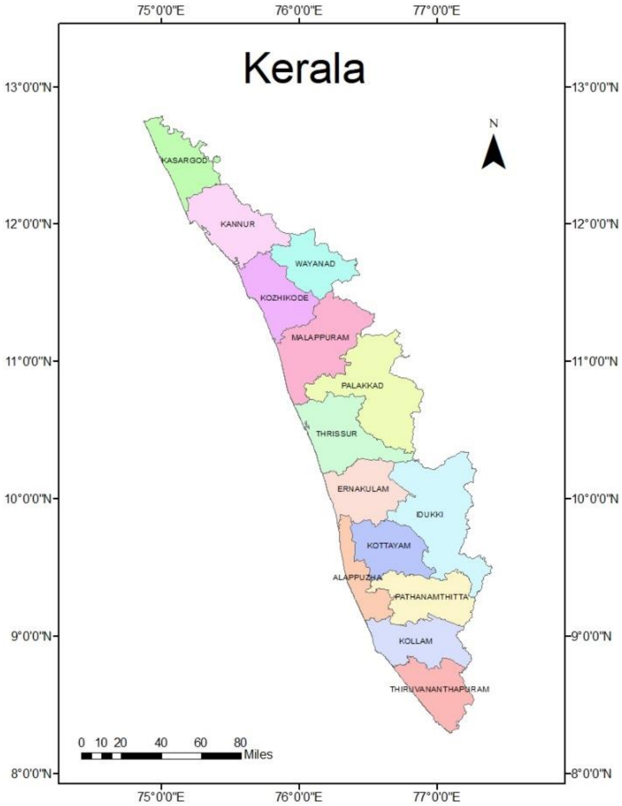

Figure 1: Map of the study area

Kerala, often known as the "Gateway of the Summer Monsoon," is the state in southern India with an area of 38,863 km^2, and its latitude and longitude are $8^0$18’N and $12^0$48’N, $74^0$52’E and $77^0$22’E respectively. The state of Kerala is blessed with 44 rivers, of which 41 are west flowing and 3 are east flowing. Notable rivers include Bharathapuzha, Periyar, Pampa, and Chaliyar. The state is divided into three regions based on its topography namely eastern highlands, hilly midlands, and western lowlands. The region experiences the typical humid tropical environment as a result of its tropical location and the state experiences average annual rainfall of 3107 mm. The mountainous eastern highlands of Idukki district, which make up the wettest region, receive nearly 5,000 mm of average annual orographic precipitation, lowlands only receive 1250 mm. Seasonal monsoons accounts major portion of Kerala's precipitation. The state experiences 120–140 rainy days on average each year as a result. In summer, cyclones moving in from the Indian Ocean can bring storm surges, torrential rain and gale-force winds over much of Kerala.

OBJECTIVES

The major objectives of the study are:

- To develop the isopluvial maps of Kerala considering 120 years of IMD gridded rainfall data (1901-2020) with a spatial resolution of $0.25^0 \times 0.25^0$ for various return periods like 2 years, 5 years, 10 years, 25 years, 50 years and 100 years.
- To evaluate the evolution of isopluvial maps of Kerala in the recent decade.
- To evaluate the impact of the updated isopluvial map on the design of hydraulic structures.

DATA AND METHODOLOGY

IMD gridded rainfall data with a spatial resolution of $0.25^0 \times 0.25^0$ was utilized for a period of 120 years (1901-2020). This dataset was prepared using the observed rainfall records from 6955 rain gauging stations across the country. The gridded data proves to be better in model evaluation and such studies since station data may have some missing data or may get biased due to improper methodologies etc. such issues are resolved in the gridded dataset by removing those errors and by providing regular space time grid data which is useful to many studies (Pai et al. 2014).

It is difficult to forecast many of the extreme events in hydrology using deterministic approaches (Adlouni et al.2010). Thus, we rely on probabilistic approaches to take decisions and the most commonly adopted method is flood frequency analysis, it consists of estimating the peak quantity for a set of non-exceedance (N. Bhagat et al. 2017). Rainfall frequency analysis helps to find the rainfall depth for a specific return period and is performed using historical rainfall data. It is assumed that the future time series will have a similar distribution as that of the observed one. Frequency analysis is performed by fitting the theoretical frequency distribution with the annual maximum rainfall series, and it is highly recommended to use at least thirty years of rainfall data for such statistical methods as short series data does not give accurate results. Commonly used probability distributions for hydrologic variables were normal distribution, log normal distribution, exponential distribution, gamma distribution, Pearson Type III distribution, Log-Pearson Type III distribution and extreme value distribution. Extreme value distribution is further subdivided into three form - EVI (Gumbel distribution), EVII (Frechet distribution) and EVIII (Weibull distribution) (S. Syafalni et al.,2015). The Standard Operating Procedure (SOP for Hydromet services, 2021) for storm analysis suggested using Gumbel's Extreme value distribution for fitting rainfall data series based on previous studies. To assume the probabilistic future prediction the Gumbel's distribution method of frequency analysis requires minimum ten years annual maximum historical data (M. K Kumar et al. 2021). The parameters in the Gumbel distribution can be calculated using any of the two methods, namely method of moments and method of least squares.

The following procedure for the development of isopluvial map as per Indian Meteorological Department (IMD) is followed. The annual maximum rainfall for 120 years was considered for all the grid points covering the state and performed frequency analysis using Gumbel extreme value distribution. If X is a hydro meteorological variable, then according to Gumbel, the cumulative probability that any extreme value of a variable X will be equal to or less than x for Gumbel distribution is given by,

$$P(X \leq x) = \exp[-\exp\{-\alpha(x-u)\}] \quad (1)$$

Let

$$y = \alpha(x-u)$$

Then,

$$X = u + \frac{1}{\alpha}Y \quad (2)$$

By definition,

$$T = \frac{1}{1 - P(X \leq x)}$$

$$T = \frac{1}{1 - e^{-e^{-y}}}$$

$$y = -log_e log_e \frac{T}{T-1}$$

The parameters in the Gumbel distribution can be calculated using either method of moments or method of least square. In this study we follow method of moments.

Method of moments:

The u in the distribution is defined as,

$$u = \overline{X} - \frac{c}{\alpha}$$

where,

$\overline{X}$: Mean of extreme(X) series

c : Euler's constant ≈ 0.58

And,

$$\frac{1}{\alpha} = \frac{\sqrt{6}}{\pi} s \ \approx 0.78 \times s$$

where s is the standard deviation of the extreme series.

$\frac{c}{\alpha} = 0.58 \times (0.78 \times s) \approx 0.45 \times s$

Equation 2 can be written as (3)

$$X_T = \overline{X} - 0.45s + 0.78sY_T$$

where, $\overline{X}$ and s are the mean and the standard deviation of annual maximum rainfall series of data and T is the return period, then parameters α (scale parameter) and u (location parameter) can be obtained. The rainfall estimates corresponding to various return periods were calculated using Gumbel's method. The return periods considered in this study are 2 years, 5 years, 10 years, 25 years, 50 years and 100 years

In order to identify the difference in design values using the conventional isopluvial map and updated isopluvial map, an unlined drain was designed having design life of 50 years. The design was based on Indian Road Congress (IRC) Guidelines of Road Drainage. To design a drain, it is essential to find the peak discharge. The empirical formulas, rational method, and SCS curve number method are the three most widely utilised techniques for estimating peak runoff in all countries. In the present study, an analysis based on the rational method is followed. Peak discharge is estimated based on Eqn. 4, in the rational method which is based on the value of the runoff coefficient, the time of concentration and the watershed area.

$$Q = 0.028PfAI \qquad (4)$$

where,

Q: peak runoff (m^3/s)

A: catchment area in hectares

I: design rainfall intensity (cm/hr)

P: coefficient of runoff

F: spread factor (converts point rainfall into areal mean rainfall)

The soil porosity, vegetation cover, surface storage, slope, initial soil moisture capacity, etc. all affect the coefficient of runoff, for the given area. Based on the type of region corresponding runoff coefficients are available in IRC: SP: 42-2014. Manning's equation (eqn 5) can be used to predict the size of the drains after peak discharge is known.

$$Q = \frac{1}{n} A R^{2/3} S^{1/2} \qquad (5)$$

where,

Q: discharge (m^3/s)

n: Manning's roughness coefficient (available in IRC: SP: 42-2014)

R: hydraulic radius

S: energy slope of the channel

A: cross sectional are of channel (m^2)

RESULTS AND DISCUSSION

Rainfall climatology

This study made use of IMD gridded rainfall data of Kerala for the last 120 years (1901-2020). The Annual rainfall cycle over Kerala is influenced by the monsoon phenomena. Most of the mean annual rainfall occurs during the Indian summer monsoon and post-monsoon seasons. The onset of the Indian summer monsoon generally commences over Kerala by June and the peak rainfall activity in the State occurs during June and July months. The retreating monsoon currents cause occasional showers during the post-monsoon season and can be perceived as minor peak in the bimodal annual rainfall cycle (Figure 1).

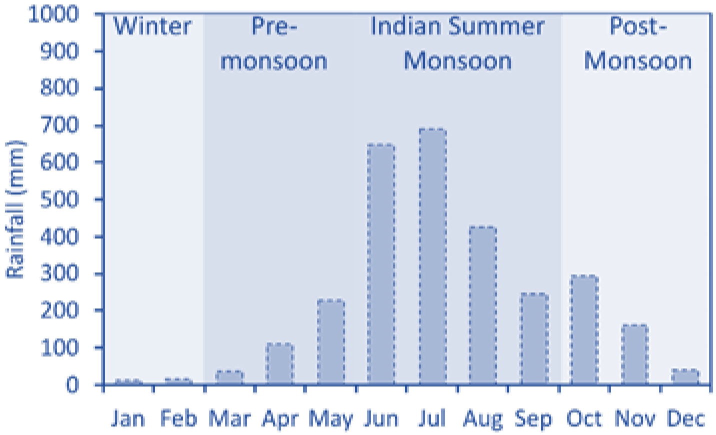

Figure 1: Mean monthly rainfall over Kerala.

The spatial distribution of rainfall over Kerala is influenced by the orographic barriers of the WG (Figure 2), and shows a typical characteristic pattern. In general, rainfall is concentrated along the coastal areas and westerly slopes of WG, whereas rainfall decreases along the leeward slopes of the WG and rain shadow regions. Lower rainfall is also a characteristic of the Palakkad Gap. The northern and central parts of Kerala receive more rainfall compared to the southern region. From the annual average rainfall for the period 1901-2020 a grid point in Palakkad (Fig 2, grid2) show the least value (636 mm), and a grid point in Kasaragod (Fig 2, grid1) shows the highest value (4803 mm) which are highlighted in figure 2.

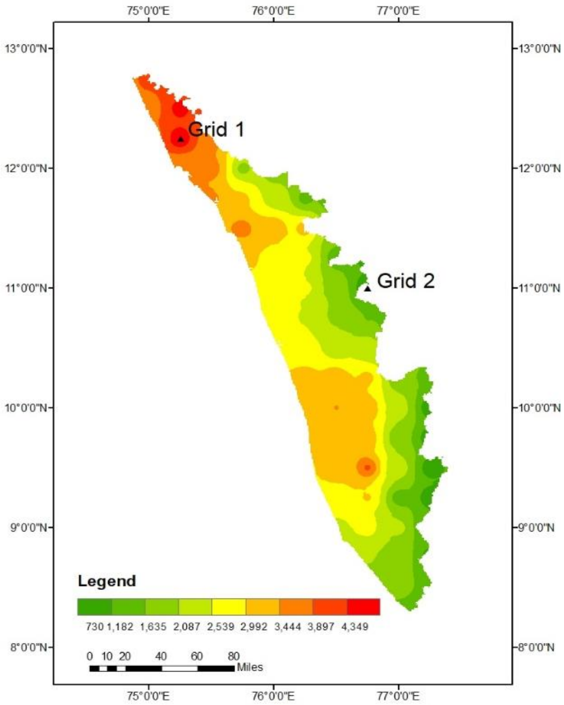

Figure 2: Spatial distribution of average annual rainfall over Kerala during 1901-2020.

Isopluvial maps for Kerala

The isopluvial maps of Kerala for various return periods are shown in Figure 3. Isopluvial maps of all return period adheres to the same pattern as Kerala's spatial distribution of rainfall. As the return period rises, districts in the north and the centre experience increased rainfall, with Kasaragod in Kerala receiving the most and Palakkad receiving the least. The southern part of Kerala is in the safer zone irrespective of the time period except some regions of Kottayam. The range of rainfall over a two-year return period is 55.2mm to 166.3mm; over five years, 75.3mm to 223.8mm; over ten years, 88.5mm to 262.1mm; over twenty-five years, 105.0mm to 310.4mm; over fifty years, 117.3mm to 346.3mm; and over one hundred years, 129.5mm to 381.9mm.

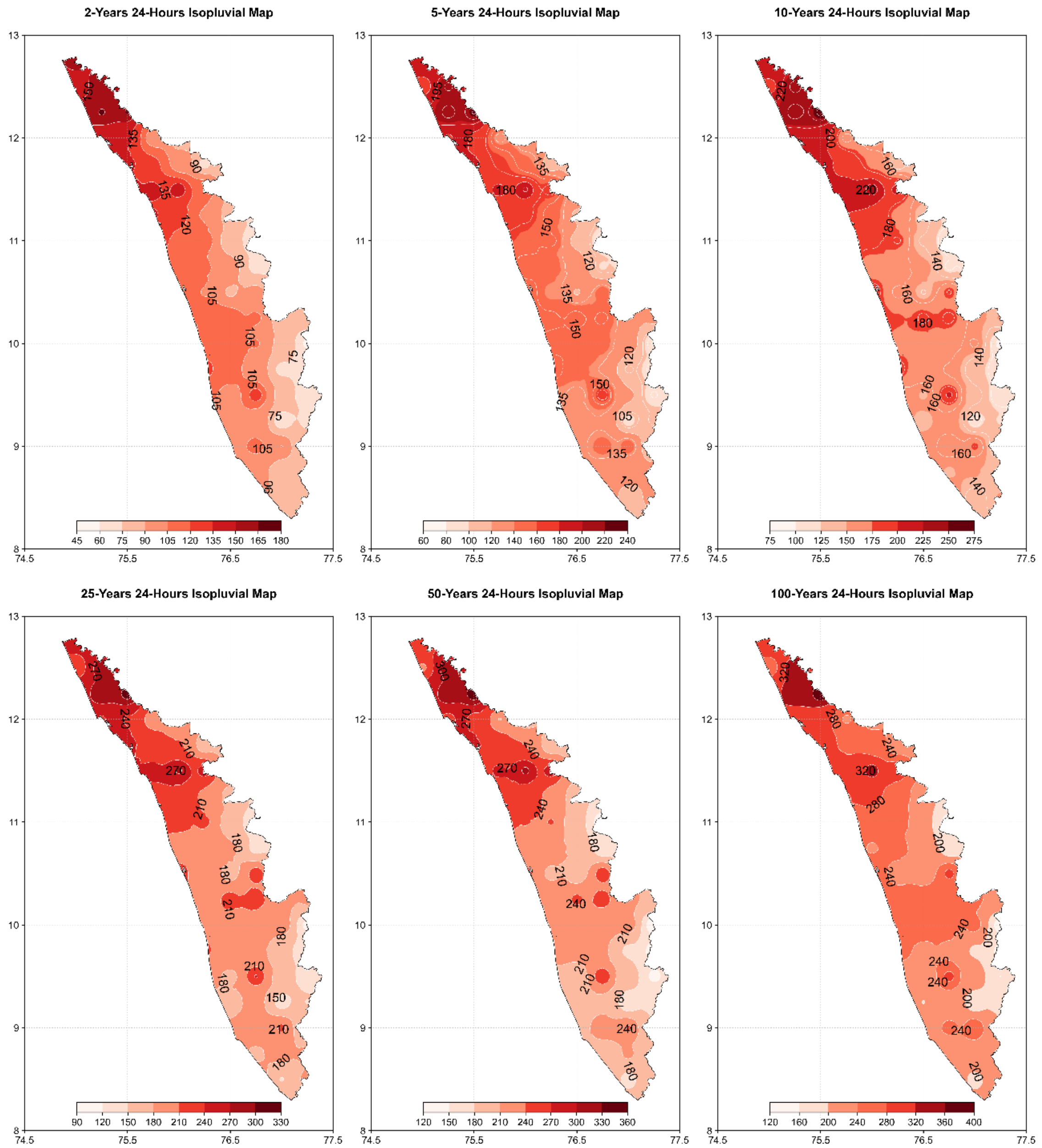

Figure 3: Isopluvial maps of Kerala considering gridded data during 1901-2020.

Variation from the previous decade

A comparison study was conducted to evaluate the changes in recent decade by dividing the rainfall data into two periods, 1901 to 2010 and 1901 to 2020. Rainfall depth was estimated for both periods for various return periods. The difference in rainfall depth between the two periods was examined for various return periods. A significant variation in the 100-year return period over the districts of Palakkad, Malappuram, Thrissur, Idukki and Kottayam was observed where, the increase in rainfall was about 50% of average rainfall received by Kerala during winter. The spatial plot of anomalies (based on previous decade) is shown in figure 4. From the figure it is evident that in northern part of Kerala there is decrease in rainfall when compared to previous decades especially in 2-year return period. In fact, a significant increase in rainfall is noticed in all the return periods in the central and southern part of Kerala. Certain grid points over Palakkad and Thrissur, exhibits sharp increase. For instance, some regions of Palakkad show an alarming situation whereby, rainfalls which were expected once in every 200 years have become more frequent and can be expected every 100 years.

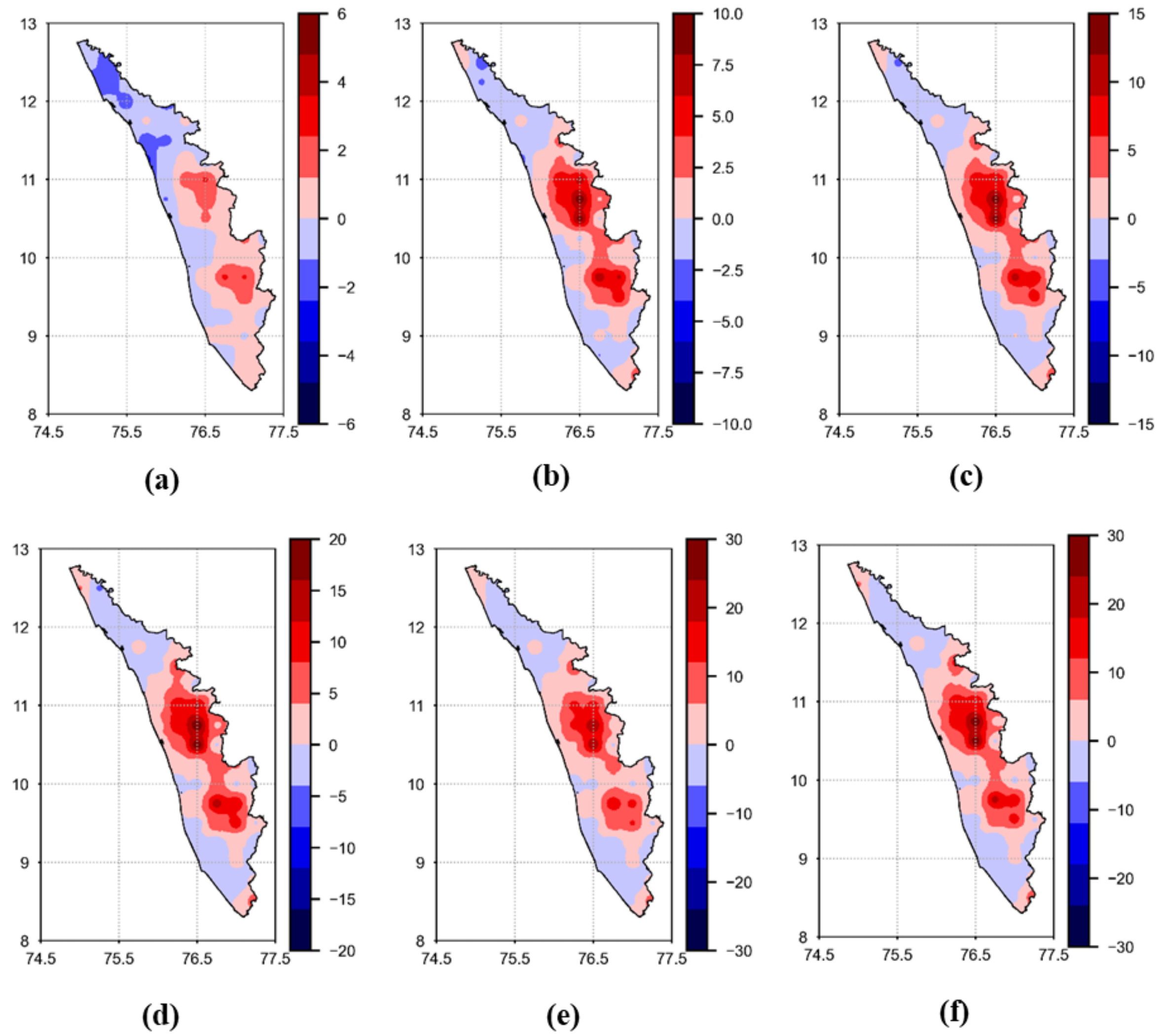

Figure 4: The spatial plot of anomalies for a) 2-year return period b) 5-year return period c) 10-year return period d) 25-year return period e) 50-year return period f)100-year return period

Since engineers mostly use isopluvial maps for design purposes, an example of design of drain with a 50-year design life was worked out utilising both outdated and updated isopluvial maps in order to the find the impact on the design of hydraulic structures. The grid point with maximum difference in the rainfall depth between the two periods is selected and from isopluvial map for the period 1901-2010 it is found that 24-hour rainfall of 50-year return period in the area is 181.54 mm and 205.94 mm considering rainfall data for the period 1901-2020. Based on this, value the runoff values were estimated, Q_{50} considering the period 1901-2010 is 0.0335m^3/s and Q_{50} considering the period 1901-2020 is 0.038m^3/s. The minimum depth of the drain below its top is 18.2 cm and 18.8 cm using outdated and updated isopluvial map respectively considering a minimum freeboard of 10 cm. The difference in depth is only 6mm which is not a significant difference and it is within the freeboard. Therefore, the updated isopluvial map has not produced any impact on the design of drains.

CONCLUSION

The rainfall characteristics in the last 120 years were analysed using IMD gridded rainfall data having a resolution of 0.25^0 and found that the annual average rainfall received by Palakkad district is least and Kasaragod received the highest rainfall. The isopluvial maps of Kerala which is having great importance in the design of hydraulic structures were prepared for various return period including 2, 5, 10, 25, 50 and 100 years and it was noticed that as the return period rises, districts in the north and the centre experience increased rainfall, with Kasaragod in Kerala receiving the most and Palakkad receiving the least. Except for few areas of Kottayam, the southern part of Kerala lies in a zone that is always safer. In recent decades the districts of Palakkad, Malappuram, Thrissur, Idukki, and Kottayam, a considerable difference in the rainfall of 100-year return period was seen, where the increase in rainfall was almost 50% of the average rainfall of Kerala received in winter and also it was identified that in the recent decades, maximum rainfall events have become more frequent and cautious measures needs to be adopted. Even though there is significant spatial variation in the rainfall events, it was not reflected in the design of hydraulic structures having design life of 50 years using the updated isopluvial map.

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AUTHOR CONTRIBUTIONS

A. B. Babu: Conceptualization, Methodology, Visualization, Writing – review and editing. **S. Nizar:** Conceptualization, Visualization**,** Methodology, Supervision Writing – review and editing. **Aswathy K.:** Writing – review and editing **S. Vijay:** Writing – review and editing. **D. S. Pai:** Funding Acquisition, Supervision Writing – review and editing.

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COMPETING INTERESTS

The authors have no competing interests to declare that are relevant to the content of this article.

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DISABILITY-INCLUSIVE DISASTER RISK REDUCTION: AN ANALYSIS OF KERALA MODEL OF DiDRR

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Abstract:

Disasters no longer being natural, disproportionately, and differentially impacts persons with disabilities from the remaining population globally due to social constructions. Disasters exacerbating the existing inequalities in society act as a threat multiplier that undermines the empowerment, and developments achieved by persons with disabilities and feed into the vicious cycle of invisibility. Despite the mandates of international frameworks such as the Sendai framework for disaster risk reduction (SFDRR) advocating for disability-inclusive disaster risk reduction (DiDRR) with disability-just, equitable, and universally accessible parameters, disability is yet to be incorporated into DRR globally with very few examples of good practices of DiDRR. This article attempts to analyze the threat multiplier effect of the disaster on persons with disability along with understanding the breakthrough role of the SFDRR in DiDRR. This article further analyzes the present scenario of DiDRR in India with a detailed study of the Kerala model of DiDRR. The ominous trend of institutionalization of persons with disabilities in the aftermath of disasters and the utmost importance of mainstreaming disability and inclusion of persons with disabilities in DRR are identified. This article acknowledges the heterogenous nature, differential disaster impact, and diverse requirements within the community of persons with disability and is in inclusive language with utmost respect and dignity towards the community.

Keywords:

Disability-inclusive disaster risk reduction, Sendai Framework for Disaster Risk Reduction, Persons with disabilities, Disaster, threat multiplier

INTRODUCTION

Disasters being serious disruption to the normal functioning of society beyond coping capacity, with their unprecedented intensity and rampant nature greatly impact the human population and socioeconomic, political, and environmental aspects across the globe (UNISDR, 2009). It's evident that disasters disproportionately affect persons with disabilities who are often considered invisible with heightened vulnerability resulting in high mortality and morbidity rates (WHO & UNICEF, 2013). According to United Kingdom statistics for the first half of 2021, persons with disabilities comprised six in ten deaths related to COVID-19 (European Disability Forum, 2021). Disability is the outcome of long-term impairment coupled with environmental and attitudinal barriers that impede active "participation in society on an equal basis" (UN, 2006). Persons with disabilities account the 16% of the world's population that's around 1.3 billion (WHO, 2022). The United Nations Convention on the Rights of Persons with Disabilities (UNCRPD) 2006, being the primary international legal mechanism that upholds the rights of persons with disabilities in every situation, advocates for inclusive and accessible disaster management and risk reduction practices under articles 11 and 32. Article 11 mandates that states must ensure the safety and protection of persons with disabilities in risky situations such as emergencies, conflicts, and natural disasters while article 32 identifies the importance of ensuring disability inclusivity and accessibility in international cooperations and development programs (UN, 2006). The United Nations global survey of Persons with disabilities in 2013 shows the huge gap in disability inclusivity in disaster risk reduction (DRR) and management as it significantly points out that about 85.57% of 5717 respondents from 137 countries never had an opportunity to be a part of a community disaster management and risk reduction (UNISDR, 2014). This survey shows, despite ratifying UNCRPD, many nations are falling behind in disability-inclusive disaster risk reduction (DiDRR) which is a clear violation of articles 11 & 32 of CRPD. Incheon Strategy 2012, of "making the right deal" for persons with disabilities in Asia & Pacific region is the first regional disability Inclusive development strategy with the exclusive seventh goal for ensuring DiDRR and management having two targets of strengthening DiDRR and enhancing implementation and support to persons with disabilities in disaster events. Nonetheless, the Asia-Pacific region is estimated to have around 690 million persons with disability, and DiDRR is still meager. ESCAP survey 2017, reports that only nine governments out of 35 have integrated disability into DRR programs in Asia Pacific (UNESCAP, 2021). Many international and regional frameworks have advocated for the inclusion of persons with disabilities such as the United Nations Sustainable development goals that specifically mentioned disability and persons with disabilities eleven times address disability inclusivity in the fourth, eighth, tenth, eleventh, and seventeenth goals (KSDMA, 2016). All these policies and frameworks together with Sendai's framework for disaster risk reduction (SFDRR) have epitomized global contributions towards DiDRR.

OBJECTIVES

The study analyzes the threat multiplier effect of disasters on persons with disability and their institutionalization followed by disasters, along with understanding DiDRR and the role of SFDRR in it, and analysis of the Indian scenario and Kerala model of DiDRR.

RESEARCH METHODOLOGY

The research in exploratory nature is carried out based on review and analysis of secondary data sources collected mainly from websites, reports, articles, newspaper articles, etc. The key terms used for the search are disability, disability and disaster, DiDRR, SFDRR, global disability good practices, DiDRR and India, Kerala and DiDRR, etc.

Disability and Threat Multiplier Effect of Disaster

The structural, physical, sociocultural, and economic barriers reduce the accessibility of persons with disabilities to education, health, transport, employment, etc coupled with a lack of policies, provisions, standards, and funding, and inadequate representation and participation in decision-making, ultimately contribute to worsening socio-economic and health condition of persons with disabilities in comparison to people without disability in terms of poor health, less socio-economic participation, diminished education achievements with increasing poverty (WHO & UNICEF, 2013). The developing nations are inhabited by 80% of persons with disabilities globally (UN, 2021). Girls and women with disabilities who may face “triple jeopardy” of marginalization due to the intersection of gender, disability, and poverty are at high risk of sexual abuse, and exploitation especially gender-based violence (GBV) and violence against women and Children (VAWG) coupled with gender inequality, under-representation, and support and service accessibility issues are particularly more vulnerable to disaster impacts (GFDRR, 2020). The study by Dunkle et al. (2018) shows that the likelihood of experiencing intimate partner violence is two to four times higher for women with disabilities in comparison with women without disabilities. All these factors become the limiting factor for the agency and active participation of persons with disabilities in the community and disaster becomes a threat multiplier for them. Disasters reinforce unequal power dynamics, hierarchy, societal and cultural stigmas and attitudes, and unequal resource distribution with institutional inequality that intensifies the exclusionary nature of DRR and management that leaves out persons with disabilities due to disability insensitivity.

There is a higher possibility of persons with disabilities being left out and excluded from DRR despite having a higher risk of mortality, morbidities, gaining additional disabilities, loss of income and assets, discriminatory treatment in disaster response, insensitive evacuation and shelter management, disability unresponsive relief distribution, increase in vulnerability and with highly neglected disaster case management for the persons with disabilities (Stough & Kang, 2015). Disasters having compound effects on persons with disabilities, often leads to supply chain disruptions that check on the availability of assistive devices and technologies which disrupt their support and service networks such as rehabilitation, medical care, etc, along with the inability to avail assistive devices that got damaged or lost or left due to disaster or during evacuation and rescue because of financial burdens and resource scarcity aftermath of the disaster coupled with the loss of livelihood and employment, as it was evident during COVID-19 (UNESCAP, 2021). UNICEF (2020) report shows that disruptions were observed during COVID-19 in the access to disability-related health services in more than 80% of Eastern European and Central Asian countries along with disrupted social protection for them in one-quarter of respondent countries. The report further points out that 50% of surveyed countries failed to adopt ‘children with disabilities-friendly learning facilities’ and the non-engagement of civil society organizations in disability-inclusive response planning during COVID-19 (UNICEF, 2020). Moreover, a high mortality rate of persons with intellectual disabilities was also observed (Williamson et al., 2021) *due to less access to intensive healthcare facilities (Baksh et al., 2021).*

Persons with disabilities are not a homogenous community, with diverse disabilities of varied intensities and nature, disasters have differential impacts among them also (Bennet, 2020). Persons with hearing and visual impairments have difficulty in receiving warnings, while persons with mental and intellectual disabilities have difficulty in understanding early warnings and responding properly, and persons with mobility issues have difficulty in evacuation and rescue. Disability with the intersectionality of gender, age, health, poverty, etc determines their disaster risk. Children with disabilities are around 240 million with one in ten children having some form of disability (UNICEF, 2021) while one in five women (WHO, 2011) and 46% of the elder population having disability globally (UNESCAP, 2022) and are particularly more vulnerable to the impacts of disasters. Elderly persons in wheelchairs and beds drowned in the St. Rita's nursing home in flood followed by Hurricane Katrina in 2005 while about 73 school-going children with disabilities under the Indonesian Society for the Care for Children with Disabilities died in Indian Ocean Tsunami in 2004 (Stough & Kang, 2015).

The first and foremost step to DiDRR is the Identification and proper documentation of persons with disabilities and ensuring an inclusive and accessible enabling environment for them using twin tracking approach and universal design etc. It's high time to transform existing frameworks and policies to disability Inclusivity across the globe and thereby ensure "none is left behind".

Institutionalization of Persons with Disabilities and Disasters

According to National Council on Independent Living report, United States followed by hurricane Harvey 2017, there is an ominous trend of transferring persons with disabilities who were independently living in the community before the hurricane into institutions due to a lack of accessible shelters or difficulties of disaster recovery. Unequal power relations and lack of equal access to DRR initiatives and services faced by persons with disability is not only a clear violation of human rights but also acts as the foundation for institutionalization that ultimately deprives the liberty of persons with disabilities (NCD, 2019). Before the Kerala floods in 2018, five institutions of caregiving under the Social Justice department had 300 women with disabilities exceeding the combined capacity of 200 which indicate the limited facilities due to overcrowding and lack of institutions. And it also shows the potential plight of caregiving institutions aftermath of the Kerala floods due to greater demand for the institutionalization of persons with disabilities, as a result of the disaster-induced financial burden and multiplied unpaid care work of women caregivers in households (Government of Kerala, 2018).

In 2001 psychosocial institution in Erwadi, Tamil Nadu witnessed a fire outbreak that has taken 28 lives of inmates who were unable to escape as they were tied up in chains, which shows the negligence from the authority side and lack of proper evacuation plans (Raja & Narasimhan, 2013) whereas the Associated Blind organization at the ninth floor of World trade center were able to successfully save the lives of its staffs including persons with visual impairments and blindness due to proper evacuation plans and prior mock drills during the world trade center attack in 2001 (Handicap International, 2009). Hence there should be appropriate legal frameworks and strict implementations to check unnecessary institutionalization of people with disabilities and must ensure proper care, facilities, disaster preparedness, and evacuation plans in such institutions upholding the right-based approach along with the promotion of deinstitutionalization. The legislation and policies should provide an enabling environment, disability-inclusive recovery, and reconstruction with prioritization, adequate investment, and allocation of resources for institutional mechanisms, caregiving, and services related to disability (GFDRR, 2020).

The Sendai Framework for Disaster Risk Reduction (SFDRR)

The SFDRR (2015–2030) advocates for the inclusion of persons with disabilities and organizations of persons with disabilities (OPDs) in DRR along with an ' all of society approach' with both direct and indirect reference to persons with disabilities on preamble, priorities action, guiding principles, and stakeholder's role with a significant infusion of terms relevant to disability such as universal design, inclusion, and accessibility, etc (Stough & Kang, 2015). Setting four transformative priorities of understanding disaster risk, strengthening, investing, and enhancing DRR for "build back better" and effective response at all levels of governance, SFDRR has begun disability-inclusive design and framework for the implementation of DRR confirming persons with disability and OPDs as an active actor and stakeholder (UNESCAP, 2022), unlike its predecessors Yokohama Strategy and Plan of Action for a Safer World and Hyogo framework for action. The third UN World Conference on DRR 2015 which resulted in SFDRR showcased the importance of implementing disability inclusivity with the accessible, venue, conference sessions, documents in accessible formats and braille, wheelchair-accessible transportation, and sign language interpretation with significant participation of 200 above persons with disabilities and 34 disability-related events (Stough & Kang, 2015).

In the preamble, SFDRR held governments with the responsibility of engaging persons with disability as relevant shareholders "recognizing their leading, regulatory and coordination role" in the design and implementation of standards, plans, and policies ensuring exclusivity and accessibility with collaborative work of academia, civil society organizations, and research institutions with public-private partnerships. The guiding principles stress the inclusion of the disability perspective into DRR policies and practices with "societal engagement and partnership" and the importance of disability disaggregated data for inclusive and efficient risk-informed decision-making for better DRR. In the priorities for action, the third priority for investment in DRR for resilience mandates the adoption of universal design in both public and private infrastructures while the fourth priority of enhanced disaster preparedness recognizes that the empowerment of persons with disabilities for public leading and ensuring universal accessibility in post-disaster phase as the key to "build back better". The role of stakeholders in SFDRR stresses shared responsibility and acknowledges the vital role of persons with disabilities and OPDs in the design, implementation, and assessment of DRR to fulfill diverse requirements and adoption of universal design (UN, 2015). SFDRR is the first of its kind document that provides diverse dimensions on disability and related themes ensuring that none is left behind.

Disability-Inclusive Disaster Risk Reduction (DiDRR)

The "full and effective participation and inclusion in society" is one of the seven guiding principles of UNCRPD (UN, 2006) and DiDRR is the rights-based approach that recognizes the diversity and ensures equal and active participation of persons with disabilities in DRR and accessibility to all basic services. Disability inclusion is not mere 'involvement' or 'integration' but more about safeguarding rights, acknowledging diversity in the requirements of persons with disability and addressing key barriers to inclusion (IFRC, 2015; KSDMA, 2016). DiDRR incorporates twin track approach that ensures "equality of rights and opportunities for persons with disabilities" with inclusion and tailored support and services coupled with empowering persons with disabilities with focused capacity-building initiatives and ensuring independent livelihood options etc.

The DRR is the prevention of existing and emergence of new disaster risks and management of residual risks, thereby enhancing disaster resilience of an individual, household, community, and nation, leading towards sustainable development (UN, 2016) and it should be inclusive. There is a severe lack of disability-disaggregated data across the globe, both in pre and post-disaster scenarios that hinder people with disabilities from availing the chance of participating and getting benefits from vulnerability reduction, capacity development, and DRR measures which further leads to inadequacy of basic requirements and accessibility issues in the post-disaster situation especially in rescue, evacuation and at the shelter. Persons with disabilities and OPDs are seldom consulted during disaster preparedness despite being most vulnerable to disaster and thereby their requirements are disregarded. Mainstreaming disability in all developmental sectors and adequate disability representation and leadership are the need of the hour. Mainstreaming of disability is the conscious efforts for the promotion of inclusion and removal of barriers that impede the equal and active engagement of persons with disabilities in society (OXFAM INDIA, 2015)

Disaster preparedness plans and emergency resource stores must be mindful of the diverse requirements of people with disabilities including care, support, assistive technologies and equipment, and medical requirements. Similarly, disaster rescue task forces, caretakers, and shelter and rehabilitation staff must be sensitized about disability with proper knowledge and skills as disasters are time and resource-scarce situations, and negative attitudes may result in discrimination in care and resource allocation. Active participation of people with disabilities in DRR and decision-making will reduce their vulnerability, enhance disaster resilience, and create awareness of their requirements and measures to overcome barriers and ultimately mitigate disaster risks (WHO & UNICEF, 2013). Hence participation and engagement of people with disabilities is the foundation for DiDRR.

Disability-inclusive Vulnerability Capacity Analysis (VCA) and Participatory Approach to Safe Shelter Awareness (PASSA) will greatly contribute to better inclusive disaster preparedness (IFRC, 2015). Disability-focused capacity development initiatives followed by VCA can strengthen the capacities of people with disabilities, OPDs, disability support, and advocacy networks to cope with disasters enabling mock drills, training on survival skills, and personal / family/community / organizational disaster preparedness plans. The Person-Centered Emergency Preparedness (P-CEP) composing a capability framework, guiding principles for tailored disaster preparedness, and four steps of facilitation is an innovative tool co-designed by service supporters with persons with disabilities. P-CEP enables the optimization of self-reliance of persons with disability, assesses preparedness level and disaster risk, and addresses risk factors with coordination between emergency personnel, service providers, and the person with a disability. P-CEP based on the principle of shared responsibility enables inclusive disaster planning.

Early Warning Systems (EWS) is the major component of DRR which is “an integrated system of hazard risk knowledge, monitoring and forecasting, dissemination and communication and response capability” which ensure DRR and safeguard individuals, communities, nations, and the rest (UN, 2016). EWS should be inclusive and mindful of appropriate communication requirements (auditory, sign language, visual forms- DAISY) for persons with disabilities and their capacity to act upon early warning messages. Fiji Disabled People’s Federation Emergency Operation Centre (FDPF-EOC), disseminate disaster early warnings and information through emails, SMS, video conference, call, radio, and TV campaigns is an example of inclusive EWS and disaster response (UNDRR, 2022).

Accessibility is the ability to access the physical environment, information and communication technology (ICT), transportation, and services on an equal basis, both directly and indirectly. Accessibility can be ensured for persons with disability by adopting ‘Universal Design’ in all the developments that are accessible to all regardless of diversity. Accessibility to persons with disabilities must be ensured even if it’s temporary such as evacuating vehicles, disaster shelters, and water, sanitation, and hygiene (WASH) facilities. The private sector is yet to become accessible and recognize persons with disabilities as a potential customer segment despite the finding of the Return on Disability (2020) report of having a total global purchasing power of 13 trillion dollars. The accessibility shouldn't remain as mere lip service rather the crisis communications, risk information, critical infrastructures, and services should be accessible to persons with disabilities with more expertise and investments in DiDRR (KSDMA, 2016).

Inclusive evacuation comprises tailor-designed evacuation aids such as Evacu-Trac and Evac+Chair for persons using wheelchairs. Similarly, the DAISY Consortium enables an accessible ICT-based evacuation training module for persons with psychosocial disabilities. Many Indian city police divisions such as Delhi and Mumbai police are already equipped with SMS helplines for persons with communication disabilities through designated cell phone numbers. The Centre for Disability and Development's innovative evacuation boat with ramp and accessible lavatories in Bangladesh is a global model for accessible evacuation. Shelters must be disability sensitive with accessible facilities meeting the requirements of persons with disabilities and disability-inclusive relief distribution. A survey on floods in Bangladesh in 2004 indicates discrimination against persons with disabilities in availing food and relief measures due to inaccessible shelters and food provisions that are particularly more inaccessible to persons with visual and physical disabilities because of overcrowding and distance (Raja & Narasimhan, 2013). Similarly, disability-inclusive recovery and rehabilitation measures are to be ensured based on their requirements with proper care and assistance.

Indian Scenario of DiDRR

India is highly exposed to multiple natural hazards with varying intensities with the second largest human population. According to the 2011 Census, about 2% of the Indian population which is around 21 million are persons with disabilities while the latest World bank report on persons with disabilities suggests it accounts for 5-8% of the Indian population. India has set the global benchmark for DiDRR by being the first nation to have national disaster management guidelines for DiDRR in 2019. Before it, National Disaster Management Authority (2019 a) introduced the concept of 'social inclusion' of all vulnerable groups including persons with disabilities to LGBTQ+ in the national disaster management plan. India is the first nation to ratify UNCRPD on 1st October 2007. The Right of Persons with Disabilities (RPWD) Act 2016 followed by UNCRPD, identifies 21 types of disabilities and mandates the participation of persons with disabilities in DRR strategies. Article 8 of the RPWD Act 2016 advocates for equal safeguarding and protection of PWD in events of risk, conflicts, emergencies, and natural disasters (NDMA, 2019 b).

The Accessible India Campaign launched in 2015 under the DEPwD aims to ensure enabling environment with universal accessibility for Persons with disabilities by setting guidelines for physical infrastructure, transportation, and ICT with features of universal design such as accessible route approach, parking, entrance, reception, corridors, lifts, toilets, drinking water facility, staircases with handrail and signage with detailed provisions, etc. The assistance to disabled persons for purchase (ADIP) scheme ensures access to assistive technology for persons with disabilities by providing grants to implementing agencies such as National Institutes/artificial limb manufacturing corporation of India (ALIMCO)/state, district, and local bodies/NGOs, etc to reduce the impacts of disability and to enhance the economic potential of them. Similarly, the Gharaunda scheme, Sahyogi scheme, Samarth scheme for ensuring care and Awareness generation, and publicity scheme (AG&P) are contributing to the empowerment of persons with disabilities in India. Many state Disaster management plans have already considered disability and also come up with DiDRR strategies. Odisha State Disaster Management plan of 2017 has recognized the vulnerability of persons with disabilities, with a special focus on children with disability, and also ensured provision for children with disability inclusive education during disasters. Odisha State Disaster Management Authority (OSDMA) also has set up a cell for persons with disabilities led by a person with a disability that ensures inclusivity in disaster EWS, response, recovery, and rehabilitation (NDMA, 2019 b).

The Department of empowerment of persons with disabilities (DEPwD), India issued Guidelines on COVID-19 that comprehensively considered major concerns and challenges of persons with disabilities. Despite the efforts, NCPEDP (2020) survey shows that only 22% of persons with disabilities respondents have access to doorstep delivery of necessities while 67% have no access and 48% with no access to the government helplines. Many state governments have set DiDRR good practices examples such as the Nagaland government's daily covid status video with Indian sign language interpretation, local dialects, and doorstep medical service/physical therapy provisions by the Tamil Nadu State Disability Commissioner (NCPEDP, 2020).

The Kerala Model of DiDRR

Kerala is the 8th most densely populated state in India which is highly vulnerable to multiple disasters of varying intensity comprising 7,61,843 persons with disabilities as per the 2011 census. According to the disability census of Kerala conducted in 2015 under the Social Security Mission, the first of its kind state-level household census of the disabled population, about 7,93,937 people are living with some form of disabilities comprising 2.32% of the Kerala population. The disability census recognizes 22 types of disabilities comprising the most prevailed locomotor disability and least prevalent thalassemia. Identified disabilities include blindness, kyphosis, dwarfism, low vision, learning disability, speech and language disability, intellectual disability, mental illness, autism, hearing impairment, leprosy cured, hemophilia, muscular dystrophy, sickle cell anemia, cerebral palsy, epilepsy, deafblind, etc. About 137446 people have multiple disabilities, the second most prevailing disability that accounts for 17.31% of the population with disabilities in Kerala (KSDMA, 2016).

Kerala State Disaster Management policy of 2010 itself identifies the importance of disability inclusivity in relief distribution and recognizes the requirement of tailored assistance and care in disaster rescue and evacuation and the provision of social audits to ensure inclusivity. Kerala State minimum standards of relief recognize the rights of persons with disabilities to access resources with adequate facilities. The Kerala State Policy for persons with disabilities of 2014 acknowledges the obligation, necessity, inevitableness, and commitment towards disability mainstreaming in all development agendas, programs, and action plans in the State of Kerala and recognizes the inherent dignity and individual autonomy, including the independence and the ability to make one's own decisions (NDMA, 2019 b). Kerala State Disaster Management Authority (KSDMA) project titled "Strengthening of emergency response capabilities with emphasis on differently abled" 2016 associated with the Inter-University Centre for Disability Studies (IUCDS) envisages a safer state for persons with disabilities through training and capacity building. The Kerala government released the "handbook on Disability and Disaster risk reduction" in 2016 which paved NDMA guidelines for disability Inclusive DRR in 2019. The KSDMA-trained volunteers of Thanal Palliative and Paraplegic Care Centre, Ernakulam, were able to successfully rescue all persons with disability in the district during the Kerala floods of 2018.

Kerala floods of 2018 have impacted more than 8600 persons with disabilities across the state. The post-disaster needs assessment report on the aftermath of the Kerala floods having a specific focus on persons with disabilities suggests disability-sensitive search, rescue, and evacuation training for rescue teams along with ensuring stock and supply of essential assistive technologies and devices. The report further mandates the establishment of District Disability Rehabilitation Centers in all districts, implementation of the ‘Accessible India Campaign' for ensuring disability-friendly government buildings, epitomizing 4% reservation of persons with disabilities in government jobs along with capacity building and accessible livelihoods for their active participation in the labour force. Despite having 70.9%, the highest literacy rate of persons with disabilities in India, their workforce is just 24% in Kerala, much below the national average (Government of Kerala, 2018).

Despite disability-inclusive interventions of KSDMA, inadequacies were observed in evacuation and rescue with disability-insensitive EWS, lack of lead time, and accessibility issues. Difficulties were faced while rescuing and evacuating persons using wheelchairs due to heaviness and had to choose alternatives such as plastic chairs and large basins, leaving out assistive devices. Mostly, persons with disabilities have experienced difficulties and accessibility issues in relief camps especially due to toilet facilities and were forced to choose shelter within the homes of friends or families despite having more psychological impact. ‘Nava Kerala initiative’ of the Kerala government identifies the diverse requirements of persons with disabilities and prioritizes them in all spheres of disaster recovery from EWS, relief measures to the adoption of universal design, and livelihood enhancement. The initiative further suggests barrier-free accessible houses and common amenities and building robust and disaster-resilient communities and the health sector with a special focus on the psycho-social requirements of persons with disabilities. The government viewed recovery as a prospect to change existing exclusionary mechanisms to an inclusive and accessible enabling environment for all. UNICEF survey on the Accountability to Affected Population (AAP) in Wayanad and Alappuzha districts of Kerala suggests out of the respondents, persons with disabilities consist 23% of those who aren’t content with relief and rehabilitation measures, and 24% of those who haven’t received any house reconstruction assistance while it was 20% of whom doesn’t have any awareness on availing information regarding relief and recovery (Government of Kerala, 2018). Hence rectifying the shortcomings observed during the Kerala floods, The Kerala model of DiDRR can become an excellent example of disability good practice.

RESULTS AND RECOMMENDATIONS

With limited opportunities to access and benefit from risk information and disaster preparedness due to systemic barriers, persons with disabilities become faces inequality in disaster events. To address this issue, disability representation should be integrated into disaster risk reduction and management upholding “ nothing about us, without us”. DiDRR must include the coordination and collaboration of cross-sectors with multiple stakeholders with persons with disabilities for the identification and removal of barriers impeding active engagement of persons with disabilities and investment in universally accessible infrastructure, ICT, services, etc. Though some progress has been made with conscious efforts, there is a long way ahead and we require more action-oriented strategies. Although SFDRR has provided a good environment for epitomizing DiDRR, the works are still progressing and there is a long way ahead with a varied rate of inclusion of persons with disability across the globe. This article acknowledges that mainstreaming disability, meaningful participation, and representation of persons with disabilities is key to inclusive DRR and recommends the following for ensuring its efficiency:

I. More explicit policy guidelines on the representation of persons with disability not just in the DRR mechanism but in all sectors at all government levels across the globe

II. Partnerships and collaboration between governments and OPDs in capacity building, resource development, reviewing disaster management provisions to identify gaps and improvement of gap areas, monitoring, and assessment of progress, etc for ensuring more informed inclusion and representation of persons with disabilities into DRR from global to local level
III. Ensuring accessibility to DRR and management provisions such as risk information, disaster management plans, and policies, early warning and evacuation systems, relief and rehabilitation measures, and relocation plans
IV. Disability-inclusive budgeting and audits and disability focal points
V. Strengthening social protection networks and schemes for persons with disabilities
VI. Inclusive and collaborative research on disability and co-designing
VII. Ensuring the person-centered information, service, and support system
VIII. Robust and disaster-resilient services and disability support system for ensuring service and support continuity during and after the disaster event
IX. Developing explicit policy guidelines on “shared and defined responsibilities” for ensuring support, requirements, and contingencies
X. Ensuring consensus between disability and DiDRR policies and practices on the ground

CONCLUSION

DiDRR is the need of the hour which transforms the narrative of persons with disabilities from passive to active and to key stakeholders of DRR through participation, the twin track method, universal design, representation, etc. The acknowledgment of people with disabilities with diverse requirements as humans with equal rights and opportunities is the key to mainstreaming disability, thereby ensuring an enabling environment devoid of environmental, attitudinal, institutional, information and communication barriers, with accessibility and dignity. Governments should set up panels at all administrative levels to monitor the implementation of accessibility in all development initiatives and mandate accessibility and universal design adoption to all new development projects to obtain approval. Incorporating diverse capacities and knowledge of persons with disabilities can be beneficial for disability inclusion and the social inclusion of all other vulnerable communities and society as a whole. Moreover, we can incorporate technological advancements in ICT for better service and support providence, crowdsourcing, and social networking for persons with disabilities, ensuring accessibility in all terms. The synergies between OPDs and DRR institutions should be enhanced with more inclusion, leadership, participation, and representation of persons with disabilities through sustainable knowledge sharing, partnerships, and joint actions from global to local levels. It’s high time to mainstream DiDRR backed by legal frameworks and policy change with a disability-inclusive budget and investments monitored by DiDRR focal points at the local level to departmental/ministerial/multi-sectoral coordination committees for ensuring meaningful participation of persons with disabilities. We should be more mindful of the intersectionality of disability, gender, race, class, caste, sexuality, age, health, and poverty that creates multiple jeopardies for persons with disabilities that are exacerbated during disasters and ensure that none is left behind.

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DISASTER LITERACY; A STUDY AMONG POST GRADUATE STUDENTS IN KOTTAYAM DISTRICT KERALA

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Abstract:

Disaster literacy is the ability to manage disasters and take informed decisions throughout different stages of disaster management. The study's goals are to evaluate level of disaster literacy among postgraduate students in Kottayam district, to pinpoint potential intervention areas for postgraduate student's disaster literacy and to suggest a model for disaster literacy among postgraduate students. Earlier research, which focuses on the levels of information literacy and disaster literacy among children of various age groups, teachers, and staff, describes the level of literacy required and suggests a new model for disaster literacy and discusses how to integrate best practices into planning and preparation efforts. In disasters, children and young people are the most at risk. This survey conducted online. In the district of Kottayam, study was carried out among postgraduates. A disaster literacy questionnaire with two sections was used in this study. A demographic questionnaire is included in first section, and knowledge of disasters questionnaire is included in the second. It came up with the result which depicts that youth are not familiar with disaster management, which would account for their ignorance of local preparedness, response, and recovery efforts. They are unfamiliar with evacuation plans, practice drills, disaster management education, and fundamental first aid skills. They haven't participated in any kind of disaster management activities. The area of disaster management must be enhanced among youth for the betterment of future. The significance of the study emphasizes the need for teachers to impart necessary knowledge, awareness, and skills about natural disasters to students, particularly during their undergraduate studies. From this literature survey, we understood that studies reported disaster literacy are fewer. From India, no such studies have been reported so far. hence the present study has been conducted on Disaster Literacy is the first study from India that reports on disaster literacy.

Keywords:

Disaster literacy, Dimensions of disaster literacy, Disaster risk reduction, Areas of interventions, Disaster literacy model

INTRODUCTION

According to the United Nations Office for Disaster Risk Reduction (UNISDR-m) (2016), disasters are unpreventable, natural, or human-made incidents that result in significant anthropogenic, material, or environmental effects and losses as well as severe societal dysfunctions. A natural occurrence can be categorized as a disaster if it meets two or more of the following four criteria, per 2015 research by the Centre for Research on the Epidemiology of Disasters (CRED): (1) there are ten or more fatalities; (2) there are one hundred or more injuries; (3) there is a state of emergency; and (4) there is a need for international assistance. Disaster literacy refers to a person's ability to read, comprehend, and apply disaster-related information in order to make informed decisions about how to mitigate, prepare for, respond to, and/or recover from disasters (Brown & Haun, 2014). K Disaster literacy is achieved by public education on disaster-related topics. It is an ongoing program/strategy aiming at informing the public about the effects of disaster results on unprotected or vulnerable communities (Lidstone & Nielsen, 1998). Governmental and nongovernmental relief organisations provide public education on disaster management in the industrialised world in order to prepare the populace for disasters (Brown, Haun, & Peterson, 2014). This is not the situation in the developing world, where a lack of disaster education contributes greatly to the population's vulnerability when disasters strike (Corotis & Enarson, 2004; Msengana-Ndlela, 2008; Zuma, Luyt, Chirenda, & Tandlich, 2012; Okorodudu-Fubara, 2013; Olowoporoku, 2012). Capacity building and social capital are key to creating meaningful social change and sustainable community resilience (Poortinga, 2012). The impact of social interactions on individual health and well-being, public health, and economic development is referred to as social capital (Szreter & Woolcock, 2004). Knowledge, attitudes, and actions related to natural disasters are among the components of disaster literacy. The knowledge dimension is the first of the three dimensions that make up natural disaster literacy. The fundamental level is shown by the knowledge one possesses in the first dimension. It is of little value to have knowledge that we come across on a regular basis but that does not help us solve problems or improve our quality of life. The second dimension consists of internalizing knowledge as attitudes. The third dimension, which relates to advanced-level natural disaster policies, is the conversion of internalized and adopted knowledge into actions (Sozcu 2019b). The term "youth" can refer to all persons of a given age range, as well as a state of being or even a state of mind. In this short, we define youth as those aged 10 to 24. This spans a wide range of experiences and transitions, including an early phase (between the ages of 10 and 14), a middle period (between the ages of 15 and 20), and a later phase (between 21 and 24). Young adults are those between the ages of 21 and 24. They are still exploring and committing to their interests and talents *(*Nugent, R. (2005)). Youth is one of the most vulnerable populations in disasters (Bartlett, 2008; Peek, 2004).

MATERIALS AND METHODS

In this study, an online survey method was used. The study participants were postgraduate students from various colleges in the Kottayam district who excelled in disaster literacy. They took part in the study by completing an online disaster literacy survey in September 2022. The online survey was completed by 137 students in total. This study used a disaster literacy questionnaire, which consists of two sections. The first section consists of a demographic questionnaire and the second section consist of a disaster knowledge questionnaire. A total of 34 questions were there and a sampling method is used. As mentioned above the questionnaire was in two sections. The demographic section consists of name, gender, age, domicile, and stream of education. The disaster knowledge questionnaire consists of awareness, preparedness, response, and basic disaster knowledge questions. The data was analyzed on quantitative analysis using Microsoft excel. The Kottayam district of Kerala was chosen as the research site. Kottayam is one of 14 districts in the Indian state of Kerala. The district of Kottayam is divided into six municipal towns: Kottayam, Changanassery, Pala, Erattupetta, Ettumanoor, and Vaikom. It is Kerala's sole district that does not border the Arabian Sea or any other state. The district is bounded on the east by hills, and on the west by the Vembanad Lake and Kuttanad paddy lands. Paddy fields, mountains, and hills are among the geographical features of the area. According to the 2011 census, 28.6% of the district's people live in urban areas, and the literacy rate is 97.2%. Kottayam's latitude is 9.594624 and longitude is 76.4855731.

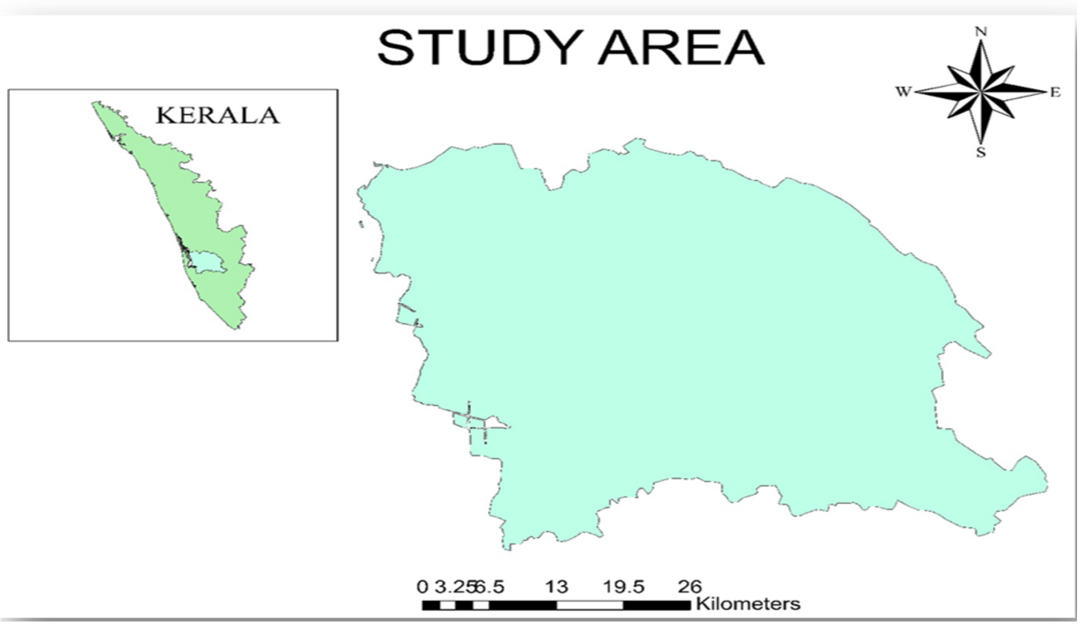

Fig 1. Study area

RESULTS

To assess the disaster literacy level of postgraduate students in the Kottayam district

This section provides a summary of the findings in regard to the research problem and its sub-dimensions. The results of each sub-goal are discussed and displayed as tables, pie charts, and bar diagrams. The current study has 137 participants (34 questionnaires were distributed with a 72% response rate). Table 1 shows the respondents' essential socio-demographic profile. It is apparent that the majority of participants,37% were rural. The question-based analysis follows;

Table .1 Social media are helpful during a disaster event

valid	Frequency	Percent (%)	Cumulative Percent (%)
Agree	59	43%	43.1%
Neutral	13	10%	52.6%
Somewhat Agree	7	5%	57.7%
Strongly Agree	58	42%	100%
Total	137	100%	

Before Disaster

Cities and local governments use social media to create public Emergency Preparedness sections that the public can follow to see the most recent news and updates about the community.

During Disaster

The public frequently receives news as videos and pictures. Officials use social media to inform the public of the location of aid and the estimated time of arrival in impacted areas.

After Disaster

Used for recovery activities like their loved ones, personal properties, and animals.It informs the general public about donation campaigns and relief funds.

Table.2 Drills and training should help to respond effectively during disasters

Valid	Frequency	Percent (%)	Cumulative Percent (%)
Agree	60	44%	43.8%
Disagree	4	3%	46.7%
Neutral	21	15%	62%
Somewhat Agree	4	3%	65%
Strongly Agree	48	35%	100%
Total	137	100%	

Approximately 49% of students agree with the premise that drills and training should aid in disaster response, with almost 35% strongly agreeing. 15% of students are undecided about this. 3% of participants agreed and 3% disagreed with this statement.

Participants in a "mock drill" scenario practice their response in the event of a disaster or emergency. Mock drills are conducted in schools, colleges, hospitals, apartments, businesses, and organizations all over the world for the sake of safety. The main goal of a mock drill is to practice responding to various disasters, including fires, medical emergencies, the release of hazardous materials (Hazmat), chemical spills, and so forth.

Table.3. Disaster management is a governmental responsibility

Valid	Frequency	Percent (%)	Cumulative Percent (%)
Agree	29	21%	21.2%
Disagree	29	21%	42.3%
Neutral	30	22%	64.2%
Somewhat Agree	19	14%	78.1%
Strongly Agree	30	22%	100%
Total	137	100%	

Disaster management is not only the responsibility of the government; it is also everyone's responsibility. Every person must participate in all disaster management activities, including preparation, response, recovery, and rehabilitation.

Table.4 Local communities have a significant role in managing disasters.

Valid	Frequency	Percent (%)	Cumulative Percent (%)
Agree	67	49%	48.9%
Disagree	4	3%	51.8%
Neutral	20	15%	66.4%
Somewhat Agree	6	4%	70.8%
Strongly Agree	40	29%	100%
Total	137	100%	

In order to create communities that are resilient to disasters, community members must first be empowered to deal with the negative effects of environmental hazards. The best strategy for achieving sustainability while reducing the risk of natural disasters is community preparedness. Most of the students in the survey responded positively that the local communities have a significant role in managing disasters.

Table.5 Do you attend any training programs related to disaster management?

Valid	Frequency	Percentage (%)	Cumulative percentage (%)
Maybe	13	9%	9.5%
No	75	55%	64.2%
Yes	49	36%	100%
Total	137	100%	

The main failure made by today's youth is that they haven't participated in any volunteer disaster management work. It's possible that they don't know how to sign up as volunteers or what to do. They are very interested in volunteering their time. Young people will become more familiar with disaster management by creating training programs, practice drills, first aid, and safety classes also gaining complete confidence to participate in volunteer work.

Table.6 What do you think your local community's disaster preparedness?

Valid	Frequency	Percentage (%)	Cumulative percentage (%)
Moderately Prepared	68	50%	49.6%
Not Prepared	27	20%	69.3%
Somewhat Unprepared	32	23%	92.7%
Well Prepared	10	7%	100%
Total	137	100%	

A lack of community disaster preparedness can be seen in the response of the students in their community.

To identify the possible areas of intervention in disaster literacy of postgraduate students.

The survey, which had 34 questions, was done online. 137 students answered the questionnaire. The majority of the students are experts in the fundamentals of disasters. They're all familiar with the fundamentals of disaster management. They are all familiar with the basics of disasters. Disaster education aims to arm people with the knowledge they need to act to lessen their vulnerability to disasters. The question of how well-trained people can be prepared for disasters and respond has received a lot of attention over the past few decades. The students are aware of Kerala's frequent natural disasters. The majority of them replied that they were all aware of Kerala's frequent floods. Whether earthquakes will occur in Kerala was a question that was raised. The majority of students responded that Kerala will experience earthquakes. There was a question regarding the impact of social media during disasters in a fundamentally social sense. Everyone believes that social media has a significant impact during disasters. The majority of those who respond to disasters agree that preparation through training and drills is a good way to respond quickly and effectively.

The lack of disaster management training programs for today's youth is one of the potential intervention areas in disaster literacy that postgraduate students have identified. In the modern age, it seems like some kind of backdrop. Disaster management training is designed to improve preparedness and response times at all levels before and after disasters by enhancing the skills of volunteers and disaster relief workers. Programs for disaster training are offered by the National Institute of Disaster Management. Disaster preparedness aims to quickly restore normalcy to the affected populations and has the potential to save the greatest number of lives and property during a disaster. They will be able to recover from the disasters with the aid of training programs, which include mock drills, first aid training, fire safety classes, and more.

The local community's disaster preparedness is the other area, and the responders even said that their community's preparedness was inadequate, perhaps as a result of a lack of expertise in disaster management. The process of bringing people together within the same community to enable them to jointly address shared disaster risk and jointly pursue common disaster preparedness is known as community-based disaster preparedness. Create a plan for neighbourhood evacuation, find out in advance which evacuation routes have been designated for your area by getting in touch with the neighbourhood emergency management office, give out maps to people in the neighbourhood, and learn the main and alternate exits from your area in case of an emergency. Consequently, community disaster preparedness can be encouraged. Risks can be prioritised and identified, which enables leaders to develop specific plans to get around these problems. Planning and preparedness for disasters are crucial for the community.

It is actually a failure in the field of disaster management that the majority of survey respondents did not even attempt to prepare for, respond to, or recover from a disaster. The majority of them haven't even performed volunteer work in their own neighbourhood. Even during disasters, it is everyone's duty to help out as a community member. Some of them were disaster victims but did not participate in volunteer work. They may not be interested or be unaware of the work being done by volunteers, for example, they participated in relief efforts as volunteers. After the disaster, some of the people assisted with cleaning and rehabilitation tasks as volunteers.

The majority of emergency personnel never even go on the disaster management website. One of the best practices and innovative disaster management tools used to reduce the risk of disaster is public awareness. By regularly visiting websites for disaster management, the public can become more aware of the problems affecting its environment and help a community become more resilient.

The majority of first responders don't have a first aid kit at home. A first-aid kit makes sure you can have peace of mind and respond to unfavourable situations in a clever and promising way. Therefore, it is equally important to regularly check the kit and keep adding more as needed, just as it is important to have a first aid kit. First aid aims to stop medical conditions from getting worse, relieve pain, and give comfort while waiting for more advanced care to arrive.

To recommend a model for disaster literacy among postgraduate students.

The study of disaster literacy is undoubtedly in its early stages because it was conducted among postgraduate students in the Kottayam district. According to Lisa Mary Brown, Jolie Haun, and Lindsay J. Peterson;2014, the disaster literacy model's knowledge and skill levels are distributed along a continuum. On the disaster literacy continuum, skills advance from fundamental (i.e., basic reading and comprehension) to workable (i.e., ability to follow disaster preparedness, response, and recovery messages) to communicative or interactive disaster literacy (i.e., advanced skills involved in helping others and managing disaster-related experiences), and finally to critical disaster literacy (i.e., capacity to analyse disaster-related information, be empowered to address barriers, and take personal control to remain safe, cope with, and recover from disasters). Theoretically, a continuum from ineffective to marginally effective disaster literacy skills can be drawn using these four levels of skill. Paasche-Orlow and Wolf, 58 defined literacies in terms of patient-internal predisposing factors, situational factors (such as education, social support, vision, motivation, and knowledge), and situational external factors (such as support technologies, mass media, education, and resources), all of which have an effect on disaster literacy and related outcomes. The proposed disaster literacy model is illustrated below.

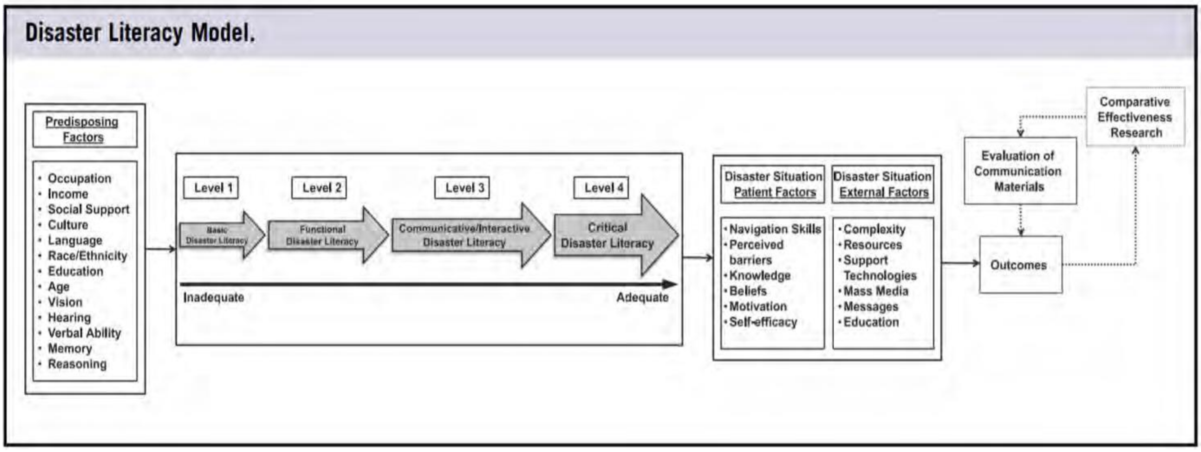

Fig.2. Four levels disaster literacy model (Brown et al., 2015, p. 270).

According to Brown et al. (2014), the disaster literacy methodology includes four levels of literacy that allow people to exercise more control and personal responsibility as well as improved knowledge of factors that influence their efforts, such as the context in which they are working. The disaster literacy model in this study is significant because it takes into account a person's capacity to access, comprehend, and react to such communications. The main goal is to gradually advance from fundamental disaster literacy to greater autonomy and involvement in crucial disaster preparedness and recovery activities. By taking into account the specific knowledge needed at each stage to get ready for, survive, and recover from a disaster, targeted disaster education and training should improve preparedness and make it easier to move from one level on the continuum to the next. The disaster literacy model in the study focuses on a person's knowledge of the various spheres of disaster mitigation, preparation, response, and recovery, each of which operates in accordance with different laws, regulations, and ways of life. These spheres include, but are not limited to, the following: (1) the state and local emergency operations systems in charge of issuing warnings and coordinating recovery efforts; (2) the various commercial and non-profit service providers on which people rely both before and after a disaster, such as transportation, emergency shelter, medical and mental health, water and electric utilities; and (3) the resources and factors that affect an individual's own disposition and capacity to deal with disasters. Before a disaster, it's crucial for vulnerable people to get in touch with their local emergency services and inform them of their location. However, it is still necessary for people to work with for-profit or non-profit service providers in order to get the assistance and services they might require in a disaster. Most importantly, individuals need to have a fundamental understanding of their own needs, resources, and vulnerabilities in order to create an effective disaster plan thus it is important to know more about the disaster and disaster management. This model ensures the ability to understand more about these. Which includes the basis, workable, communicative and critical level of disaster learning.

IMPORTANT OBSERVATIONS

- Youth are unaware of the disasters and they have no idea about disaster management.
- They all have basic knowledge about disasters, but the impacts of the disasters are not known by the young generation.
- They may not be familiar with disaster management, which would explain why they are unaware of the community's disaster preparedness, response, and recovery activities.
- They haven't attended any disaster awareness training or other related events.
- Both the local government and non-governmental organisations show less interest in disaster management efforts.
- They are not familiar with evacuation plans, mock drills, disaster management training, basic first aid knowledge, or how to use it and they don't have one at their home.
- They are ignorant of whether or not they are residing in a vulnerable area in their current community and the local governments and other authorities' operations are not well.
- Even the younger generation has not taken part in any recovery or disaster-related activities.
- They haven't performed volunteer work in their own neighbourhood before, during, or after a disaster.
- Despite their interest in joining as volunteers, they are unsure of the exact joining procedures.
- The majority of young people are eager to volunteer their time, and they are all curious about disasters and the activities involved in managing them.
- Participants overwhelmingly concur that social media is very useful during disasters and that they learned about all the news, safety measures, and disaster warnings through this media.
- Some people do think that the government should be in charge of disaster management.
- Many participants have engaged in numerous activities both during and following disasters, such as completing disaster-related research, conducting pre-disaster risk mitigation projects, raising awareness of disaster risk, engaging in public outreach and extension to keep needs and activities in the public eye, working with elected and public

officials to lower the risk of disaster, facilitated community meetings to identify and come to an agreement on risk reduction priorities.

- The participants have a lack of interest in visiting disaster management websites.

IMPORTANT RECOMMENDATIONS

- Parents are primarily responsible for educating their children about natural disasters.
- Teachers, starting in preschool and continuing through all levels of education, are crucial in this process.
- For students to achieve natural disaster literacy, teachers must impart the necessary information, awareness, and skills about natural disasters, particularly during their undergraduate studies.
- Since they represent a shared area of interest for both the natural and social sciences, natural disasters are a topic of study that crosses disciplinary boundaries.
- Natural disasters are a factor in the scope and outcomes of science and social science education in primary and secondary schools, so these subjects should be covered in the curricula.
- The best subject in high school where students can learn about natural disasters is geography. However, the study by Sozcu (2019a) claims that there are problems with disaster literacy because the results of natural disasters cannot go beyond theoretical understanding, and students and parents adopt a strategy that focuses on test-oriented learning for exams, like high school and university admission tests.
- The planning of awareness seminars, programs, classes, etc. could increase community interest in disaster management.
- The community must receive mock drills, training sessions, and first aid training from a non-governmental organization or the local government.
- The young generation's involvement in volunteerism needs to be increased.
- The local government must create a community disaster management plan.
- The younger generation needs to become more interested in learning about disasters, and disaster management efforts, and frequently visit websites that deal with disaster management.
- Students, faculty members, and other staff members in educational institutions must receive professional, thorough training in disaster management procedures.

CONCLUSION

In this study disaster literacy among postgraduate students was focused on. Considering the findings of the results, it was concluded that students, had insufficient knowledge and awareness about disaster preparedness and their knowledge and awareness may significantly improve through the implementation of the educational program in the field of disaster management and also by including disaster management courses and training in their curriculum. The proposed disaster management guidelines are reliable and valid to use. During the response and recovery phases of a disaster, people who have planned ahead typically fare better. However, issues arise when the requirements, preferences, capacities, and resources of weaker individuals are not sufficiently taken into account. Their capacity to comprehend and effectively apply potentially life-saving information is constrained by the misalignment between the literacy requirements of existing materials and the literacy abilities of many vulnerable subgroups.

Disaster literacy will be a weapon to be used in all kinds of issues that are faced by local subgroups. It is clear that disasters cannot be prevented, it is a naturally occurring phenomenon and we could only minimize the intensity of the hazard and reduce the risk. Disaster literacy from the preschool level increases the ability to withstand any kind of disaster. As a result, disaster literacy can be used in those areas where preparedness for any disasters which are problematic.

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FLOOD RISK ANALYSIS OF PERIYAR RIVER BASIN WITH CHANGING CLIMATIC PATTERN USING HEC-RAS MODELLING

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Abstract:

The study was conducted on the Periyar river basin located at Idukki, Ernakulam and Thrissur districts in Kerala and Coimbatore district in Tamil Nadu. The study's goal was to describe Mullaperiyar dam break analysis and mapping of dam-induced flood risk analysis. The study was carried out in United States Army Corps of Engineers (USACE), the River Analysis System (HEC-RAS) hydrological engineering centre and ARC-GIS. The dam induced flood study based on Idukki, Ponmudi, Madupetty, Sengulam, and Idamalayar dam suggest that downstream areas are highly vulnerable to catastrophic flooding. The flood inundation map was generated by HEC-RAS. The extent of flooding can be estimated using information on the geographic location, flood depth, wave velocity at various locations, and water surface elevation. The flood inundation map generated by HEC-RAS and imported to ArcGIS to delineate flood intensity map. The simulation result showed in failure of Mullaperiyar dam break caused failure of consequent dams which include Cheruthoni dam, Idukki dam, Kulamavu dam, Malankara dam, Lower Periyar dam and Bhoothathankettu dam. Due to consecutive dam breaks, the majority of downstream areas are at very high risk of severe flooding.

Keywords:

HEC-RAS, dam induced flood, inundation map, simulation.

INTRODUCTION

Flood

Flooding is arguably the weather-related hazard that is most widespread around the globe. It may happen practically everywhere. Water is what defines a flood pouring onto a dry area of land. Floods are frequently assumed to be the result of significant rainfall. It can happen in a variety of indirect ways pertaining to current weather conditions. Therefore, a total flood must be described using procedures that maybe has little to no relationship to meteorological events. However, it is evident that in some final. The origins of flooding, therefore, ultimately lie in atmospheric processes creating precipitation, no matter what specific event causes the flooding. Floods cause damage due to the tremendous force of the moving water as well as the deposit of mud and debris when the floodwaters have finally subsided. (Doswell III et al.,1986).

Types of floods

Flash floods

This type typically results from strong rain, dam failure, or snowmelt and happens within a relatively short period of time (between two and six hours, and occasionally even within minutes) It can occasionally be brought on by heavy rain from thunderstorms moving slowly. Flash floods are the most dangerous because people are frequently taken by surprise. Typically, there is no notice, no planning, and the effects might be severe quick and destructive (Doswell III et al.,1986).

River flooding

It is the most frequent inland flood type. River flooding happens when a body of water is filled to its capacity. Localized flooding can significantly damage nearby properties and pose a serious safety risk when a river bursts its banks usually as a result of heavy rain falling over a lengthy period of time (Doswell III et al.,1986)

Coastal flooding

Severe storms frequently cause the most damage in coastal locations, especially if they have intensified over the oceans. Extreme weather conditions and high tides can raise sea levels, which can occasionally lead to coastal flooding. Low-lying seashore areas typically have barriers against the water, whether they are man-made or organic, like sand dunes. Coastal flooding is anticipated to become a frequent and seriously problematic issue as global warming progresses.

Groundwater flooding

Groundwater flooding takes time to happen. The earth becomes so saturated with water from prolonged rain that it can no longer absorb any more. Flooding results from water rising over the ground's surface in this situation. This kind of flooding may linger for weeks or even months at a time.

Dams

Dams are hydraulic structures built across waterways to retain water in upstream reservoirs created for irrigation, hydropower generation, domestic and industrial water supply, multipurpose reservoirs serving as flood control and drought mitigation devices, and storage spaces for sequestering sediment (Hurdowar-Castro, et al., 2007).. When a high flood occurs, there is not enough room to attenuate the approaching flood and excess flood overflow over the dam section, leading to a dam breach scenario that generates a massive amount of flood wave inundating downstream reaches of the dam. The amount of siltation is increasing every year, resulting in reduction of reservoir's useful life and decrease in storage capacity. Dam breakdowns are defined as partial or catastrophic failure that causes an immense flood to erupt uncontrollably downstream (Fread, 1993). Flooding caused by a dam failure is worse than flooding caused by a lot of rain. Seepage failure, failure due to overtopping, foundation failure, construction failures, and failure owing to poor quality materials are the main causes of dam breaks. The dams could fail suddenly or gradually. A concrete dam often collapses suddenly from overtopping, whereas an earthen dam does so by material erosion and piping action.

Types of dams

Gravity dam

A large-scale dam made of stone or concrete is known as a gravity dam. They are made to contain big amounts of water. The weight of the dam is actually able to withstand the horizontal surge of water pouring against it because to the use of concrete. The dam is effectively held in place by gravity, preventing it from being swept away by water. Gravity dams are well suited for blocking rivers in wide valleys or narrow gorge ways. Since gravity dams must rely on their own weight to hold back water, it is necessary that they are built on a solid foundation of bedrock

Earth dam

An earth dam is constructed of soil that has been compacted in layers, with the most impervious elements used to create the core and more permeable materials used on the upstream and downstream edges. If the water level rises above the dam, a face made of crushed stone inhibits wind or rain erosion, and a large spillway, typically made of concrete, guards against catastrophic washout. Because of the soil's shear strength, earth dams are able to withstand forces applied to them.

Rockfills Dams

Large boulders and rock fragments are used to construct a rockfill dam. To lessen seepage through the dam, an impermeable membrane is positioned on the rockfill on the upstream side. Typically, asphaltic concrete or cement concrete is used to create the membrane. Steel and timber membrane were also employed in early rockfill dams, but these are now obsolete. To distribute the water load and give the membrane strength, a dry rubble cushion is positioned between the rockfill and the membrane. Sometimes, instead of an impervious upstream membrane, the rockfill dams have an impervious earth core in the middle to stop seepage.. The side slopes of rockfill are typically maintained at 1.4:1, which is considered to be the angle of repose of rock (or 1.3:1). Rockfill dams require foundation stronger than those for earth dams

Arch Dams

A curved arch dam has a convexity that faces the upstream side of the river. An arch dam uses its arch action to primarily transfer water pressure and other pressures to the abutments. For small valleys with sturdy flanks that can withstand the thrust created by the arch movement, an arch dam is a great option. Similar to a gravity dam, an arch dam has a portion that is roughly triangular, although it is much thinner. The vertical curve of the arch dam can be either single or double. In general, double-curved arch dams are more practical and cost-effective.

Buttress Dams

There are three different types of buttress dams: the deck type, the multiple-arch type, and the massive head type. A deck-type buttress dam comprises of buttresses that support a sloping deck. The water pressure from the deck slab is transferred to the foundation by buttresses, which are triangular concrete walls. Compression members include buttresses. According to the size and configuration of the dam, buttresses are normally spaced every 6 to 30 metres throughout the dam. The buttresses, which are typically evenly placed, support the deck, which is often a reinforced concrete slab.. The arch.es are typically composed of concrete and have a modest span. There is no deck slab in a buttress dam of the massive-head variety. Instead of the deck, the buttresses' upstream edges are flared to create enormous heads that span the space between them. Compared to gravity dams, buttress dams.

OBJECTIVES OF STUDY

- To examine the mapping potential of dam-induced flood and flood intensity
- To conduct 2-D dam break study of Mullaperiyar Dam using HEC-RAS

SIGNIFICANCE OF STUDY

- Can predict the overall area subject to dam flooding
- Map the inundation area with ARC GIS and HEC- RAS
- Route the outflow hydrograph from the breached dam throughout downstream from the dam to the downstream boundary of the simulation using HEC-RAS (US Army Hydrologic Engineering Center-River Analysis System)

REVIEW OF LITERATURE

Flood inundation maps for the Akarcay Bolvadin Subbasin in joint area of Aegean, Mediterranean and Central Anatolia Regions of Turkey demonstrate how the topography of the research region is established for the hydraulic model by sectioning along the river on the Digital Elevation Model (DEM) produced by the Geographical Information System (GIS) programme ArcGIS. As a hydraulic model, HEC-RAS software is utilised. A middle module called HEC GeoRAS is used to allow data movement between ArcGIS and HEC RAS. The Fuller Method is used to calculate flow data for various recurrence intervals. Acquired flood depth and velocity estimates are a result of hydraulic modelling. As long as a flood early warning system based on rainfall or runoff, flood risk communication, and evacuation planning are implemented. Flood risk assessment must be used to market flood disaster insurance. Within the framework of a participative management approach, it is necessary to put education and awareness-raising studies, effective communication elements use, good organisation of relevant public establishments, nongovernmental societies, and community, inter-institutional coordination, and crisis desk into practise. (İcaga et al.,2016)

Dam breaking is a labour-intensive and involved procedure. Here, the Neyyar Dam in the district of Thiruvananthapuram was subjected to the dam break tool in HEC-RAS. Simulation and analysis of a dam break based on provided geometry information. Here, the analysis's output illustrates the maximum water surface at each river station after the dam breaks, which was animated with the aid of Arc Map. HEC-RAS and HEC-GeoRAS, when used in conjunction, give users the ability to model a river's hydraulics, simulate a dam failure, and map the ensuing flood wave.. Planning for land use and creating emergency response strategies will benefit from a proper study of the risks associated with dam failure since it will help prevent catastrophic loss of life and property (Razack, R. 2014).

For the purposes of planning and decision-making with regard to dam safety, regulating downstream projects, emergency evacuation planning, and real-time flood forecasting, the prediction of the dam break flood is crucial. It is important to forecast not only the likelihood and mode of a dam failure, but also the flood hydrograph of discharge from the dam breach and the propagation of the flood waves, in order to quantify the flood damage caused by a dam breach. The studies are intended to map or outline areas that may be inundated by floodwaters as a result of a dam breach, as well as flood depth, flow velocity, travel time of the flood waves, and other factors. For the analysis, the structure's topmost mode of collapse was taken into account. The dam break flood generation is realistic given the breach parameters used. For the Idukki dam, the maximum flow is 28345.8 cumecs at the downstream river reach. Just below the Idukki dam site, the flow depth ranges from 58.24 metres to 18.21 metres at the reach's conclusion. (abhijith et al., 2017)

Kerala's Mullaperiyar Dam, with an operational capacity of 2,99,13,00,000 m^3, was built on the Periyar River. The dam has been in operation for 119 years, which is greater than its intended lifespan of 50 years. The study of Mullaperiyar Dam's dam break analysis using the HEC-RAS programme is presented. This analysis includes forecasting a dam break, river reach, discharge, unsteady flow equation, etc. Estimated to be 15403 cumecs, or nearly double the peak of the Probable Maximum Flood hydrograph, is the generated peak of the dam break flood hydrograph. The depths of flows range along the 36 km river reach, ranging from 45.33 m (immediately below the dam site) to 21.79 m at the reach's terminus (chainage 36 km from dam sites). Although a dam burst is a complex and devastating process, it is impossible to pinpoint the specific cause with the aid of software. Studies are done on various types of dams built based on usage and location. It is also examined how the new dam safety law, which the Indian government passed. (Khan et al., 2022)

METHODOLOGY

Study Area

The Periyar river basin lies between North latitude of 9°15’30’’ and 10°21’00’’, east longitude of 76°08’38’’ and 77°24’32’’. It flows from Western Ghats to Lakshadweep Sea. Periyar is known as the lifeline of Kerala because it is a back bone to the economy of Kerala. Periyar flows through some parts of Idukki, Ernakulam and Thrissur districts in Kerala and Coimbatore district in Tamil Nadu. Periyar is the longest river in Kerala with a length of 244 km and has second largest river basin in Kerala. It originates from the Sivagiri group of hills in Sundara Mala in Tamil Nadu.

There are 17 dams in the Periyar river basin, 15 of which are controlled by KSEB, and 2 of which are maintained by the Irrigation Department. Mullaperiyar, Idukki, Bhoothathankettu, and Idamalayar are the principal ones. The dams operated by KSEB in the Periyar river watershed not only generate 1264.85 MW of power but also aid in flood control and maintaining river flow during dry seasons. The Periyar River's dams have a combined storage capacity of 3278.70 Mm^3. Total quantity of water used to generate power is 436.47m^3/sec. Figure 3.1 below shows Periyar river basin.

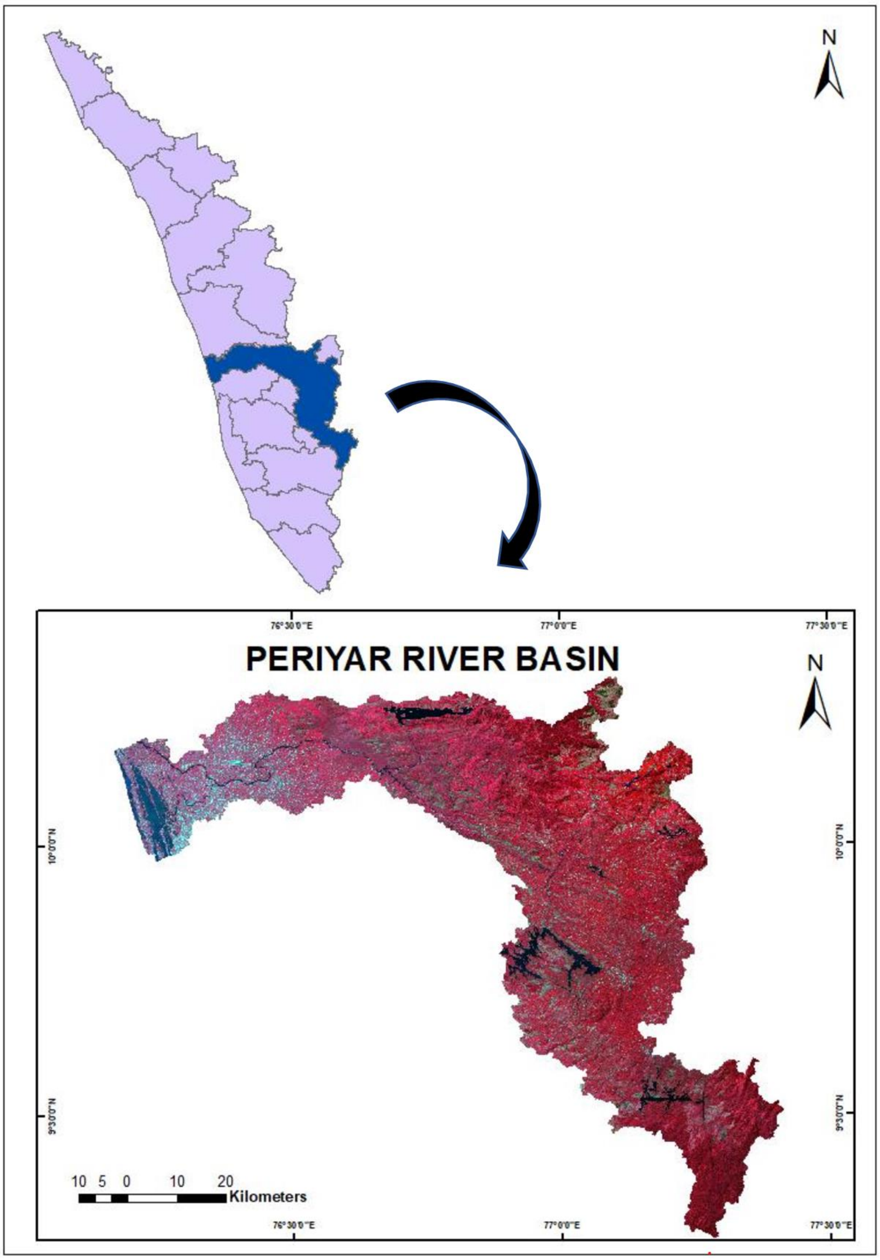


Fig 3.1 Periyar river basin

Dam Induced Flood Analysis

US Crops Army's Hydrologic Engineering centre's River Analysis System (HEC-RAS) simulation model is used for dam induced flood analysis. In the present study dam flood simulation was carried out using HEC-RAS software. To predict the flood inundation from the reservoir it is necessary to have details of the reservoir. Reservoir data includes Maximum storage capacity, spillway height, spillway width, dam crest width, Dam height. The analysis of flood inundation consists of outflow from the dam must be routed through the downstream valley to determine the resulting flood at population centres. Two-Dimensional Unsteady flow analysis is carried out for analysis and to determine the resulting flood at downstream side of dam.

Datasets used

Table 3.1 Details of datasets used for the study

Sl. No	Data type	Source	Resolution
1	SRTM DEM	https://search.earthdata.nasa.gov/search	30m

Precipitation Data

Precipitation data was collected from Kerala State Electricity Board Limited (https://dams.kseb.in/?p=329)

Analysis Performed

The storage area (Dam) and the perimeter were drawn using RAS Mapper. The data used for the flood inundation were Precipitation data, Digital Elevation Model (DEM), WGS 84 datum and UTM projection were used. From DEM terrain model was created.

After creation of terrain model, 2D flow area boundary and storage area boundary were marked and then mesh formation was done.

Boundary Condition – 1) Storage area - 2D flow area connection

2) Exit boundary - Normal depth

3) Precipitation data was added

Flood Hazard Assessment

A flood's strength is regarded as a widely used indicator for estimating the risk of flooding. The characteristics of a risk that cause harm are referred to as intensity, and it is frequently assessed using the water depth and flow velocity.

Flood intensity = Water depth x Flow velocity

Around the world, a number of standards for estimating possible damage have been created, including those of the American Society of Civil Engineers and the US Bureau of Reclamation.

The water depth and flow velocity derived from the hydraulic model were multiplied in raster calculator in ArcGIS and later reclassified and ranking were given to the respective layer. We accept the ASCE standard, which states that a depth x velocity greater than 2.10 m^2/s puts human lives in danger. Table 3.1 shows the flood hazard classification according to the ASCE classification.

Table 3.2 Flood hazard classification according to American Society of Civil Engineers (ASCE) criterion

Flood Hazard Classification	Flood Intensity Values (Water Depth x Flow Velocity, m^2/s)
Low-Medium	< 2.1
High	2.1 – 3
Very High	> 3

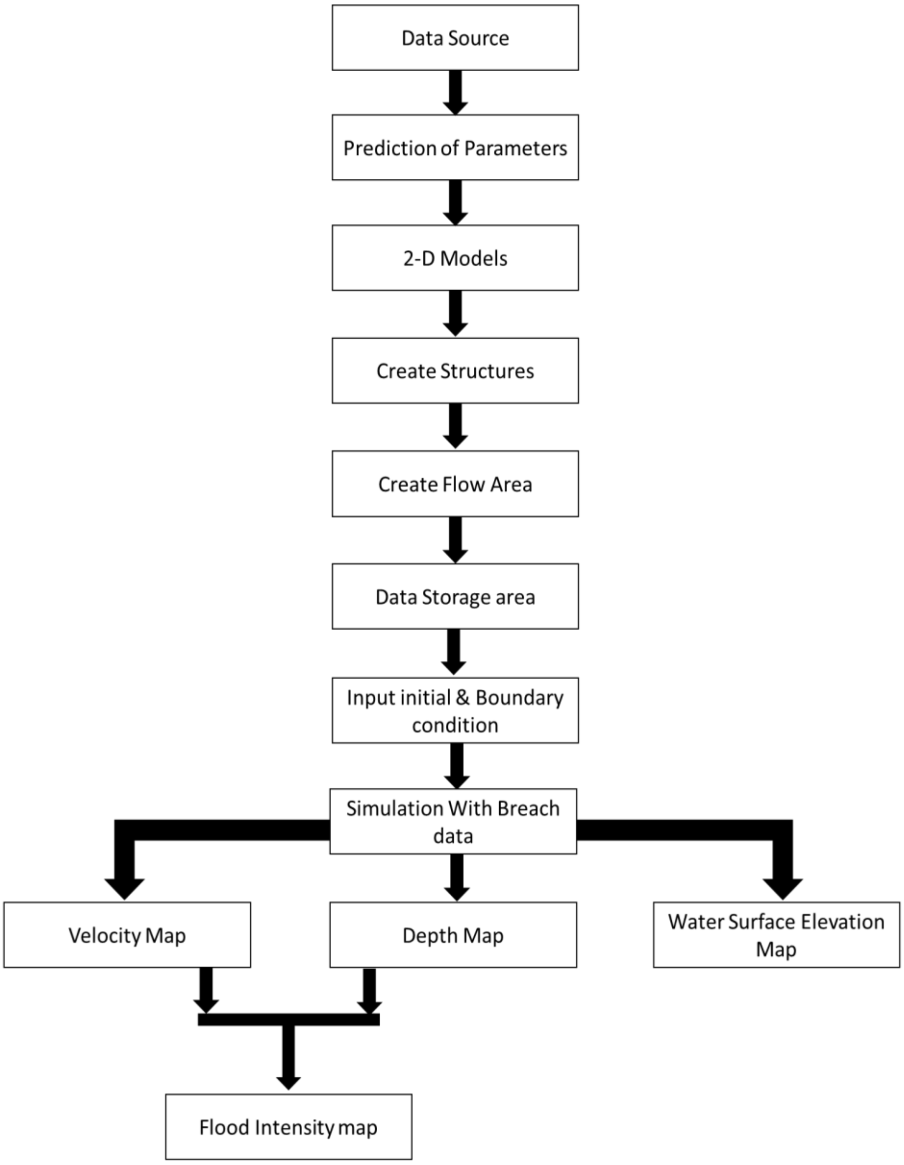


Fig 3.2 Methodology adopted for Dam induced flood mapping

TWO-DIMENSIONAL DAM BREAK STUDY OF MULLAPERIYAR DAM USING HEC-RAS

Study area

The Mullaperiyar Dam, the first Surkhi concrete dam, is located on the west-flowing Periyar River in a "V"-shaped valley in the Western Ghats. The uncoursed rubble masonry and lime surkhi mixture mortar used to construct the front and back sides of the dam are in the ratios of 2:1:3. Two parts of lime, one part of surkhi, and three parts of sand make up a lime surkhi mortar. The hearting, which is composed of lime surkhi concrete with 3.125 parts stone and 1 part mortar, can contain more than 60% of the dam's volume. Later, in the 1980s, a 10 m-wide concrete backing was installed to the old dam's downstream face as a measure of the structure's strength. Strengthening has been enhanced to 6.4 m after the concrete backing was attached (21 feet). As a result, it is a diverse building made up of upstream masonry and debris.

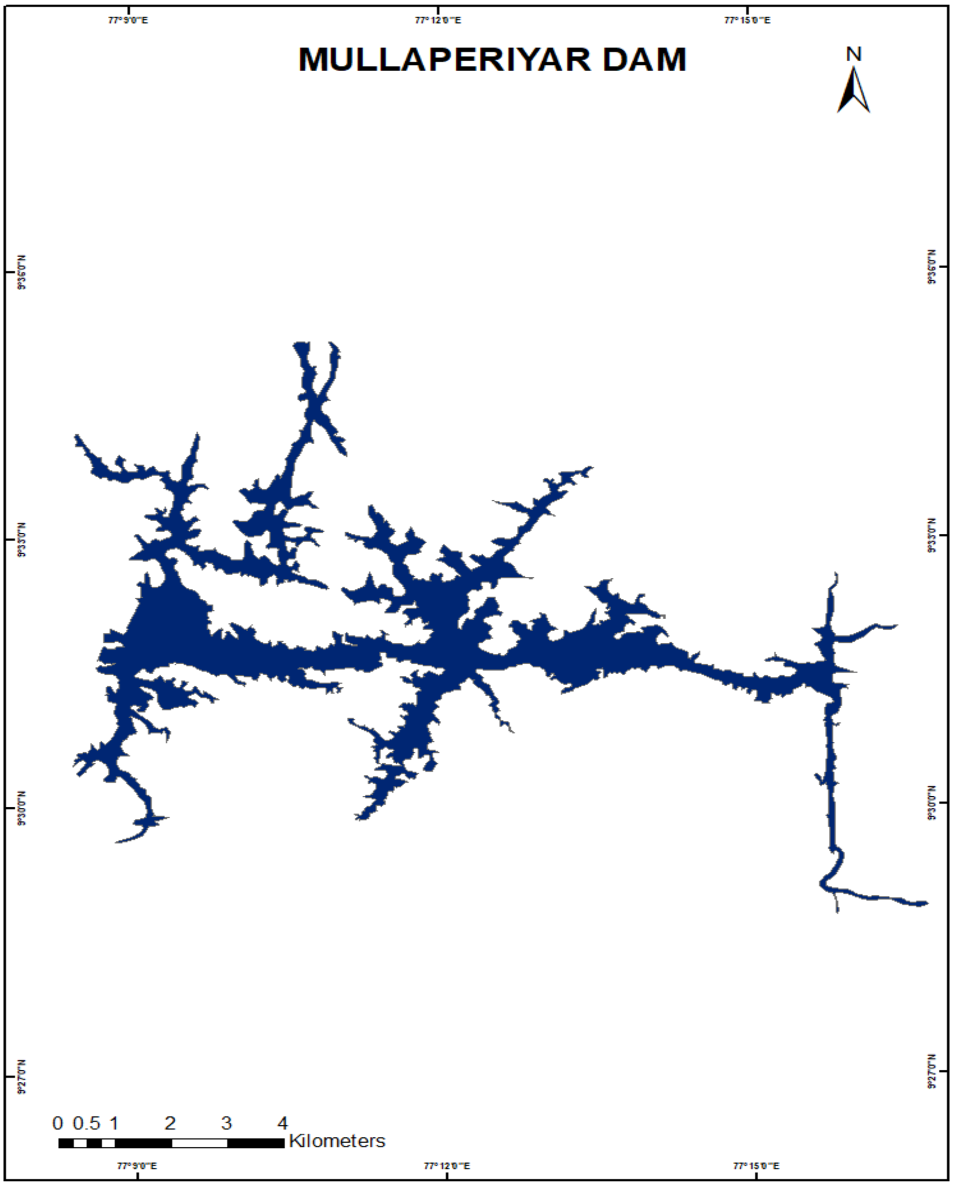


Fig 3.4 Mullaperiyar dam

HEC-RAS 6.3.1 Model is used to create simulation for dam break analysis of Mullaperiyar dam in Idukki district in Kerala. Two-dimensional unsteady flow analysis is carried out for dam break analysis and determine the resulting flood at downstream side of the dam. Unsteady flow analysis method used with Implicit Finite Volume algorithm and Wave Diffusion equations.

Data sets used

Details of DEM used are given below (Table 3.5)

Table 3.5 Details of data sets used for analysis

Sl. No	Data type	Source	Resolution
1	SRTM DEM	https://search.earthdata.nasa.gov/search	30m

Hydrograph Data

August 5 to August 10,2022 hydrograph outflow data in cumecs from Mullaperiyar dam were collected from Hindu newspaper (https://www.thehindu.com/)

Analysis performed

The storage area (DAM) and the perimeter were drawn using RAS Mapper. The data used for the dam break analysis were Discharge data, Digital Elevation Model (DEM), WGS 1984 datum and UTM projection were used. From DEM terrain model was created.

After creation of terrain model, 2D flow boundary and storage area boundary were marked and then mesh formation was done.

Boundary condition – 1) Storage area - 2D flow area connection

2) Exit boundary - Normal depth (0.0004)

3) Discharge data from dam was added

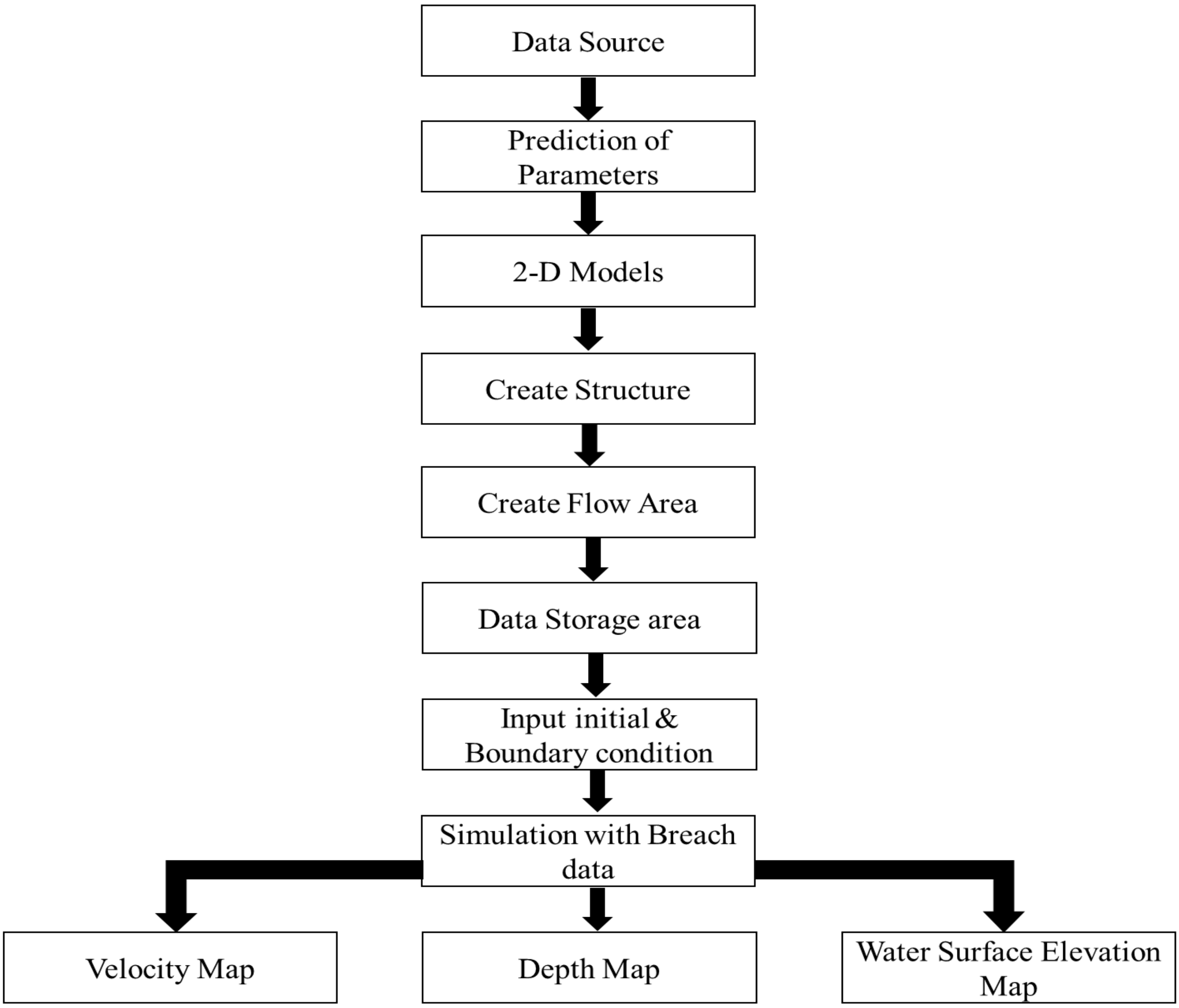


Fig 3.5 Methodology adopted for Dam break analysis

RESULTS AND DISCUSSIONS

Dam Induced Flood Mapping

Idukki Dam Induced Flood Mapping

Idukki Arch dam doesn't have any shutters to be opened so it must rely on the Cheruthoni dam to maintain the reservoir water level. The dam induced flood inundation map of Idukki dam downstream is mainly focuses on Cheruthoni dam. The downstream flow of Idukki dam is through Lower Periyar dam. Therefore, the combined storage data of Lower Periyar dam and Idukki dam data is used for the dam induced flood scenario

After creation of 2D flow area boundary and storage area boundary, the geometric data obtained (fig. 4.1) Storage capacity of Idukki dam is given below (table 4.2)

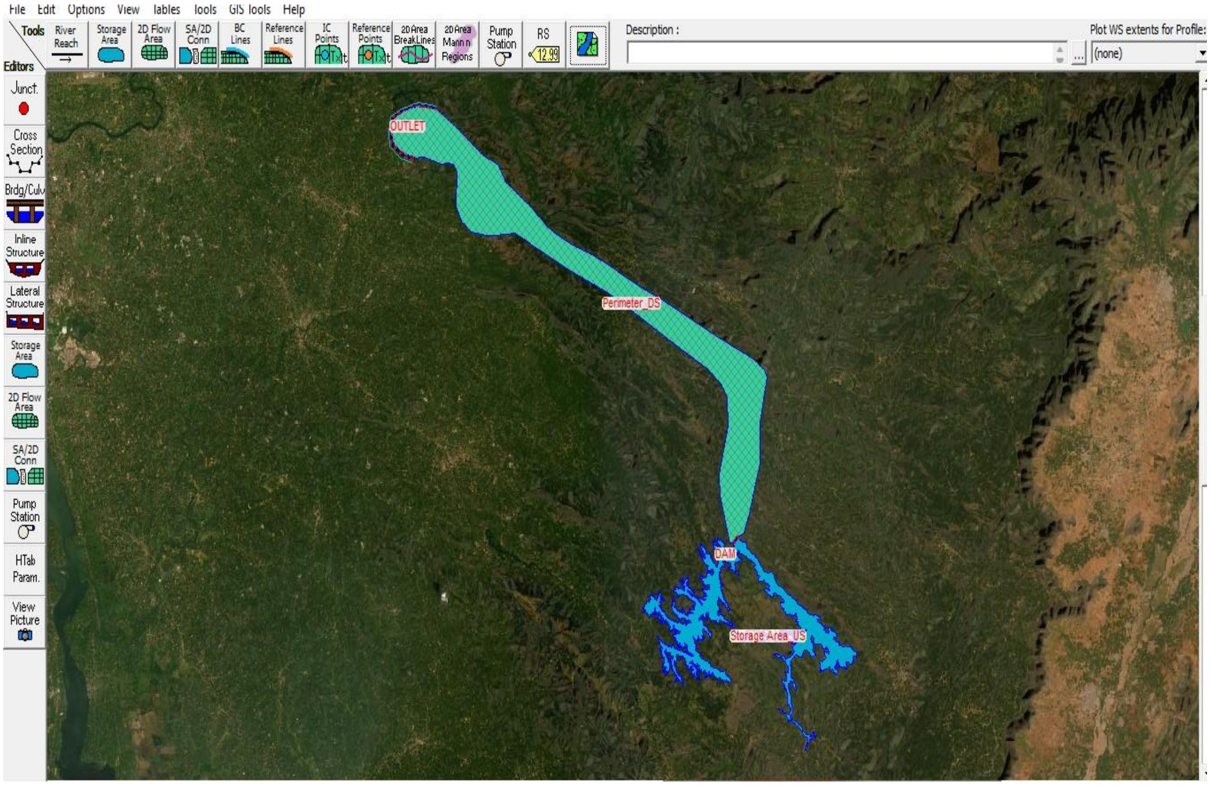


Figure 4.1 Geometric data of Idukki dam

Table 4.2 Storage capacity of Idukki dam

Elevation (m)	Volume (m^3)
714.79	1069.82
715.067	1175.89
717.571	2583.4
717.984	2905.77
718.834	3656.22
719.283	4095.9
719.797	4637.35

The dam induced flood analysis were performed using the same parameters for dam breach analysis. The breach geometry is used for the analysis. Dynamic Breach geometry (breach depth and width, breach side slope factor, timing (breach initial time, breach formation time, etc). The dam induced flood can be calculated by using unsteady flow analysis. Once entered all of the geometry and unsteady flow data, unsteady flow calculations are performed. The Centre station and Final bottom elevation were taken from graph. The top of dam elevation is calculated by adding the height of the dam with Breach bottom elevation (which is taken from the graph). Pool elevation at failure is the storage capacity of the dam in m^3. Pool elevation at failure is calculated by adding the breach bottom elevation with breach height. The equation developed by the Froehlich (2008) were used in this dam induced flood map analysis (fig 4.2)

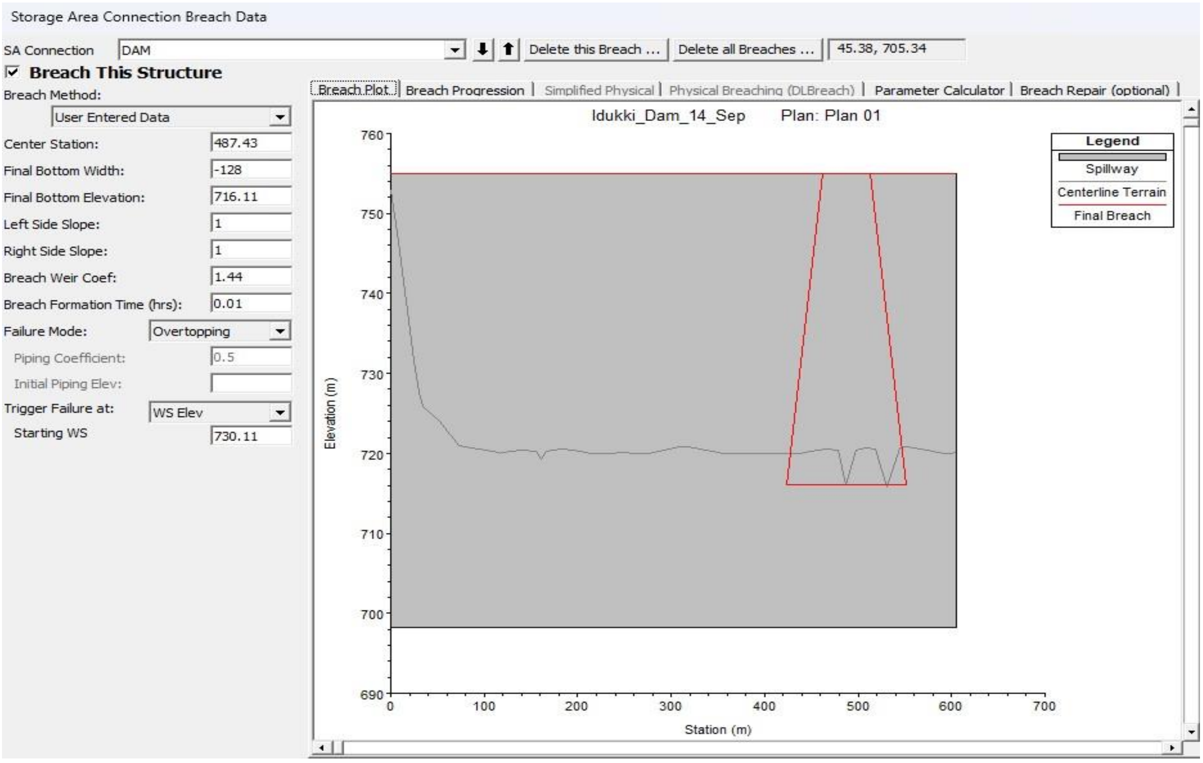


Fig 4.2 Storage area connection of Idukki dam

Unsteady flow simulation is carried out for dam induced flood study. Hydrograph output interval taken as 30 minutes and computation interval were taken as 20 second. The result obtained from the dam induced flood study combines of depth, velocity and water surface elevation maps are shown below (fig 4.3, 4.4, 4.5).

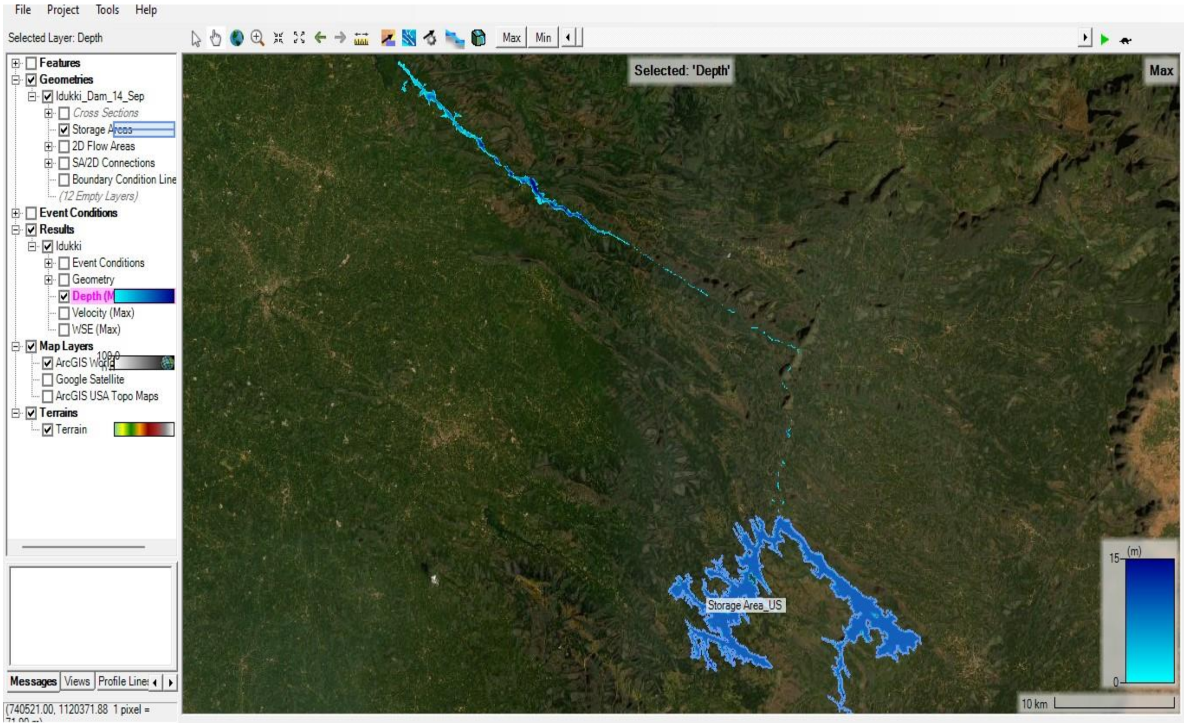


Fig 4.3 Flood Inundation Map showing depth

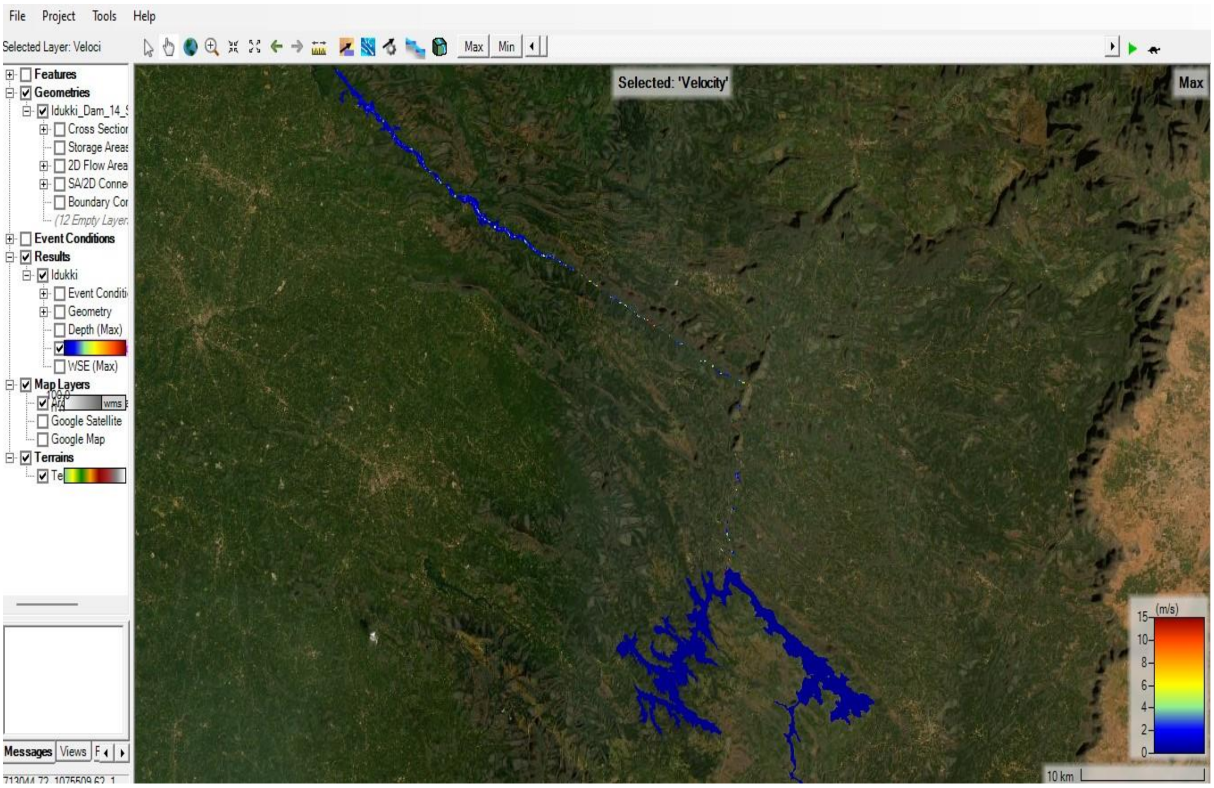


Fig 4.4 Flood inundation map showing velocity

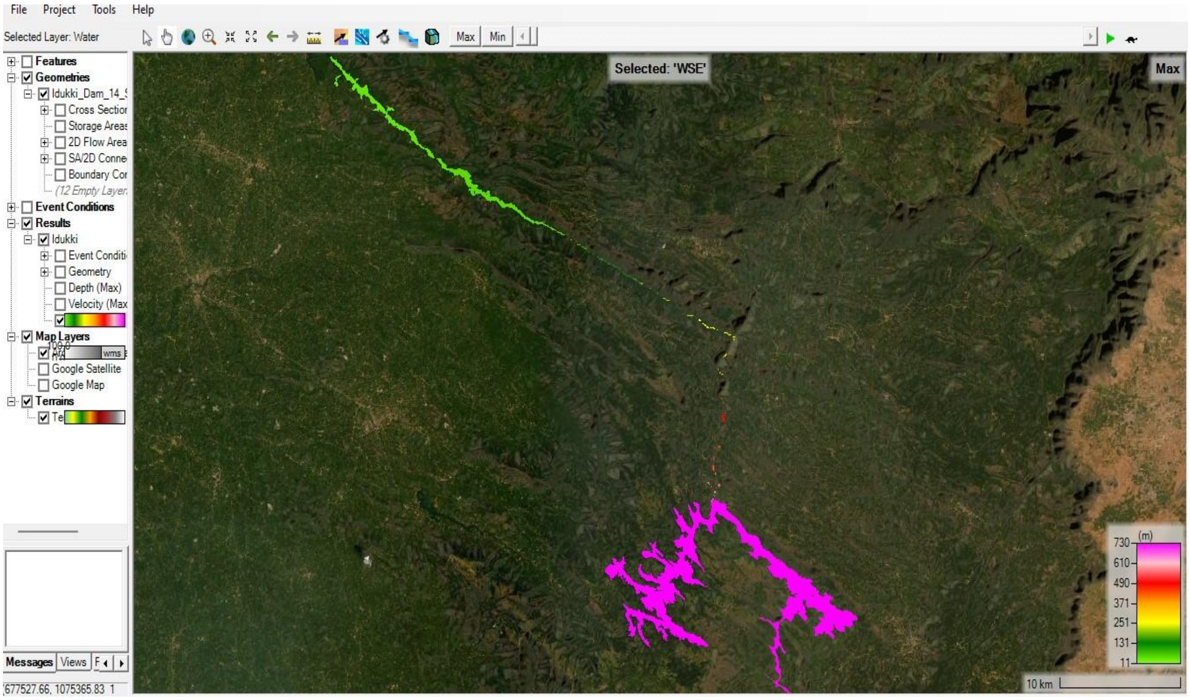


Fig 4.5 Flood inundation map showing water surface elevation

Because of a dam-induced flood, areas that are susceptible to flooding include Idukki Town, Cheruthoni, Thadiyampad, Karimban, Chappath, Panamkutty Power Station, Lower Periyar Dam Area, Karimanal Police Station Area, Neendapara, Chembankuzhi, Maniyanpara, Neriyamangalam, Inchathotty, and Thattekaad

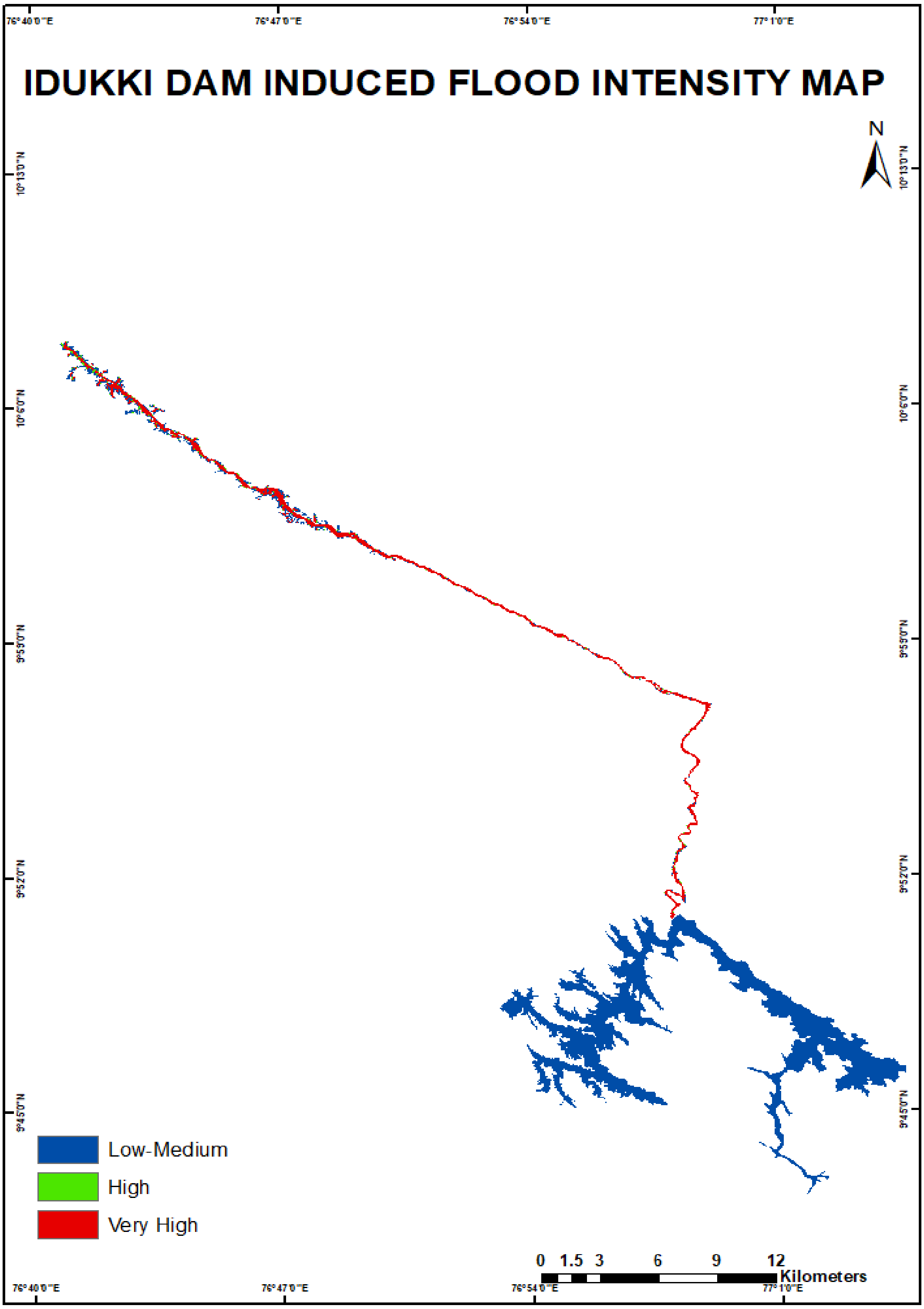


Fig 4.6 Idukki Dam Induced Flood Intensity map

Based on the present study Idukki dam induced flood intensity zones of the study area can be classified into three categories- Low-Medium, High, Very high zones indicated in the map. About 50.81635 ha (85 %) falls in Low – Medium intensity zone, 0.740323 ha (1%) in high intensity zone and 8.48118 ha (14 %) area falls in Very high Intensity zones. (Table 4.3, Fig 4.6)

Table 4.3 Geographical area of Flood Intensity Zone

Flood Intensity Zones	Area	
	Ha	Percentage (%)
Low-Medium	50.81635	85 %
High	0.740323	1 %
Very High	8.48118	14 %

Ponmudi Dam Induced Flood Mapping

The study mainly focuses on dam induced flood analysis of Ponmudi dam and it focuses on Ponmudi and the downstream reservoir Kallarkutty. The downstream flow of Ponmudi dam is through Kallarkutty dam. Therefore, the combined storage data of Ponmudi dam and Kallarkutty dam is used for the dam induced flood mapping. The storage capacity of Ponmudi dam is given in the table (table 4.5).

After creation of 2D flow area boundary and storage area boundary, the geometric data obtained (fig 4.7).

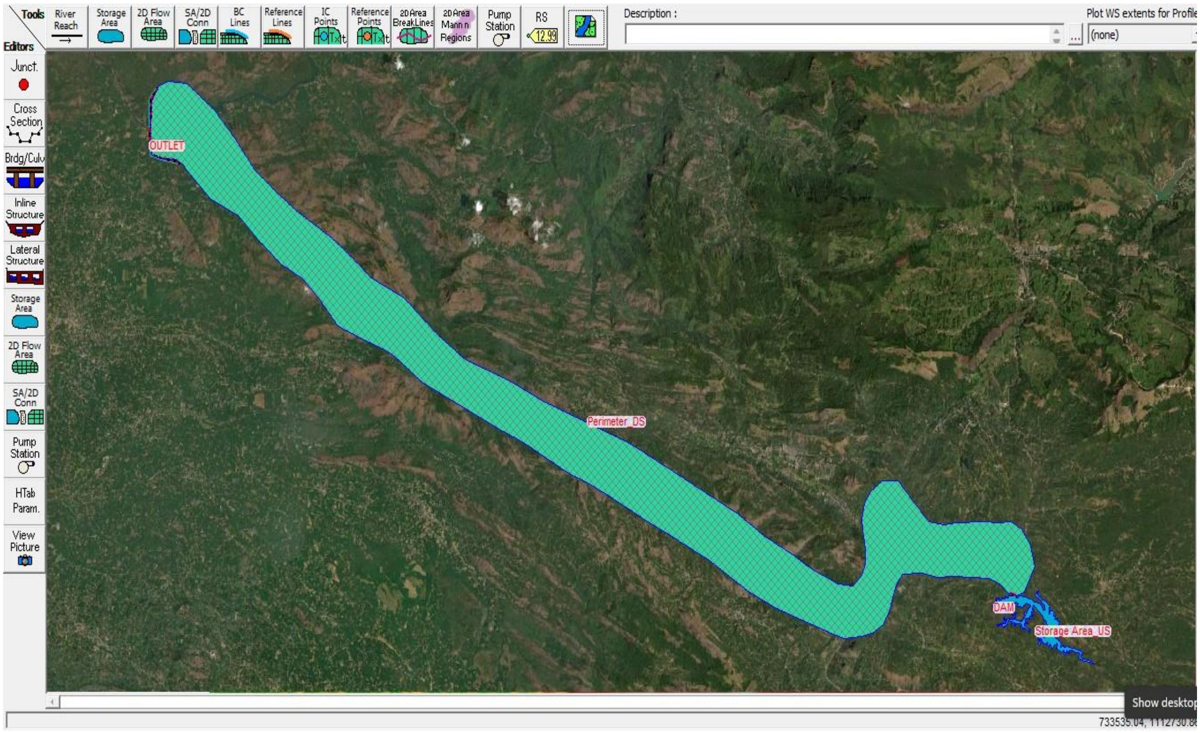


Fig 4.7 Geometric data of Ponmudi dam

Table 4.5 Storage capacity of Ponmudi dam

Elevation	Volume (m^3)
694.61	101.359
694.824	111.878
695.239	135.796

696.533	242.787
697.472	352.592
717.395	30730.1
730.893	62934.39

The dam induced flood analysis were performed using the same parameters for dam breach analysis. The breach geometry is used for the analysis. Dynamic Breach geometry (breach depth and width, breach side slope factor, timing (breach initial time, breach formation time, etc). The dam induced flood can be calculated by using unsteady flow analysis. Once entered all of the geometry and unsteady flow data, unsteady flow calculations are performed. The Centre station and Final bottom elevation were taken from graph. The top of dam elevation is calculated by adding the height of the dam with Breach bottom elevation (which is taken from the graph). Pool elevation at failure is the storage capacity of the dam in m^3. Pool elevation at failure is calculated by adding the breach bottom elevation with breach height. The equation developed by the Froehlich (2008) were used in this dam induced flood map analysis (fig 4.8).

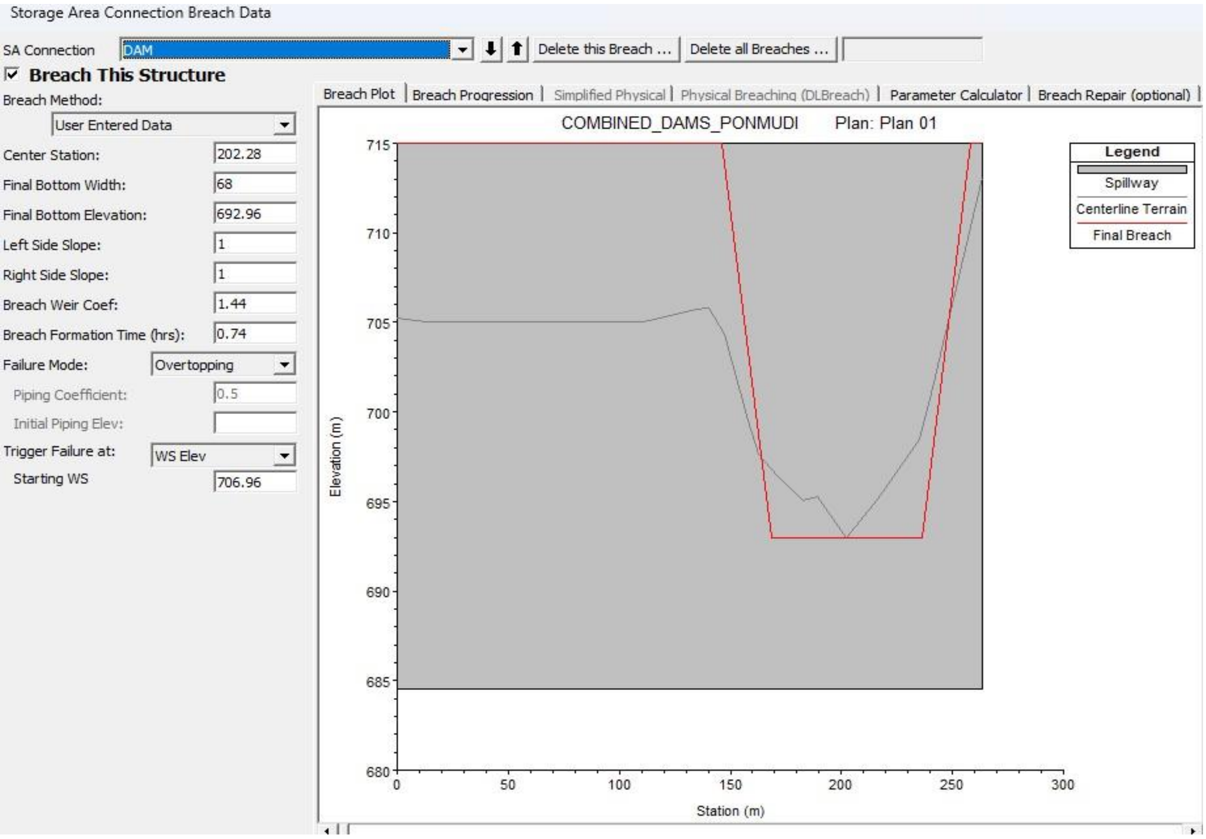


Fig 4.8 Storage area connection of Ponmudi dam

Unsteady flow simulation is carried out for dam induced flood study. Hydrograph output interval taken as 1 hour and computation interval were taken as 20 second. The result obtained from the dam induced flood study combines of depth, velocity and water surface elevation maps are shown below (Fig 4.9, 4.10, 4.11).

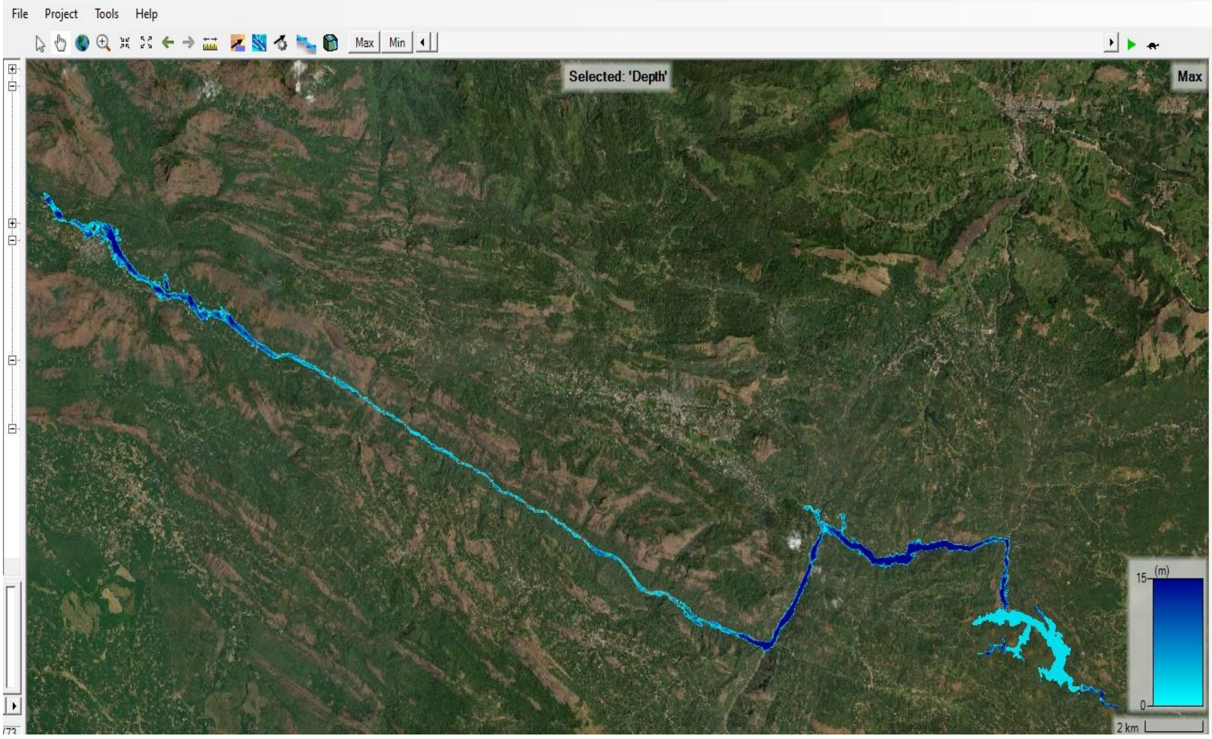


Fig 4.9 Flood Inundation Map showing depth

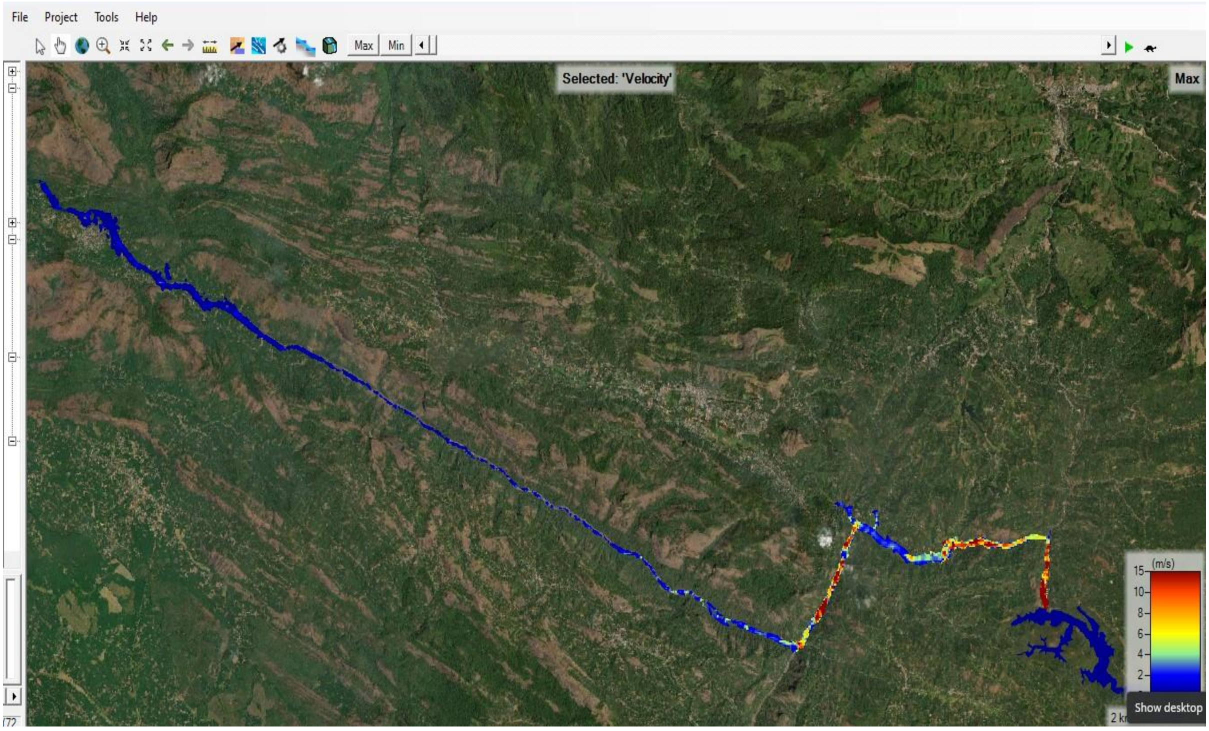


Fig 4.10 Flood inundation map showing velocity

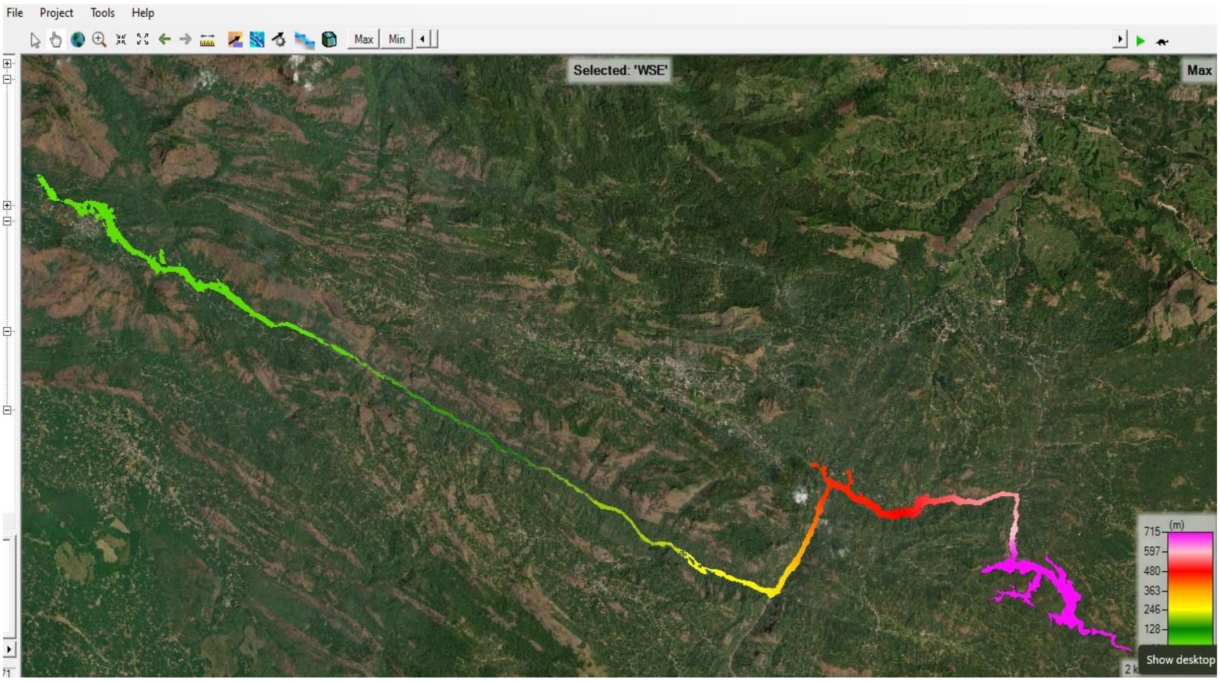
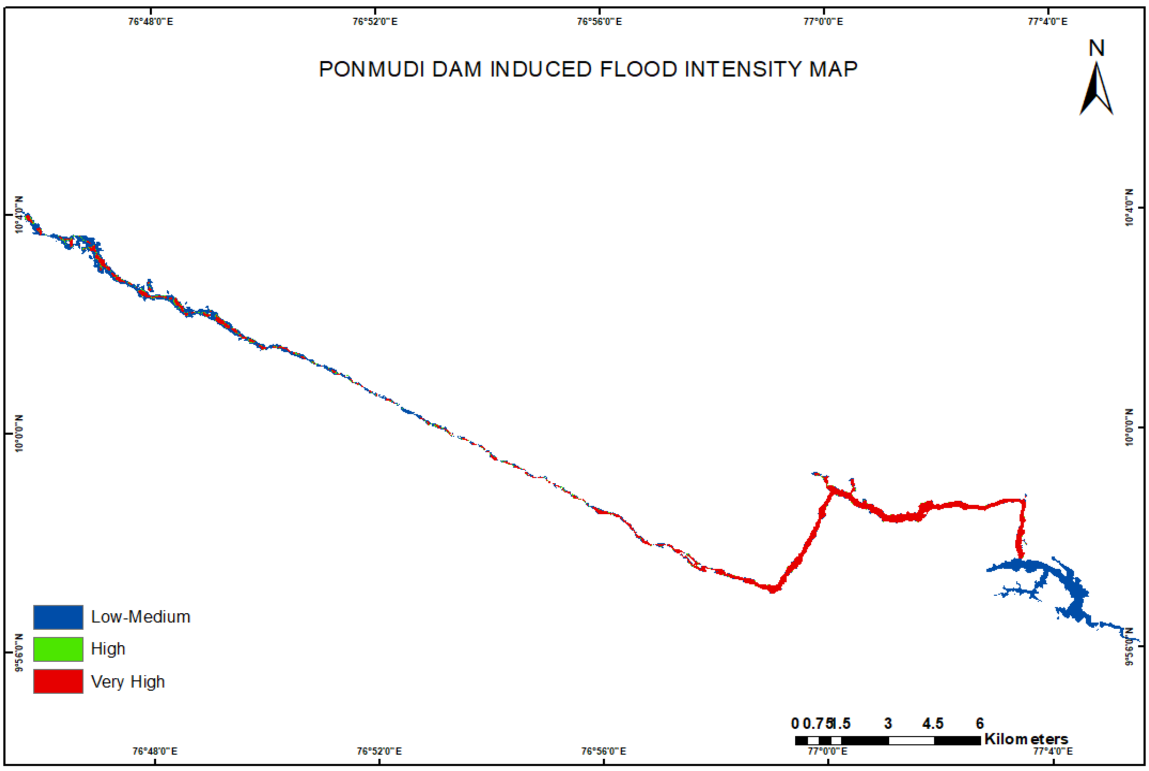


Fig 4.11 Flood inundation map showing Water Surface Elevation

The present study suggests that due to opening of dam the areas such as Adimali–Rajakkadu road, Panniyarukootty area, Vellathooval bridge, KSEB Panniyar power station, Kallarkutty reservoir area, Kallarkutty bridge, Panamkutty bridge, Neriamangalam-Painavu road, KSEB Lower Periyar power station Karimanal areas, Kanjiramvely bridge, Neriamangalam bridge. Kallarkutty dam and Lower Periyar dam may face severe flooding.



4.12 Ponmudi Dam Induced Flood Intensity map

Based on the present study Ponmudi dam induced flood intensity zones of the study area can be classified into three categories- Low-Medium, High, Very high zones indicated in the map. About 4.54002 ha (50%) falls in Low – Medium intensity zone, 0.360259 ha (4 %) in high intensity zone and 4.092054 ha (46 %) area falls in Very high Intensity zones. (Table 4.6, Fig.4.12)

Table 4.6 Geographical area of Flood Intensity Zone

Flood Intensity Zones	Area	
	Ha	**Percentage (%)**
Low-Medium	4.54002	50 %
High	0.360259	4 %
Very High	4.092054	46 %

Idamalayar Dam Induced Flood

Idamalayar dam is constructed as part of Idamalayar Hydro Electric Project.The spill water flows to Idamalayar river. Tail water from power plant flows to Idamalayar river. The downstream flow of Idamalayar dam is through Bhoothathankettu dam. Therefore, the combined storage data of Idamalayar dam and Bhoothathankettu dam is used for the dam induced flood scenario.

After creation of 2D flow area boundary and storage area boundary, the geometric data obtained (Fig 4.13). Storage capacity of Idamalayar dam shown below (Table 4.8).

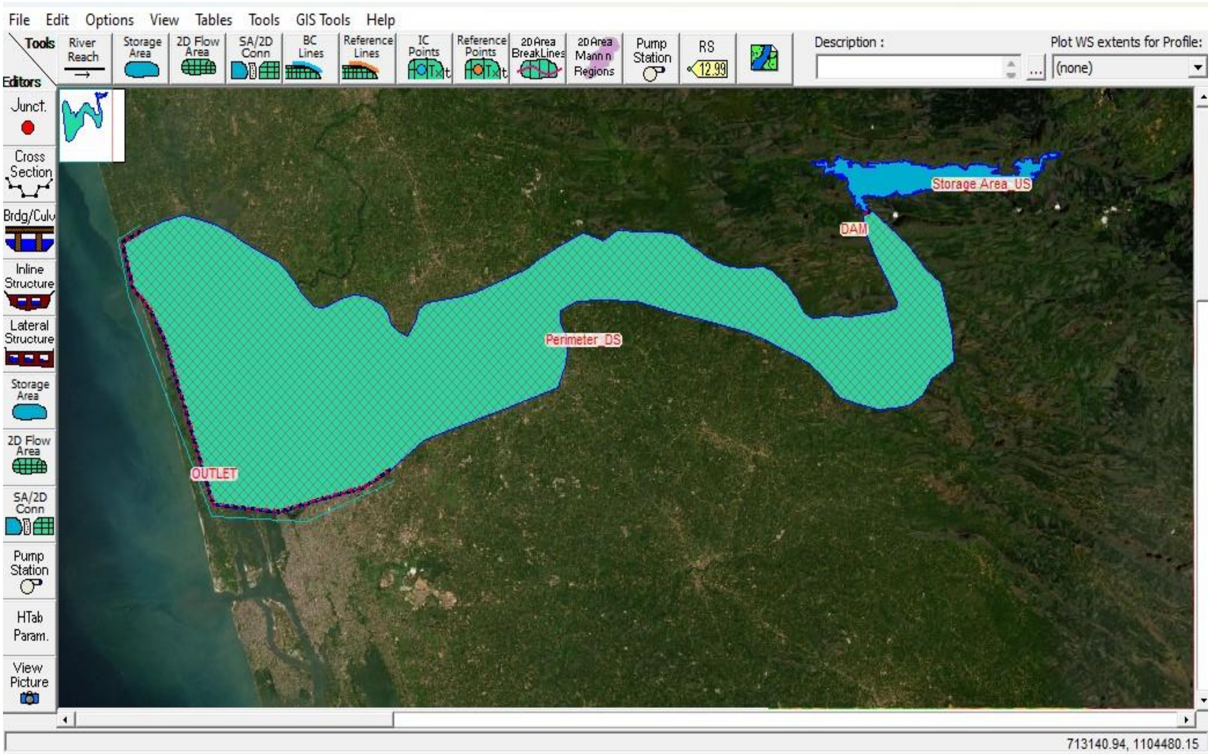


Fig 4.13 Geometric data of Idamalayar dam

Table 4.8 Storage capacity of Idamalayar dam

Elevation	Volume (m^3)
147.576	38993.76
149.693	93652.77
152.238	161014.7
155.169	239955
167.723	585549.2
172.74	725243.1

The dam induced flood analysis were performed using the same parameters for dam breach analysis. The breach geometry is used for the analysis. Dynamic Breach geometry (breach depth and width, breach side slope factor, timing (breach initial time, breach formation time, etc). The dam induced flood can be calculated by using unsteady flow analysis. Once entered all of the geometry and unsteady flow data, unsteady flow calculations are performed. The Centre station and Final bottom elevation were taken from graph. The top of dam elevation is calculated by adding the height of the dam with Breach bottom elevation (which is taken from the graph). Pool elevation at failure is the storage capacity of the dam in m^3. Pool elevation at failure is calculated by adding the breach bottom elevation with breach height. The equation developed by the Froehlich (2008) were used in this dam induced flood map analysis (Fig 4.14).

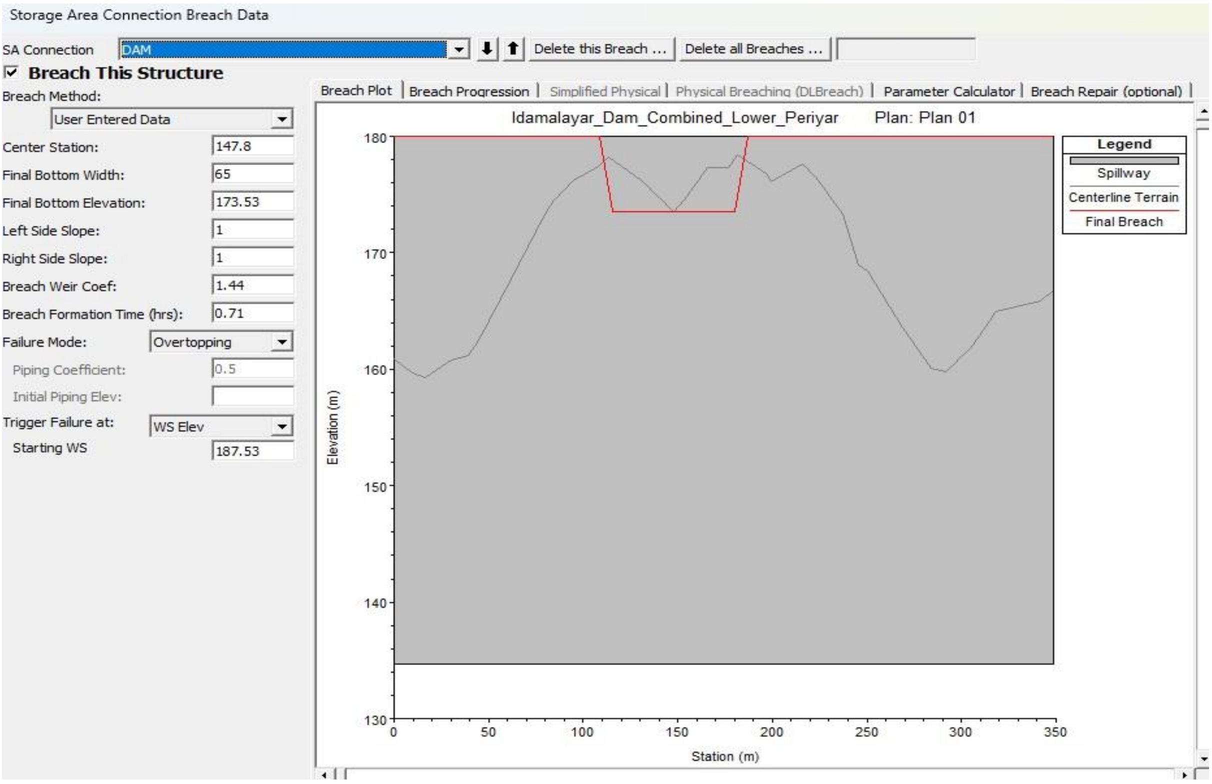


Fig 4.14 Storage area connection of Idamalayar dam

Unsteady flow simulation is carried out for dam induced flood study. Hydrograph output interval taken as 30 minutes and computation interval were taken as 30 second. The result obtained from the dam induced flood study combines of depth, velocity and water surface elevation maps (Fig 4.15, 4.16, 4.17).

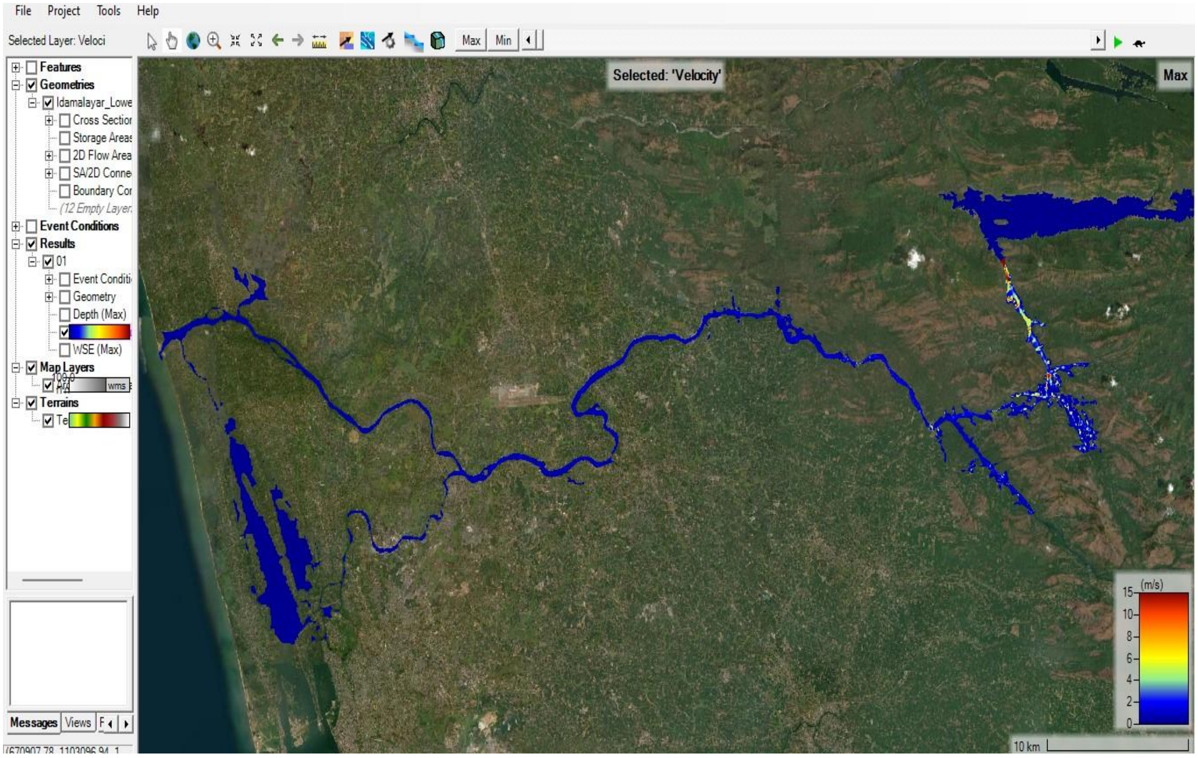


Fig 4.15 Flood inundation map showing Velocity

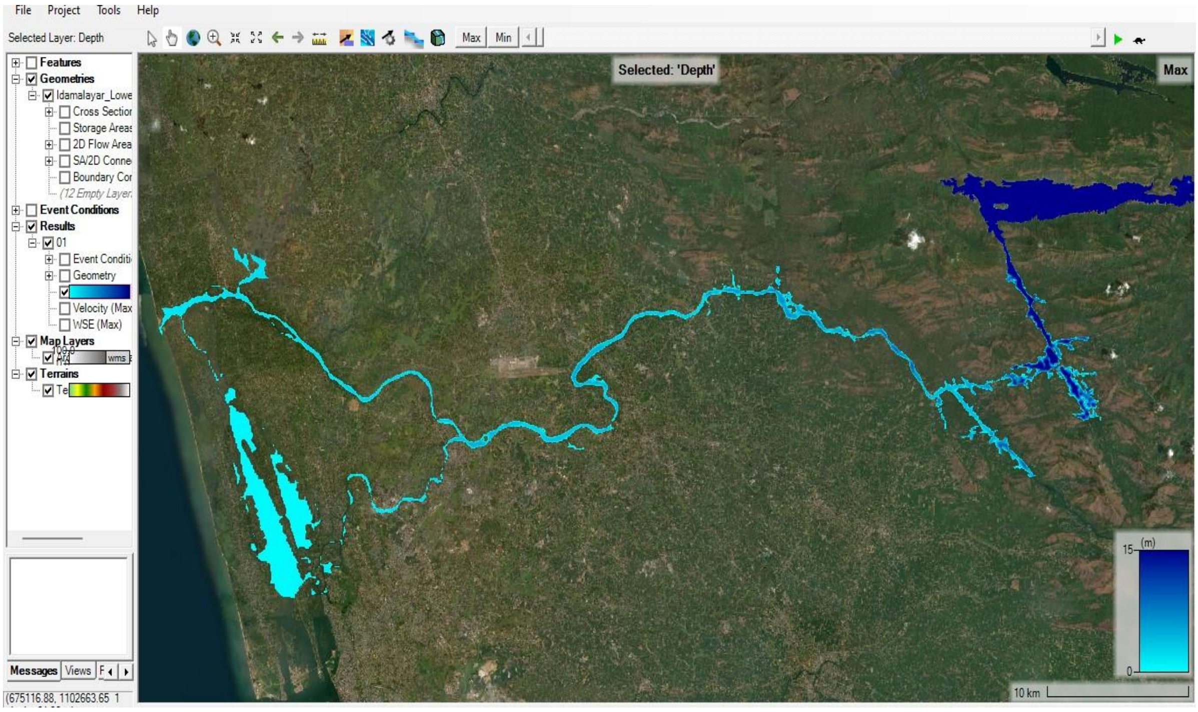


Fig 4.16 Flood Inundation map showing depth

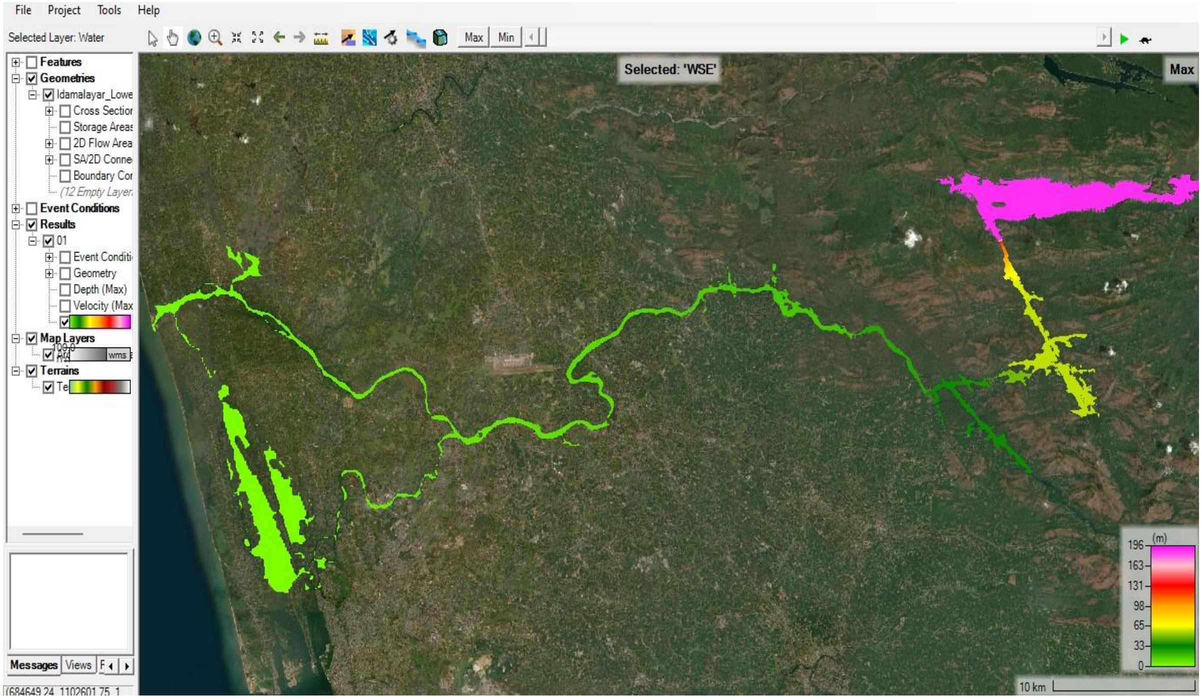
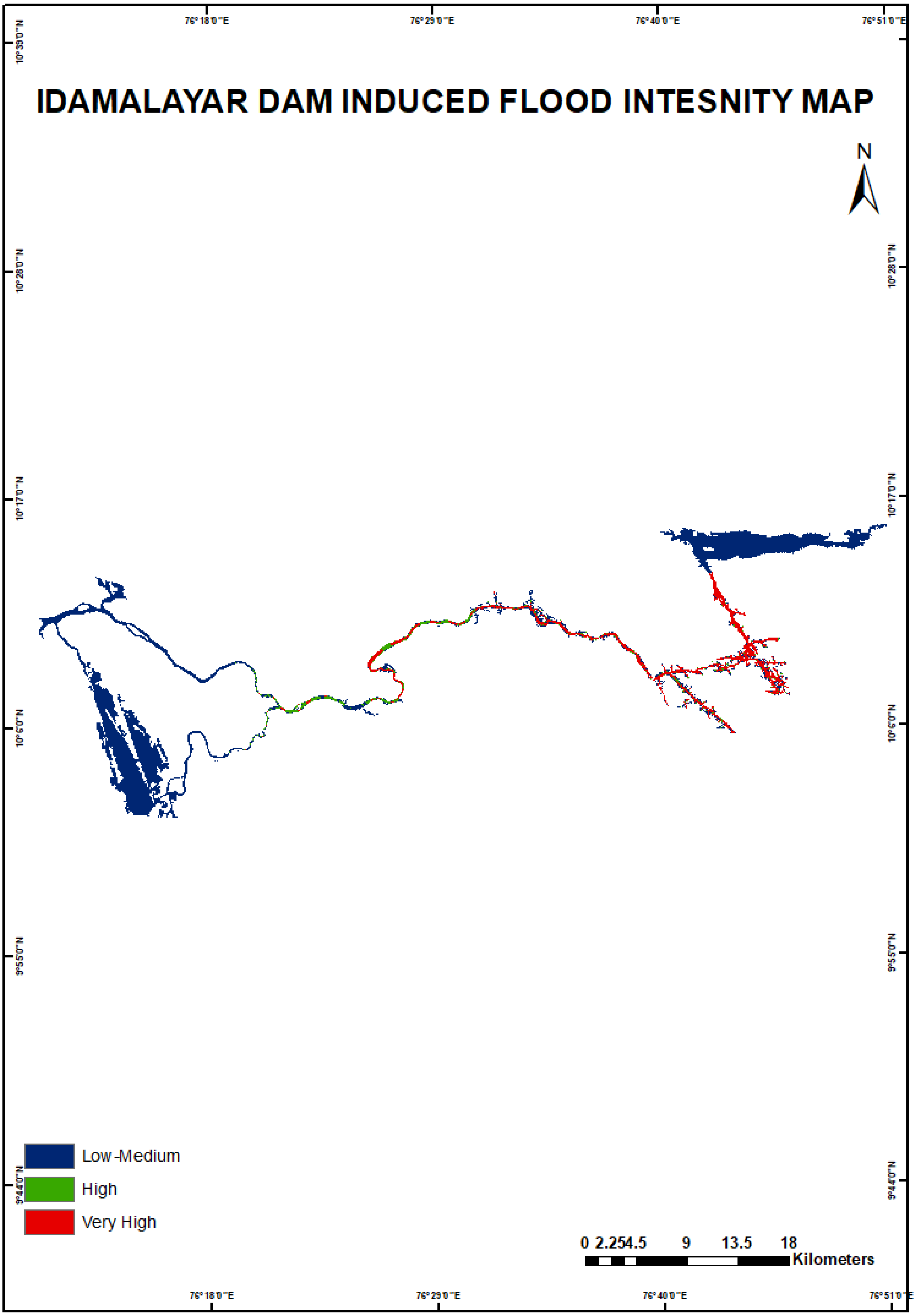


Fig 4.17 Flood inundation map showing Water surface elevation

Present study suggests that due to opening of Idamalayar reservoir the areas such as Makarachal, Vadattupara, Government LPS School Kuttampuzha, Anakkayam Kadathu has prone to severe flood risk. Majority of the areas in Kuttampuzha are prone to flooding. The areas such as Njayapilly, Thattekad areas, Bhoothathankettu park, Thodakayam, Alattuchira areas, Kodanad, Cheranalloor, Chelamattom areas, Kizhakkumbhagom, South vallom, Mudickal, Marampally, Thekkumbhagam, Kuttamassery, Aluva East, Aluva areas, Edayar, Mathrupalli, Edampaadam, Moolampilly, Chathedam,Puthenvilkara, Elenthikara, Manjali, Thalakolly, Pulikkappuram, Murickal, Kadamakkudy, Paravur, Kedamangalam, Chakkarakadavu, Pattanam, Munambam, are prone to flood risk.


IDAMALAYAR DAM INDUCED FLOOD INTESNITY MAP
N
Low-Medium
High
Very High
0 2.25 4.5 9 13.5 18
Kilometers
76°18'0"E
76°29'0"E
76°40'0"E
76°51'0"E
10°39'0"N
10°28'0"N
10°17'0"N
10°6'0"N
9°55'0"N
9°44'0"N

Idamalayar Dam Induced Flood Intensity map

Based on the present study Idamalayar dam induced flood intensity zones of the study area can be classified into three categories- Low-Medium, High, very high zones indicated in the map. About 90.16947 ha (78 %) falls in Low – Medium intensity zone, 6.102715 ha (5%) in high intensity zone and 18.94473 ha (17%) area falls in Very high Intensity zones. (Table 4.9, Fig.4.18)

Table 4.9 Geographical area of Flood Intensity Zone

Flood Intensity Zones	Area	
	Ha	Percentage (%)
Low-Medium	90.16947	78 %
High	6.102715	5 %
Very High	18.94473	17 %

2D Dam Break Study of Mullaperiyar Dam Using HEC-RAS

More than 60% of the Mullaperiyar dam's capacity is made up of lime surkhi concrete hearting, together with downstream masonry made of rubble, an unrouted open joint, and a 10 m concrete backing. There are minor saddles on either side of the main valley; the one on the left was blocked by a Baby Dam of the same type, which is connected to the high land by an Earthen Dam and measures 73.15 m (240 feet) in length and 16.15 m (53 feet) in height. The spillway's crest level is 867041 metres

The geometric data is created using creation of 2D flow area boundary and storage area boundary, the geometric data obtained (Fig 4.3.1). The storage capacity of Mullaperiyar dam is given in the table (Table 4.3.2).

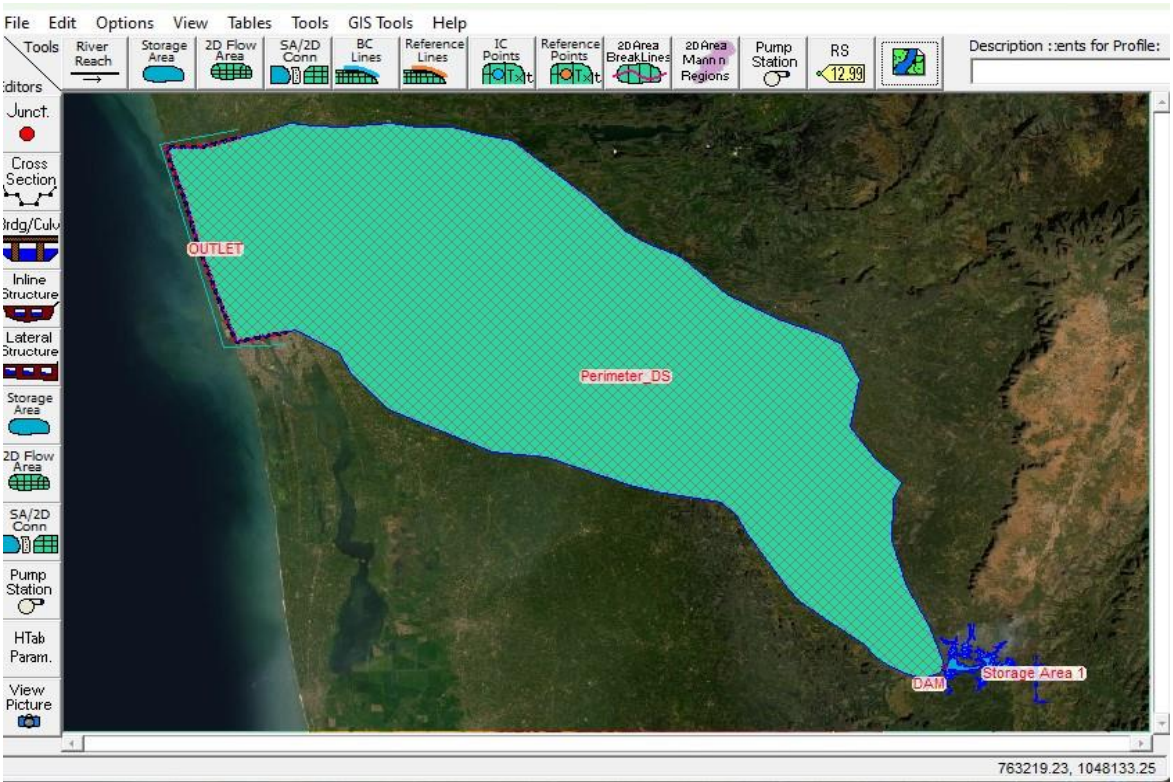


Fig 4.3.1 Geometric data of Mullaperiyar dam

Table 4.3.2 Storage capacity of Mullaperiyar dam

Elevation	Volume (m^3)
861.182	6292.547
861.705	6862.354
862.156	7377.791
862.787	8135.505
865.213	11505.49
869.994	20550.3

The dam break analysis was performed using the parameters for simulating the dam breach analysis. The breach geometry is used for the analysis. Dynamic Breach geometry (breach depth and width, breach side slope factor, timing (breach initial time, breach formation time, etc). The dam break analysis can be calculated by using unsteady flow analysis. Once entered all of the geometry and unsteady flow data, unsteady flow calculations are performed. The Centre station and Final bottom elevation were taken from graph. The top of dam elevation is calculated by adding the height of the dam with Breach bottom elevation (which is taken from the graph). Pool elevation at failure is the storage capacity of the dam in m^3. Pool elevation at failure is calculated by adding the breach bottom elevation with breach height. The overtopping failure mode is taken for the study. The equation developed by the Froehlich (2008), were used in the study (Fig 4.3.2)

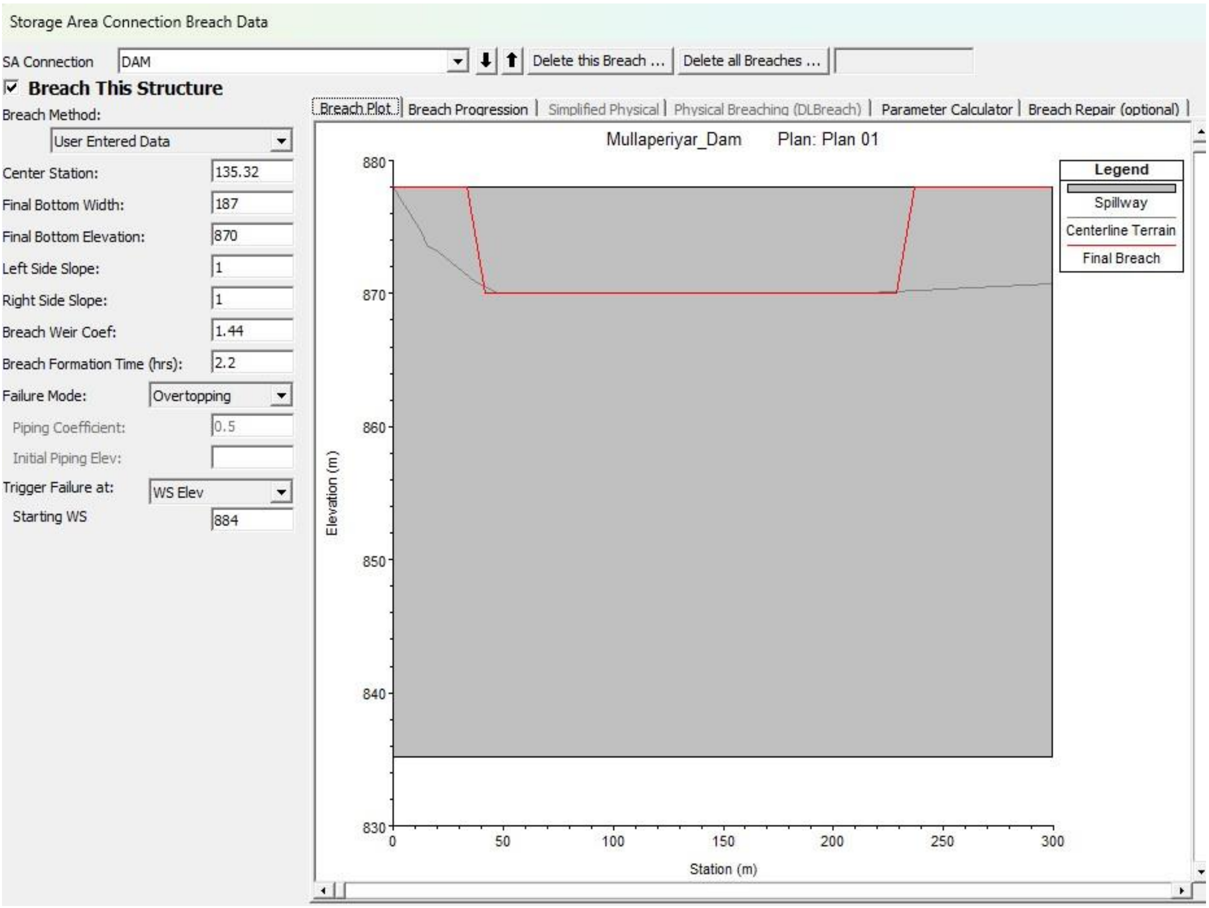


Fig 4.3.2 Storage area connection breach data

K. R. Baiju, Karunakaran Akhildev, Joice K. Joseph, Naveen Babu, Anithomas Idiculla, Asha Rose, Shibu K. Mani, Mahesh Mohan, and A. P. Pradeepkumar. (2023). Proceedings Volume of the 5th International Disaster, Risk and Vulnerability Conference (DRVC) January 19th – 21st, 2023. School of Environmental Sciences, Mahatma Gandhi University, Kottayam, Kerala, India – 686560. p- 1 to 447

Unsteady flow simulation is carried out for dam induced flood study. Hydrograph output interval taken as 30 seconds and computation interval were taken as 10 second. The result obtained from the dam induced flood study combines of depth, velocity and water surface elevation maps (Fig 4.3.3, 4.3.4, 4.3.5).

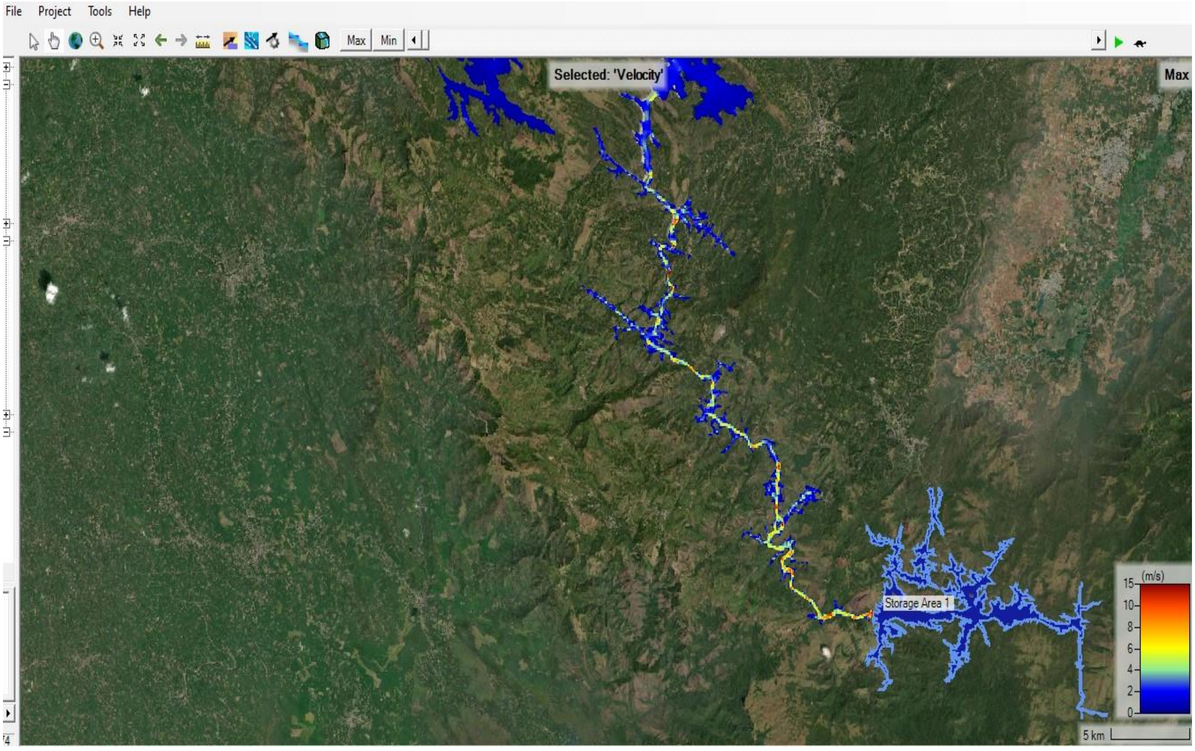


Fig 4.3.3 Mullaperiyar dam break with respect to velocity

Figure 4.3.4 shows Idukki dam and Malankara dam break followed by Mullaperiyar dam break

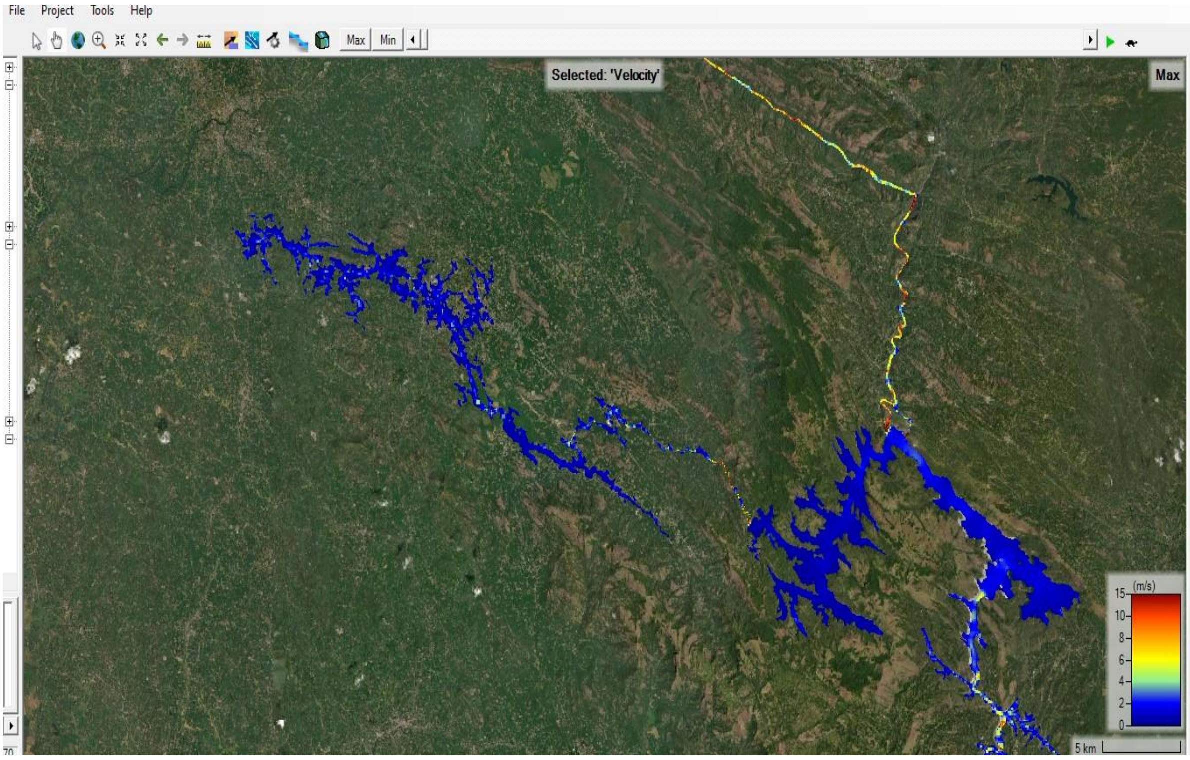


Fig 4.3.4 Idukki and Malankara dam break with respect to velocity

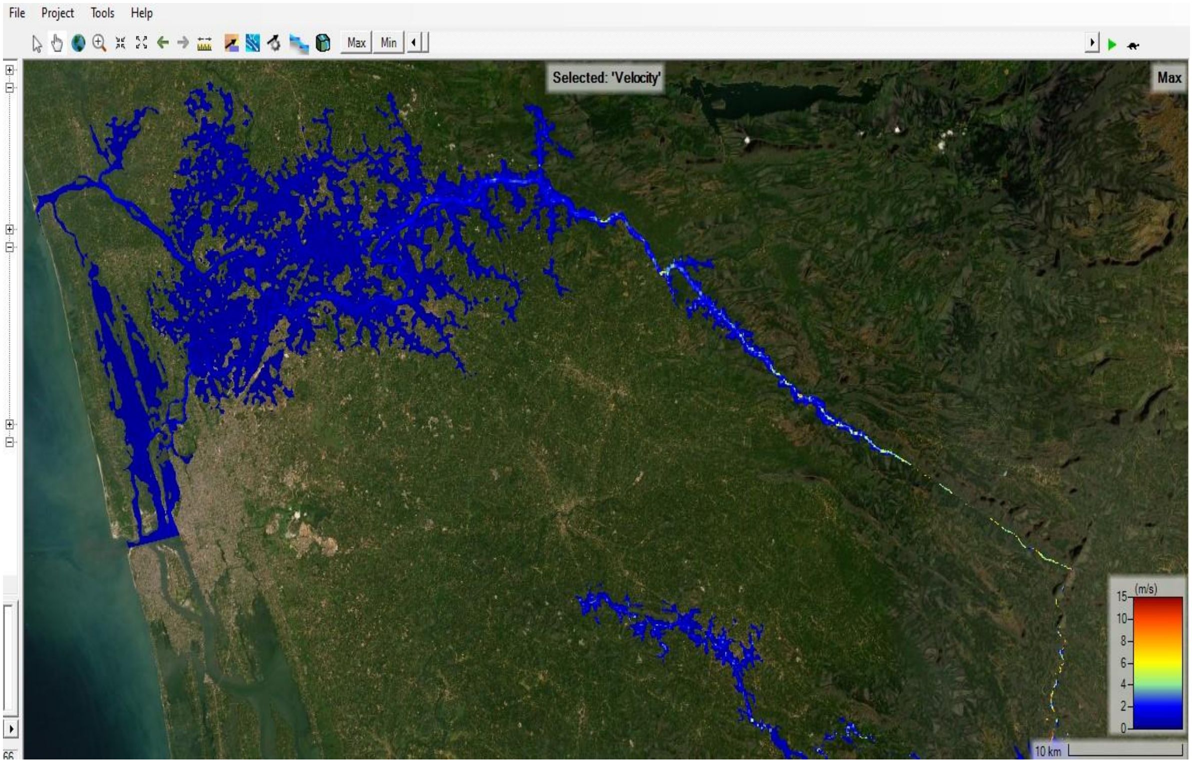


Fig 4.3.5 Flood inundation map by consequent dam break

According to the current study, Mullaperiyar Dam's failure causes the Periyar River to overflow its channels, flooding most of the areas. The areas such as Vandiperiyar, Keerikara, Karintharuvi, Alady, Upputhara, Ayyappankovil, Marykulam, Kozhimala and reaches Idukki dam storage area. Followed by the breakage of Kulamavu dam, Cheruthoni dam and Idukki arch dam. Water from the Kulamavu dam travels past towns like Naliyani, Pannimattom, Anakkayam, and Kolapra before arriving at the storage area of the Malankara dam. Later causes the Malankara dam to break. Water from the Malankara Dam that has broken its seal floods through Keerikode, Thodupuzha, Muthalakodam,Kadalikad, Manakkad, Arikuzha, Thekkumala, Manjallor and Arakuzha areas.

Following the collapse of the Cheruthoni and Idukki arch dam, the water first enters the town of Cheruthoni at a speed of 10.16 metres per second. and passes through Karimban and Thadiyampad before joining the Periyar River. Later, with a speed of 12.50 m/s, it reaches the Lower Periyar dam. As a result, the Lower Periyar dam breaks, causing water to rush through high-risk flood zones such Neendapara, Chembankuzhi, Maniyanpara, Neriamangalam, Thattekad, and Kalappara before reaching Bhoothathankettu Dam at a speed of 7.94 metres per second.As a result, the Bhoothathankettu dam breaks, causing water to spill into places like Thodakayam, Paniyeli, Kombanad, Alattuchira, Vadakkambilly, Kodanad, Perumbavoor, Angamali, Nedumbassery, Cochin International Airport, and the majority of Ernakulam neighbourhoods, which are vulnerable to severe flooding. According to the study, the Ernakulam district is experiencing severe floods in its vast majority. Mala, Kodungallur, Annamanada, and Alathur are some locations in Thrissur that are particularly vulnerable to catastrophic flooding brought on by dam failure.

CONCLUSION

The purpose of the study was to outline the Periyar river basin's dam-induced flood mapping. The study based on opening of dams which includes Idukki, Ponmudi, Madupetty, and Idamalayar dams suggests that downstream areas are more vulnerable to severe flooding when the dams are opened.

Dam breach analysis of Mullaperiyar dam suggest that dam's failure causes the Periyar River to overflow its channels, flooding most of the areas. When the Mullaperiyar dam fails, water flows via places like Vandiperiyar, Karintharuvi, Upputhara, Ayyapankovil, Kozhimala, and reaches Idukki Dam. Later causes the failure of the Cheruthoni, Idukki, and Kulamavu dams. Water from Kulamavu dam reaches Malankara dam and causes Malankara dam to break. Water from Cheruthoni, Idukki arch dam flows through Cheruthoni town and reaches Lower Periyar dam and causes to breakage of Lower Periyar dam. Consequently, water began to surge through Bhoothathankettu Dam, leading to the dam's failure. As a result, water spills into the Ernakulam district, which is frequently devastated by floods. Some areas of Thrissur, such as Mala, Kodungallur, Annamanada, and Alathur, may also be subject to severe floods.

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FRAMEWORK FOR CLIMATE RESILIENCE DEVELOPMENT OF PERI-URBAN AREA: A CASE OF KERALA

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Abstract:

Climate change is projected to have a detrimental impact on planned development outcomes in many countries, with potential consequences for livelihoods and ecosystems that could be difficult to overcome. Action on climate change and development processes are inextricably linked. Climate change is the backdrop against which development is taking place. To sustain development initiatives over time in a changing climate, decisions and actions must be taken that limit emissions of greenhouse gases (GHGs) and adapt to their effects like unpredictable weather, such as flash floods and droughts, as well as an increase in sea level.

This paper aims to derive suitable approaches for climate resilient development (CRD) of peri-urban areas in the context of Kerala. The objectives are 1) critically reviewing the adaptable pathways for climate resilient development already realised in some selected regions. and 2) assessing the opportunities and challenges of CRD in the peri-urban region in terms of spatialdevelopment.

The analysis of case studies indicated the need to emphasis a sectoral approach. The sectors prioritized are water resources, Agriculture, health, Forest and biodiversity and energy.

The review of developmental challenges in the peri-urban regions of Trivandrum, Kochi and Kozhikode revealed the major challenges in adopting the pathways of CRD as recommended elsewhere. These challenges are broadly indicative of development challenges, Environmentalchallenges and climate challenges.

In this background, the study recommends Integrated Water Resource Management as a suitable strategy for CRD in peri-urban context of Kerala. The suggested framework encompasses the threats, challenges and driving factors of the peri-urban regions and approaches that can be used in CRD.

Keywords:

Climate change, Climate-resilient development, Climate-resilient development pathways Adaptation, Mitigation.

INTRODUCTION

Considering climate change can improve the sustainability of benefits offered by development strategies, programs, and initiatives and bring alternate solution development approaches to light. Climate change poses risks to achieving several development goals, such as the availability of sufficient clean water the possibility to come to development issues from a novel perspective, including threats from current climate change.

Climate Resilience is a key focus of the Intergovernmental Panel on Climate Change (IPCC). It involves reducing exposure and vulnerability to climate hazards, reducing greenhouse gas emissions, and conserving biodiversity. These goals are incorporated into decision-making and policy-making across all aspects of society, including energy, industry, health, water, food, urban development, housing, and transport. (Overarching Frequently Asked Questions and Answers, 2022)

The definition by USAID says that climate-resilient development is essential to enabling people, communities, businesses, and other organizations to respond to current climate variability and prepare for future climate change, while maintaining development progress and reducing potential damages.

CRD Identifies climate stressors, utilizes appropriate climate information, and Reduces vulnerability to climate stressors. It also Promotes flexibility and validity, making CRD different from the conventional method.

Research has found that the processes of urbanization and climate change mitigation are closely intertwined. The global community is increasingly recognizing the importance of taking action to address climate change. Peri-urban areas can make a significant contribution to urban sustainability at the global level. Urbanization continues to proliferate, and peri-urban areas are typically characterized by low-density development. To help contain urban sprawl, it is essential to create a plan for managed, organic growth in the peri-urban areas. In light of this, research must further explore the possibilities of controlled organic growth in order to identify effective strategies for mitigating climate change in urban areas.

In recent years, Kerala has been affected by extreme weather conditions such as heavy rainfall, floods, and landslides, highlighting the state's vulnerability to climate change and necessitating a coordinated response to address its associated risks. This has posed a set of challenges that require sustained effort to mitigate and manage. The state is facing growing challenges due to climate-related disasters, requiring sustained focus and action to address them. This study aims to derive suitable approaches for climate resilient development (CRD) of peri-urban areas in the context of Kerala.

The paper has been structured into the following sections. The first section of the study discusses critically reviewing the adaptable pathways for climate-resilient development in any region. The second section focuses on assessing the opportunities and challenges in the peri-urban region in terms of spatial development, with a particular emphasis on CRD. The last part concludes by proposing suitable approaches for climate resilient development (CRD) in peri-urban areas of Kerala. The analysis of case studies indicated the need to emphasis a sectoral approach. The sectors prioritized are water resources, Agriculture, health, Forest and biodiversity and energy.

MATERIAL &METHODOLOGY

The study was conducted using qualitative content analysis of relevant literature. This research provides an analysis of climate-resilient pathways in different parts of the world, the potential and challenges in implementing CRD pathways, and recommends Integrated

Water Resource Management as a suitable strategy for CRD in the peri-urban context of Kerala and the framework encompasses the threats, challenges and driving factors of the peri-urban regions, as well as approaches that can be used in CRD. A flowchart showing the study methodology is shown in figure (1).

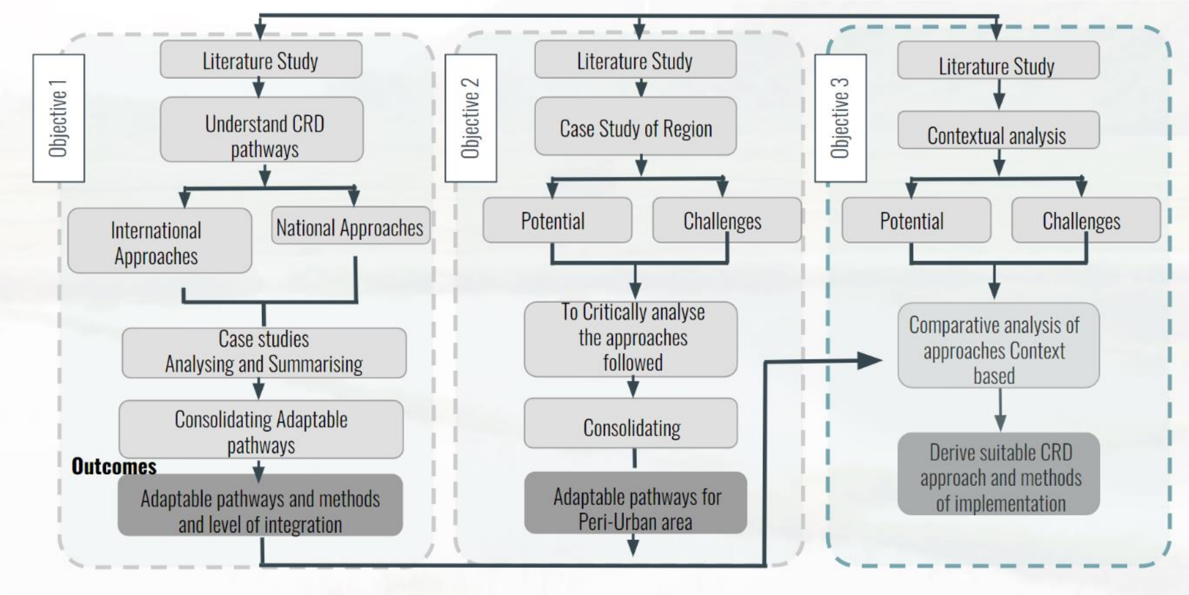

Figure 1: Methodology flowchart

BACKGROUND STUDY

To sustain developmental efforts over a period in a changing climate, decisions and actions must be taken that limit emissions of greenhouse gases and adapt to their effects. This is especially relevant given the complex interactions between climate change and development. By hindering the capacity to adapt and mitigate, development processes might increase vulnerabilities to climate impacts. The flowchart in figure (2) Explains why we need to pay attention to climate change. Urban development, health, agriculture, and many other fields will be impacted by climate change. Existing non-climate stresses including deforestation, migration, population increase, and rising water demands may be made worse by these climate changes. These effects of climate change can risk efforts to achieve development objectives like economic growth, reduction of poverty, enhancing access to education, improving child health, battling disease, and protecting the environment. Climate change adaptation efforts should be based on these development objectives. When deciding which activities to incorporate into a development strategy, climatic stressors need to be recognised and evaluated in order to make the most significant use of the limited resources available to facilitate growth over the long term. This paradigm makes it easier to incorporate climate factors into development planning and execution.

Current climatic stressors, drought, flooding, and cyclones, make many development programs susceptible. These vulnerabilities might already be increasing due to climate change, and they might continue to increase in the future.

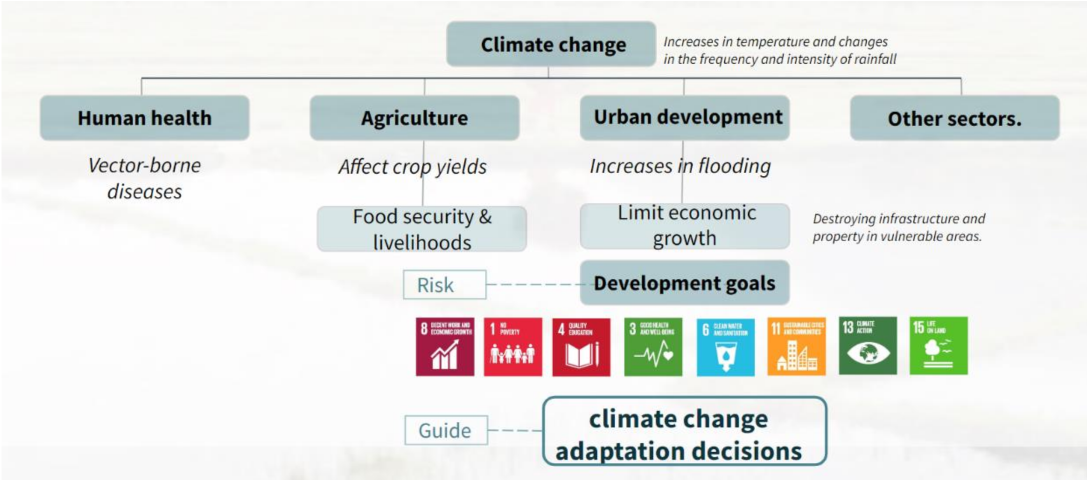

Figure 2: Flowchart representing the importance of CRD consideration in planning (Source: Prepared by Author)

REVIEW LITERATURE

Climate Resilient Development Pathways

To critically review Adaptable pathways for climate resilient development, International and National approaches have been identified; case studies were studied to substantiate the standard methods taken.

First, tried to understand what the climate resilient pathway is. Climate-resilient pathways are increasingly becoming a focus of climate change policy due to their potential to mitigate the effects of the climate change and to promote sustainable development. Climate-resilient pathways involve strategies, choices and actions that reduce climate change and its impacts while ensuring that risk management and adaptation are implemented and sustained. In its fifth assessment report, the Intergovernmental Panel on Climate Change (IPCC) defines climate-resilient pathways as "development trajectories that combine adaptation and mitigation to realize the goal of sustainable development"(Denton et al. n.d.). This shift in climate policy, away from a focus on defending against and coping with climate impacts to a narrative of opportunity and change, is changing the orientation of development towards growth. The domains of climate resilient development pathways identified from the review of succeeding literature are Climate-first approach, Mainstream oriented, Social learning and participation oriented, Transformation oriented, Multi-level governance and policy cycles, climate action-oriented, sector-level approaches, Financial management and instruments, monitoring, evaluation and learning(MEL), Spatial planning scales and climate proofing approach.

The two main categories of CRD pathways are Adaptation and Mitigation. Adaptive and mitigating strategies must be considered when creating climate-resilient development pathways. Adaptation strategies typically involve a single set of actions that may have limited effects. These strategies are meant to handle current and future climate change. When the challenges become severe, adaptation limitations and the risks of irreversible damage reduce the possibilities of constructing resilient pathways. In contrast, mitigation strategies involve actions that may have adverse outcomes. Mitigation works to mitigate future climate risks and is essential for creating pathways that can withstand climate change.(Lera and Clair n.d.)

In order to effectively manage climate risks at all scales, it is essential to integrate mitigation and adaptation responses. This integration can positively affect sustainable development but must be thoroughly analyzed to ensure that the chosen response does not have any negative consequences. Depending on the context, one may take precedence over the other; however, neither should be excluded entirely. (Lera and Clair n.d.)

Now the section looks into the standards of CRD Pathway domains suggested by National and international standards. The IPCC's fifth assessment report has identified four distinct clusters of approaches to climate-resilient pathways, which are deemed to offer development trajectories towards sustainable development by way of adaptation and mitigation. These include climate action-oriented pathways, social-learning and co-creation-oriented pathways, mainstreaming-oriented pathways and transformation-oriented pathways. It is recommended that climate resilient development pathways be seen as the integration of climate action and development decisions for long-term sustainability, keeping in mind issues such as justice and equity to deal with the associated trade-offs. (Werners et al. 2021a)

The OECD (Organization for Economic Co-operation & Development) has collaborated between its Development Co-operation Directorate (DCD) and Environment Directorate (ENV) to develop guidance on how governments and development co-operation can work together to strengthen climate resilience. This guidance provides an overview of different approaches and practices that can be taken to enhance climate resilience. Literature showcased four main approaches to developing climate resilience: multi-level governance and policy cycles, sector-level approaches, financial management and instruments, and monitoring, evaluation, and learning (MEL). (a) multi-level governance and policy cycles foster collaboration between governance levels, while (b) Sector-level approaches involve assessing climate risks and integrating them into investment plans. (c) Financial management and instruments involve securing financial needs and selecting suitable instruments. Finally, (d) Monitoring, evaluation and learning (MEL): requires developing indicators and conducting portfolio and allocation evaluations. Overall, developing an effective climate resilience strategy requires tailoring MEL frameworks to a variety of contexts.

Paper Titled “A framework for mainstreaming climate resilience into development planning”, the The IIED Working paper outlined three general policy responses to integrate climate resilience into development planning, which all have different entry points. (a)The climate-proofing approach is a valid strategy for countries that prefer a project-based approach to development planning, as it seeks to protect existing projects from the impacts of climate change by increasing the capacity to cope with, and recover from, existing climate variability. This approach also serves to streamline integration into current country precedence and capacity. b) In order to prepare society for increased variability and more frequent and severe extremes, a climate-first approach addresses existing climate-related risks by increasing the ability to cope with such changes, (c) Development-first approach: Climate resilience must be incorporated into the planning stages of development to ensure that developmental outcomes are resilient to climate change. Policymakers must prioritize making development planning processes resilient to climate change.(Pervin et al. 2013a)

The International Institute for Environment and Development (IIED) suggests that in order to effectively implement climate resilience, it must be integrated into three essential dimensions of the development systems: development policy objectives, spatial planning scales, and temporal planning scales. (a) Development policy objectives: In order to promote sustainable growth, it is necessary to factor in climate resilience when planning development strategies. This requires people to have access to economic, ecological and social resources, infrastructure, and governance to successfully adapt to the impacts of climate change. (b) Spatial planning scales:

It is important to include local adaptation plans in national adaptation plans as local plans are tailored to the unique needs of an area and are more capable of responding to the region's conditions. (c) Temporal planning scales: Adaptation needs to be incorporated into the development planning process, which includes the annual, five-year, and ten-year plans and mid-term expenditure frameworks. (Pervin et al. 2013)

Climate Resilient Development Pathways in Global Drylands suggest two main CRD approaches: (a) Development-first approach requires climate information that will increase understanding of priority sectors or regions and lead to more informed planning and decision-making. Long-term climate information is relevant to particular, but not all activities–decisions around agriculture occur on shorter timescales than infrastructure. Specific steps are integrated into the current project cycle or planning process to mainstream climate considerations into development planning. (b) Adaptation approach: focused at the project level. Opportunity to fill a gap with guidance at the project level; and second, there was very little dedicated funding for adaptation, so adaptation work would have to be incorporated into other development projects. Sustain losses, cope, share failures, reduce the impact, defend, armor, protect, relocate, research, protect and restore natural and semi-natural ecosystems. Reduce deforestation, reduce habitat fragmentation, encourage natural regeneration, and restore fragmented habitats.

The section further discusses the case study that substantiates the CRD pathways global level. Six case study regions were selected (a) Nepal, (b)Bangladesh, (c) Cambodia, (d) Jamaica, (e) Ethiopia and (f) Argentina to see the National level approaches that have been applied in the regions.

In Nepal, with immense cultural and geographical richness and diversity, we could find that the approach selected were multi-level governance and policy cycles, Sector-level approaches, financial management and instrument, MEL Pathways, and Making the Region a special economic zone, Training agricultural technicians, capacity building and economic empowerment highlighting the marginality and social exclusion, Measuring Climate data information.(Pandey, Prakash, and Werners 2021)

Bangladesh with a strong track record of growth and development. Sector-level approaches - Agriculture: Adaptation approaches. Re-excavating traditional ponds, canal, Water control structures, Mini-ponds, Supplemental irrigation, Drought-resistant rice varieties, Homestead gardens, and intercropping are the strategies they followed to strengthen climate resilience.

Cambodia is known for its economic stability & growth, manufacturing & agricultural commodities exports. Monitoring and Evaluation (M&E) framework adaptation intervention that aims to improve the productivity of smallholder farmers, Climate proof roads were the actions they take towards climate resilience.(Selvaraju et al. 2007)

In Jamaica, a nation heavily dependent on its service sector, a strategy of Adaptation & Mitigation was chosen as the primary approach to climate resilient development. The pathways implemented were the Forest Management and Conservation Plan, the Strategic Forest Management Plan, and a Security of Energy Supply - diversification of fuels, renewable energy sources Study Area. (Climate Change Policy Framework for Jamaica Government of Jamaica n.d.)

In Ethiopia, a country where Agricultural goods and services, Fast economic growth with a decrease in poverty rates. The approaches chosen by the government are financial management and instruments -climate change-related investments, Local development planning. They used Track climate and disaster-related spending and institutionalised local climate-resilient development planning as pathways to tackle the climatic challenges.(OVERVIEW IIED Climate Change Group Project name: Building resilience in Ethiopia: climate-resilient development planning and budgeting Budget 2020)

Argentina is the one of the largest economies in Latin America, Service oriented. An adaptation plan approach was used to tackle the climatic challenges. Running the decentralized districts, managing the health service or maintaining green areas and the solid waste collection were the adaptive pathways used.(Chettry 2022; Hardoy and Ruete 2013)

Finally, tried to conclude the review of adaptable pathways by summing up all the strategies/actions/guidelines or interventions used in the pathways mentioned above. For successful Climate resilient planning (CRD), the region may have to follow a combination of approaches instead of looking for specific ones. Thus we mapped all the focus areas of implemented actions/ approaches highlighted in all these approaches identified above. Fig 1 explains the main highlighted points in practices and the Main domains that can be followed.

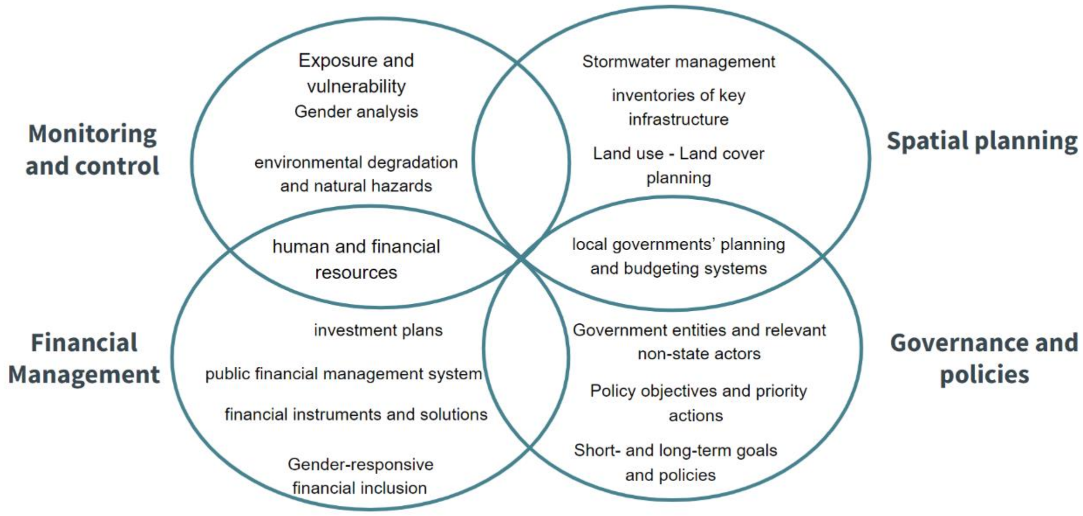

Figure 3: Highlighted actioned from analysis of pathways

level approaches, Establishing linkages between national climate goals and sector-specific policies on climate resilience, Assessing the climate risks to a sector, and reflecting them in the development plans, Integrate into sector investment plans; (b) Multi-level governance and policy cycles, Build inclusive governance arrangements for climate resilience, Empower local action by facilitating collaboration across levels of governance, Enhance governance for greater coherence across different development agendas; (c) Monitoring, evaluation and learning (MEL), Develop indicators consistent with human and financial capacities that can inform monitoring and evaluation, Conduct climate resilience portfolio and allocation. (d) Financial management and instruments: Identify necessary action on climate resilience and assess associated financial needs. Integrate climate resilience into public financial management. Select and combine financial tools for managing climate risks.

The second section of this literature review focuses on identifying and evaluating the potentials and challenges in peri-urban regions in spatial development, with a special focus on CRD. The regions were taken to compare challenges and potentials that hinder the CRD.

Context of Nepal Climate change hotspot, poverty-ridden region. The observed impacts in the area of water resources, agriculture, and forest and biodiversity sectors. The main challenges and potential concerning the context are development challenges including those arising from reconstruction in the aftermath of natural disasters and social-awareness-related issues such as sanitation and hygiene. The analysis identified that the Adaptation measure considers the socio-vulnerable group.(Pandey, Prakash, and Werners 2021; Rai et al. n.d.)

Context of Bangladesh Agriculture is the largest sector of the economy. Agricultural production is under pressure from increasing demands for the food area. The main challenges and potential concerning the context are livelihood adaptation to climate variability, change in drought-prone regions, and over-exploitation of groundwater to support irrigation in the dry months. From the analysis, it is identified that adaptation measures for climate change impact considering the significant economic sectors.(Selvaraju et al. 2007)

In Cambodia, on average, four percent of Cambodia's roads were damaged by floods. The main challenges and potential with respect to the context are high flood intensity, being highly vulnerable to flood impacts and having quite a high number of families affected by floods. From the analysis, it is identified that long timescales associated with climate change and adaptation, attributing the outcomes of adaptation to specific actions, interventions or policies, and shifting baseline conditions of climate change over time, make it challenging to interpret adaptation results.

In Jamaica, poverty, human settlement in high-risk areas, environmental degradation, and inadequate infrastructure and housing were the main focuses. The main issues confronting this context were high poverty levels, limited financial resources, absence of legislative and regulatory support for incorporating climate change into policies and plans, and low labor productivity. The evaluation suggests that climate change adaptation and mitigation should be taken into account in all government ministries, departments, and agencies' legislation, policies, strategies, programs, plans, and projects.

In Context of Ethiopia Highly exposed to recurring crises, including escalating climate change impacts, which affect economic development, livelihoods and food security. The main challenges and potential with respect to the context are Introducing new methodologies into national and local government processes takes time. Improved estimates of domestic contribution would also help to make a case for additional funding from external sources. The analysis identified a comprehensive, multi-sector risk assessment-based local development planning system could be implemented to improve the communities resilience to climate change. In addition, additional budgeting resources should be allocated to new ministries.

Argentina's National economic stability and international conditions favored the agricultural sector. Increased public funds and a boost in business activity and construction brought economic mobility. The main challenges and potential with respect to the context are city is still struggling to complete greenhouse gas inventories. For local authorities, adaptation to climate change has been a much more diffuse issue than mitigation. The analysis identified that the mechanisms for local governments to access international funding are complex.

From the analysis above, it is identified that most countries are moving towards sector-level approaches, and the most suitable approach identified is the Sector-level approaches. The major sectors that can be considered are Water Resources, Agriculture, Health, Forest and Biodiversity, Energy, Urban front and transport and Infrastructure.

The third section of this literature review of developmental challenges in the peri-urban regions of Trivandrum, Kochi and Kozhikode revealed the major challenges in adopting the pathways of CRD as recommended elsewhere. These challenges are broadly indicative of development challenges, Environmental challenges and climate challenges.

Peri-urban areas are characterized by a mix of urban and rural features and are rapidly changing due to human activities. They are located outside of municipal areas and serve as a point of contact between urban and rural areas. These areas have ambiguous governance and are in a state of transition.

Peri-urban ecosystems provide essential services such as carbon sequestration, climate regulation, water and air purification, and pest and disease control. However, urban waste is damaging these areas by polluting rivers, depleting freshwater resources, and introducing climate change-related challenges such as changes in farming systems and labor participation.

Three case studies were done to discuss the potential and challenges in the peri-urban area.

The case studies were selected from the surrounding area of the most populated corporation area from the north, south and center parts of Kerala.

In the Trivandrum peri-urban area of southern Kerala, the spatial boundary has grown by 112% in the span of a decade. This area is a well-known hub for education and research and is also turning into a major center for IT development. The development challenges faced include a 21% decrease in non-built-up areas, as well as an increase in the real estate market and the establishment of service sector industries. The identified environmental challenges in the area have resulted in significant alterations to the natural landscape and have caused harm to the local environment. Those living in low-lying and wetland areas are particularly affected. The agriculture vulnerability index is high due to the low percentage of collective farming, insufficient net irrigated area, variation in soil moisture, minimal storage facilities and a number of primary agriculture credit societies. Nonetheless, the area has the potential for rapid growth and industrial expansion, with land values that are lower than the city core. It is therefore important to develop urban growth boundaries that take into account regional resources, vulnerable ecosystems and climatic considerations.

In the second case study, Kochi, Kerala's most populous middle area, has seen a reduction in its forest and plantation coverage to around 73%, and an increase in its built-up area. Additionally, only 1% of the corporation area is covered by green open space, and a quarter of the city area is covered by water bodies. The primary difficulties identified in Kochi include land conversion from residential to commercial or mixed-use, ribbon development of commercial activities along railways, overlooking inland waterways, and hazardous industrial use near active residential areas. Environmental issues include ecological imbalances, loss of gradient in slope, and lack of social and environmental services. Climate-related issues involve sea level rise, floods and coastal erosion, poor air and water quality, and a high percentage of vulnerable populations. The potential of the area is seen in exclusive developments, canal systems for waterways, and the development of small-scale industries with available raw materials.

In the Kozhikode district of the North part of Kerala, a large-scale housing development is needed due to the high population density in the area. The main challenges identified are underdevelopment, environmental, and climate-related. These include a high percentage of vulnerable populations, a lack of relief shelters, treated water supply, land use and landcover changes, poor irrigation coverage, low per capita groundwater availability, surface water shortage, saltwater intrusion, drinking water quality problems, coastal erosion, high incidence of infectious diseases, and flood and landslide-prone areas. However, there is potential for exclusive developments, canal system waterways, and small-scale industry development with the raw materials available.

A overview of the peri-urban area's challenges and potential concludes this section. urban centres' accelerated expansion into their periphery. The effects of urbanisation on the sustainability of ecosystems are influenced by peri-urban, peri-agricultural, agricultural, and undeveloped areas. In the peri-urban regions of the fast rising cities, they are causing escalating water security issues. In addition to productive greening techniques (fruit trees, herbal shrubs, high-value vegetables) that increase water infiltration and shorten the time lag for flood occurrence on hill slopes and in valleys, maintaining the land use pattern beyond the city edge also improves potential adaptation to heat waves by moderating microclimates. As temperatures drop, the effects of the urban heat island are lessened. Physical, morphological, sociodemographic, cultural, economic, and functional changes are made to it, causing an unfavourable, complex land use/land cover (LULC) pattern. Planning for the use of land that considers agricultural ecosystems as the primary component of urban and peri-urban natural resource systems must be multidisciplinary and integrated. Urbanization occurs to varying degrees for various people. A phenomenon known as "organised irresponsibility" has arisen, allowing influential individuals to profit from the absence of control and ongoing impermanence. Many residents of informal settlements who lack adequate infrastructure and services are subject to social exclusion processes. A conflicted environment lacking the strategies needed to achieve a balance between opposing interests in order to eliminate poverty, safeguard the environment, and enhance the production of natural and human resources in order to maximise the synergy between urban and rural ties.

In peri-urban settlements, residential areas with high incomes generally have access to essential services and higher consumption of water and electricity, whereas gap, low-cost and social housing estates are more vulnerable to extreme weather and have poorer insulation, as well as a higher risk of flooding. On the other hand, informal settlements contain populations that are more socially vulnerable to climate change due to the poor quality of construction materials used, while mixed settlements with poorly built households are more likely to suffer from the impacts of climate change.

Peri-urban areas emerge at a faster pace. Provide the much-needed land and water resources for urban expansion besides serving as containers of urban wastes. Significant heterogeneity and rapid changes in land use. Range of functions, spanning from agricultural production to residential and recreational areas. Offer attractive residential alternatives to city centres or more remote locations.

DISCUSSION AND FINDINGS

Summary of potentials of the peri-urban area.

It is identified that the sectoral approach is suitable for the Kerala context. The strategies will be focused on sectors like Agriculture, Health, Water Resources, Forest and

Biodiversity, Energy, Urban Front and Transport.

For the Agriculture Sector, the Adaptation pathways chosen are Crop Improvement and management, Sustainable Land Use and Management, Water Use efficiency in various agricultural practices, Flood control and Drought management, Promote Energy Efficiency and Conservation in Agriculture practice, Providing better weather forecasting and Capacity building of the farmers.

For the Health Sector, the adaptation pathways chosen are Financially Sustainable Options, Strengthening Institutions and Integration, Networking for Outreach, Self-help groups, Proactive health Adaptation strategies, Preparedness and capacity building for emerging epidemics, and Strengthen Early Warning System.

The water resource adaptation pathways chosen are the Rejuvenation of rivers, Promoting rainwater harvesting, Implement Water Recharge Programmes, Recycling and reuse of greywater, increase in water use efficiency.

For the Forest and Biodiversity, the adaptation pathways chosen are Sacred grooved and ecological conservation, Temple pond - ensure water security, Special protection of unique ecosystems like shola forests, sandalwood areas, wetlands and other ecosystems, increasing green cover outside the forest areas, Develop integrated water resource management plan for the forest areas, Assessment of climate vulnerability and climate change impacts on state biodiversity and forest resources, Develop forest management plans for different forest types in view of Climate Change, Deforestation Reduction and the carbon market.

For the energy, the adaptation pathways chosen are Utilization of solar energy, Renewable Energy Development, and Programmes for enhancing Energy Efficiency.

Suggesting suitable approach & pathways: Sectoral Approach & Adaptation pathways.

In line with the study As per National Action Plan for Climate Change (NAPCC), the Kerala State Action Plan on Climate Change (2014) outlines the need for dynamic climate change planning that assesses changing climates and the vulnerabilities of systems to climate change in order to identify adaptation actions. Revision of the Action Plan was necessary and was published in 2022. The plan aims to help reduce the vulnerability of climate change, particularly in sectors such as agriculture, livestock, coastal fisheries, health, water resources, forests, and biodiversity. It is focused on increasing adaptation capacity, strengthening resilience, and decreasing the vulnerability of natural and socio-economic systems through adaptive activities that are inclusive and participatory.

In the agricultural sector, the expected direct and indirect effects are reduced yields, decreased soil fertility, reduced nutrition, and reduced income. Adaptation strategies to improve resilience to climate change and profitability in the value chain include crop improvement and management, sustainable land use and management, water use efficiency in agricultural practices, better weather forecasting, designating special agricultural zones, farmer capacity building, and research on agriculture and climate change.

In the health sector, the expected impacts, both direct and indirect, including strengthening institutions and integration, networking for outreach, establishing self-help groups, preparing and building capacity for emerging epidemics and improving early warning systems.

In the water resources sector, there are potential direct and indirect environmental impacts such as drought and floods, drinking water contamination, and reduced agricultural output.

To address these issues, adaptation pathways such as the rejuvenation of rivers, promoting rainwater harvesting, implementing water recharge programs, recycling and reusing greywater, and increasing water use efficiency should be taken into consideration.

In the forest and biodiversity sector, direct and indirect impacts include increased soil erosion, decreased water table, and other issues. Ways to build adaptive capacity involve protecting unique ecosystems, increasing green cover, and forming forest management plans in view of climate change. Deforestation reduction and the carbon market are also essential components.

In the energy sector, the main impacts expected are high carbon emissions, so adaptation pathways should include the utilization of solar energy, the development of renewable energy, and the implementation of programmes to enhance energy efficiency.

In terms of Urban Front and Transport, the consequences (direct/indirect) anticipated are the emission of greenhouse gases, and the enactment of pollution control strategies and schemes for low carbon, climate-friendly urban transport.

The project concluded with a framework for the water resource management sector with a plan for Integrated water resource management. This framework acknowledges the importance of water for social and economic development, as well as in sustaining the natural environment. It also considers water as one of the multiple essential resources and insists that water-related matters should not be addressed in isolation.

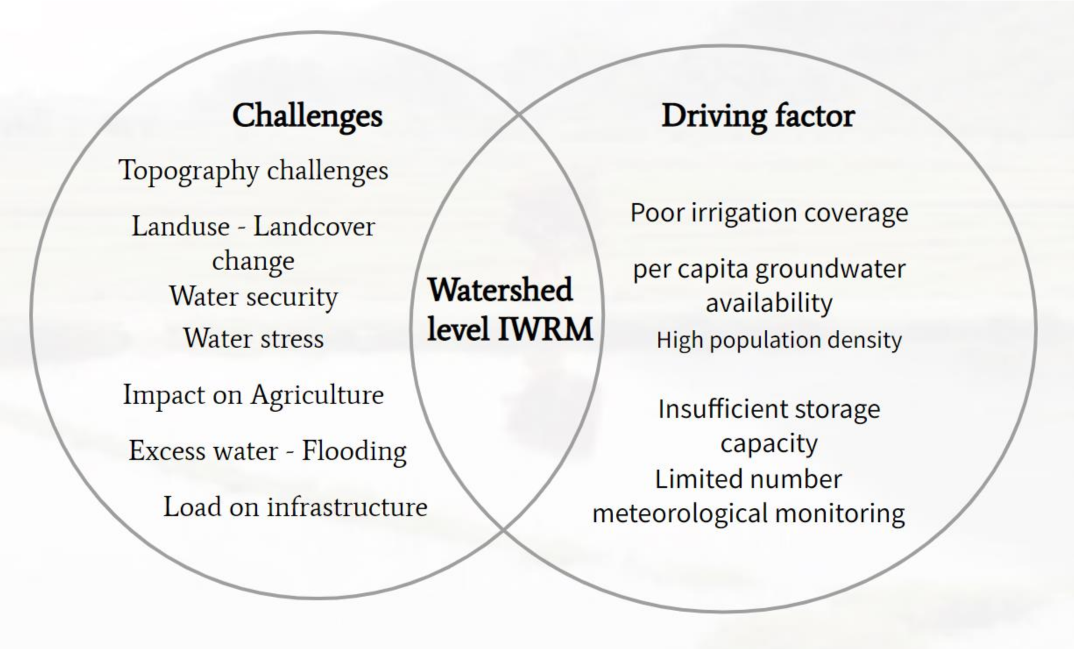

Figure 4: Concuding Framework for Watershed level IWRM

Managers in both the government and private sectors are facing the challenge of allocating dwindling water supplies among a growing number of demands, particularly in light of changing demographics and climate conditions. The traditional approach to water management is no longer sufficient, and a comprehensive solution is needed.

CONCLUSION

This paper reviewed conceptual and empirical advances on climate resilient development pathways. The project here is concluded with a framework for water resource management sector with a plan for Integrated water resource management plan. It is necessary to conduct additional studies on the connections between sustainable development, mitigation, and adaptation and the relationships between incremental variations and more profound transformations (Mitigation of Climate Change Climate Change 2022 Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change n.d.; Pervin et al. 2013b; Werners et al. 2021b)

ACKNOWLEDGEMENT

I would like to express our deep and sincere gratitude to Dr.Shyni Anilkumar and Dr. Amritha P K for their support, valuable suggestions and guidance in completing this Project work. I also extend my heartfelt thanks to the Department of Architecture and Planning, NIT Calicut and to all our friends and family for their support and co-operation.

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FRAMEWORK FOR FLOOD RESPONSE PLANNING FOR URBAN REGIONS OF KERALA

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Abstract:

Planning and coordinating disaster response is essential for risk reduction and efficient disaster recovery. There is a need to create a scalable and adaptable framework for directing the decision-makers. Flood emergency response is the implementation of a set of pre-planned actions to reduce risk to population and property.

The aim of the study is to develop an appropriate framework for planning response actions during a flood emergency. The objectives of the study are 1) to analyze the current emergency response mechanisms practiced in the context of flooding in the urban region and 2) to adapt an appropriate flood emergency response framework for the urban regions of Kerala.

The entire study is based on content analysis of relevant literature. The challenges and issues in response management have been consolidated from the Comparative case analysis of flood response mechanisms in local, national, and international contexts . Overview of the flood response measures adopted during the 2018 and 2019 flooding in Kerala is also attempted to contemplate the context specific challenges and shortcomings.

The flood response, mechanism has five stages. Once the hazard has been triggered, the decision to evacuate is the first step. This is followed by warning, withdrawal, sheltering, and return.The majority of the challenges encountered during the withdrawal and sheltering stage, as identified through the content analysis, can be mitigated through planning and hence is categorized under pre-disaster stage. Such a framework could play a decisive role in planning and prioritizing the measures for the various phases of response activities to be implemented in flood preparedness, during and post-flooding.

INTRODUCTION

Floods are a fast on-set disaster and have the potential to cause massive destruction to both lives and property in a very short amount of time. Therefore, it is of utmost important that vulnerable communities are prepared to respond quickly in order to minimize these losses. The prevalence of flooding events, particularly in urban areas, is an increasingly important issue on a global scale. However, for developing countries, this risk is even more critical as their resources and capabilities are limited. In order to effectively prepare for such emergencies, it is essential that the affected communities are equipped with the necessary skills and knowledge to respond quickly and adequately. The availability of the required resources is equally important when it comes to responding to floods. It is also essential that organizations involved in emergency response are able to collaborate and coordinate their efforts in order to ensure timely and effective responses. This can be done through effective planning and allocation of resources in advance so that the right response can be provided at the right time. In conclusion, timely response from vulnerable communities is vital for minimizing life and property losses during floods.

Flood emergency response is an important part of disaster management, as it involves the implementation of pre-planned activities to reduce the effects of flooding in a target community. Nationally developed contingency plans can be adopted by governments in many countries but are often not tailored to the specific needs of local communities. This lack of participatory approaches to the planning and development of warning response measures, therefore, weakens the effectiveness of these plans.

In order to address this issue and create effective flood emergency response plans, local stakeholders must be involved in all stages of the planning process. By integrating their knowledge and experience into the development process, more accurate warnings and responses can be created that consider any local vulnerabilities and exposures to flooding. Additionally, stakeholders can provide their perspectives on how best to communicate risk information, as well as what measures should be taken in advance of an event.

Overall, the more collaborative and participatory approach that involves all parties in the planning process will result in better preparedness and increased efficiency in flood emergency response. In particular, it will allow for more targeted and timely action that is tailored to the specific needs of a community. This will ensure that all members are aware of the risks posed by flooding and can take appropriate steps to protect people as well as the infrastructures at risk.

Also, there should be a unified approach to the planning and management of response activities. Currently, various decisions on response activities are carried out during the outbreak of the hazard and in isolation. Hence in this context, there is a need to derive a directed approach to plan the response activities considering the challenges and issues of a specific region. Therefore, this study attempts to develop a theoretical framework for planning response actions during a flood emergency.

The study follows the objectives such as:

1. To analyze the current emergency response mechanisms practiced in the context of flooding in urban region
2. To adapt an appropriate flood emergency response framework for the urban regions of Kerala.

The paper has been structured in the following way:

The first section represents the materials and methods adopted for the study. Secondly, the paper describes the first objective of the study by briefing the case studies analyzing the challenges and issues in current flood response mechanism in local, national and international context. The next part gives an overview of the Kerala floods 2018 and 2019.Next section deals with the discussions and findings from the study including the flood response framework which will fullfill the second objective followed by the conclusion.

MATERIALS AND METHODS

The entire study is based on qualitative content analysis of relevant literature. Initially a background understanding of the flood response mechanisms adopted in different parts of the world has been analyzed, which is followed by a glimpse of the Kerala floods 2018 and 2019.The challenges and issues in response management have been consolidated from the Comparative case analysis of flood response mechanisms in local national, and international contexts .Finally a flood emergency reponse framework will be formulated based on the intial studies as well as by analysing the best case studies through which the existing challenges can be mitigated. The framework is devised for the urban regions of Kerala, hence an overview of the urban flooding regions of Kerala is also analysed. The flowchart showing the study methodology is given below:

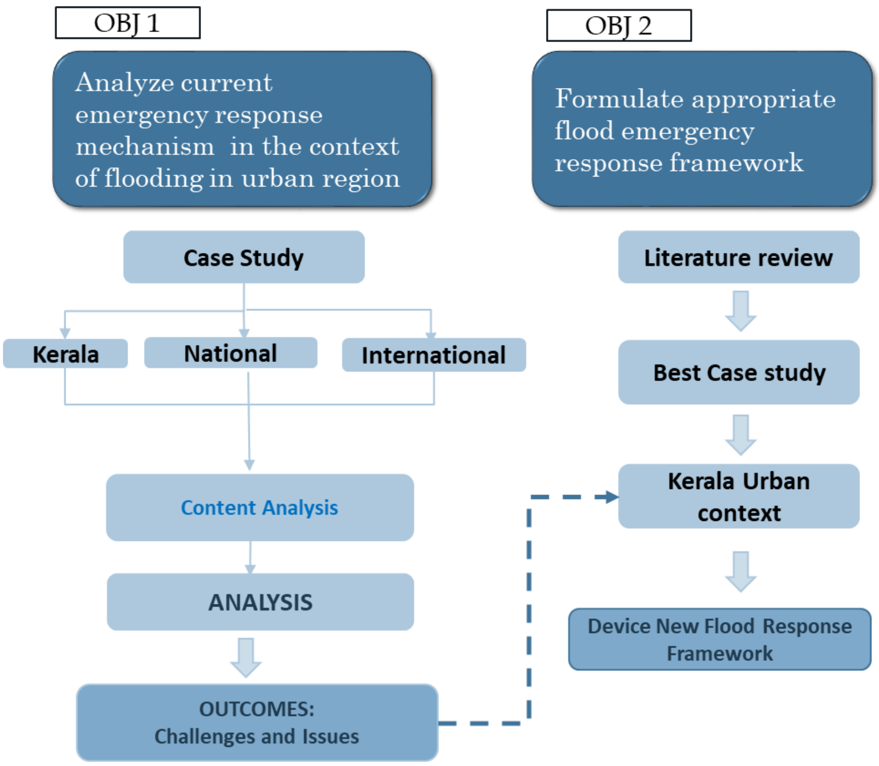


Figure 4 Methodology of Study

LITERATURE REVIEW

This section starts by giving an introduction to the various stages of flood response planning ,followed by the comparative case studies based on the challenges and issues in the current flood response mechanism with respect to local,national and international context which has been represented in a tabular form.

An effective response to disasters such as floods is the result of a comprehensive disaster management program. This program should incorporate a well-developed decision-making framework that aligns various incident and site-level response activities. It is imperative to understand the risks and vulnerabilities involved, plan ahead, and have regular drills to maintain the capabilities required for dealing with any kind of disaster.

To ensure an effective emergency response, it is important to assess the risks and vulnerabilities posed by floods. This assessment should be used to develop an appropriate and comprehensive flood management program that takes into account all potential scenarios. The program should also include a decision-making framework so various incident and site-level response activities can be aligned rightly. Regular exercises can help maintain the required level of preparedness for responding to disasters in an efficient manner.

The flood response mechanism is an extremely important part of emergency response. It consists of five stages that can help save lives and protect property from the effects of flooding. The initial stage is the decision to evacuate once the hazard has occurred. This is followed by a warning stage in which information about the flooding hazard is passed to the public, giving them knowledge about the vulnerable regions and allowing them to take appropriate action.

The next stage is withdrawal or evacuation, in which people are displaced to a safe location for temporary shelter. This helps keep everyone safe from immediate danger and allows for further planning to be put into place. The return phase then allows people to safely go back home once it is deemed safe by authorities.

It is crucial that all flood emergency response mechanisms are well-structured and organized. All stakeholders involved should understand their roles and responsibilities, and they should work together to ensure that all processes are running smoothly. The effective implementation of these five stages of the flood response mechanism can mean the difference between life and death in such an emergency situation.

Case Studies

This section deals with the first objective which looks forward to analyse the challenges and issues in the current flood emergency response mechanism for which case studies at local, National and International context are studied. At local level Kerala floods 2018 and 2019 has been analysed ,National level, Banglore 2022 and Chennai 2015 and finally under International level examples from Pakistan flood 2022 and Australian flood 2022 has been studied. Table 2 given below depicts the comparative analysis of the selected case studies:

Table 1: Challenges and Issues in flood response mechanism in Local, National and International Context

Significance	Flood Context	Challenges
Local	**Kerala Floods 2018**	Lack of access to the affected areas due to road blocks along with landslides and flooding hampered the rescue operations. Bridges and roads were completely destroyed, and no communication system was functional. Continuous heavy rainfall, endangering weather conditions, and terrain raised the fear of landslides every minute and made the rescue operation very difficult. In several places that were inaccessible through

		boats, NDRF teams used rope rescue techniques to make access to the stranded people and provide essential commodities. The fatigue and resource constraints hampered the ability of affected communities to respond to the disaster in the initial day Inadequacy of formal emergency services to provide such large-scale support Kerala failed to empower and equip its local bodies to respond to calamities. Kerala has failed to evolve long-term mitigation plans as its focus is more on reactions to emergency situations. No local-level and community-specific action plans and capacity-building exercises are taking place
	Kerala Floods 2019	The main issues faced during the operation were related to the direct damage resulting from the flooding. Many roads were either destroyed or under water for several weeks, many bridges were washed up, and electricity was cut off in many areas for a few days. The limited access hindered the relief efforts by IRCS and other actors. Even retrieving information for rapid assessment was difficult as communications were cut-off in many places, including cell phone access. In some cases, affected communities were only reached after 15 days when receding waters finally permitted responses to access the area. The limited resources available to the IRCS Kerala branch prior to the disaster meant a significant scale-up was needed to reach the operational capacity level to implement the response.
National	**Chennai Floods 2015**	School authorities faced numerous challenges, ranging from the sudden need to shift and secure school records and postpone exams, to maintaining physical infrastructure and equipping schools to serve as shelters. Food logistics arrangements across the affected communities included the unavailability of manufacturing capacity and delivery mechanisms. The lack of accessibility to several parts due to

		severe flooding made identification of delivery points and transport routes more difficult First responders and information providers faced difficulties in providing accurate real time information to local communities on flooded areas, accessibility of roads, road condition, traffic flow and current weather scenario. lack of mechanisms to mitigate impacts of flood, such as road closure notification, absence of traffic control warning signs, emergency detour routes, etc. which are essential during such extreme events. Chennai police were unable to ensure effective and timely response, due to lack of common command system, clear assignment of duties and demarcation of roles to respective officials, for times of emergency.
	Banglore Floods 2022	Residents had to be evacuated on tractors There were huge traffic disruptions, power outages, loss of productivity, and many normal activities had to be halted. The flooding of the pump houses hit the water supply to the city, and some areas had to depend on water from bore wells and tankers.
International	**Pakistan Floods 2022**	Relief efforts have largely focused on the provision of shelter, safe drinking water, food items, and health interventions amidst supply chain disruptions The international community, have provided aid, but accessibility due to standing flood waters, flood effects, and complex topographies remain a major challenge.
	Australia Floods 2022	Local authorities did not provide adequate flood warnings, evacuation, or rescue support, leaving older people, people with disabilities, and those who were pregnant facing life-threatening circumstances with little government assistance. Emergency services offered no assistance, leaving families with small children, older people, and people with disabilities unable to leave.

Kerala Floods

This section deals with the second objective which aims at analyzing the response actions taken during flooding in Kerala as well as a glimpse to the flooded urban regions of Kerala.

Kerala Floods 2018

Between 1 June and 19 August 2018, Kerala endured the greatest floods the state has ever seen since the Great Flood of 1999.In that particular year, the state received 42% more rain than usual.There were two successive active rain spells, with above-average rainfall peaks occurring on June 14 and 20.Around July 20, there was another instance of rainfall that was above average.Later, from August 8 to August 17, Kerala experienced another busy rainy spell.All 35 major reservoirs were closed to the full reservoir level due to the rainfall scenario that persisted through the end of July 2018. They lacked buffer capacity to handle the massive influx starting on August 8.The authorities were forced to use substantial releases into the rivers in August due to the catchment areas' ongoing unprecedented severe rainfall, which overflowed all river banks and caused widespread flooding throughout nearly the whole state.

Following the floods, a wide range of stakeholders including the NDRF, Indian Army, state-led organizations, local volunteers, fishermen, women volunteers, non-state actors, and technology innovations responded to the tremendous inundation in a highly effective way.

The table below represents the actions or activities taken by various stakeholders during the Kerala floods2018:

Table 2 Response activities carried out by various stakeholders during the 2018 Kerala floods

Agencies/Stakeholders	**Response Activities**
National Disaster Response Force (NDRF)	Pre-positioned its three teams in Ernakulum, Thrissur, and Idukki. On the request of the Kerala state emergency operation center, three additional teams were sent by road from NDRF base Arakkonam and four teams were airlifted from the Indian navy ship INS Pre-positioned its three teams in Ernakulum, Thrissur, and Idukki. On the request of the Kerala state emergency operation centre, three additional teams were sent by road from NDRF base Arakkonam and four teams were airlifted from the Indian navy ship INS Rajalion. As per the direction of the Government of India, 44 additional NDRF fresh teams were airlifted. Used rope rescue techniques to gain access where boats were impassable.
Indian Army	Over 23,000 people were saved as a result of "Operation Madad," and over 2,000 people received medical care. Cleared 22 landslides, built 15 temporary bridges, and restored communication at 42 places. 53 military boats were used to remove citizens from flood-affected districts, while helicopters were important in the evacuation of those trapped on the rooftops of their flooded homes.
Indian Air force (IAF)	Offered prompt aid by executing "Operation Karuna" and a humanitarian assistance disaster relief (HADR) mission. The impacted population received tonnes of supplies every day, including food, clothing, and water as well as medical assistance with physicians on board.

State-Led Response	Because formal emergency services were insufficient to give such extensive assistance, the government was forced to solicit citizen participation in coordinated emergency responses, rescue efforts, and relief activities. In addition to providing food packages, Rs 10,000 in financial aid was also given to each family to help them repair their flooded homes. Under the Pradhan Mantri Awas Yojana (PMAY), the prime minister announced a financial aid package worth '600 crore for building homes in areas that lost many of theirs to flooding. In accordance with the Mahatma Gandhi National Rural and Employment Guarantee Scheme, the Ministry of Rural Development approved 1,800 corers. A total of 1,400 crores had been credited to the Chief Minister's Disaster Relief Fund (CMDRF) by millions of people and organisations in India and beyond.
Fisherman	At least 65,000 lives were saved by a total of 4537 fishermen who ventured out in 669 boats. Fishermen from Vypin, Cherai, and Allappuzha travelled to Aluva to aid families who were stranded and needed to leave their homes.
Kudumbashree	Kudumbashree members cleaned homes and public buildings, offered family counseling, proceeded to run community kitchens in disaster-stricken areas, gathered supplies and distributed them in camps, assisted in packing take-home kits, provided volunteers for various activities, rehabilitated flood victims in their homes, and carried out mass cleaning campaigns in some districts.

Kerala Floods 2019

Kerala once again faced floods and landslides between August 8 and December 31, 2019. The commencement of the 2019 Monsoon was slow and delayed. On June 8th, 2019, IMD formally proclaimed the start of the monsoon season. However, rainfall in Kerala was 32% below average until July 31. In Kerala, June and July are typically considered to be "rainy months." Wayanad, one of the most afflicted Districts, with a 55% rainfall deficit as of July 31 compared to the long-term normal (Normal). However, Kerala state experienced a lot more rain than normal during the month of August as a result of the effect of low pressure area and depression created over the Bay of Bengal and intensification of Monsoon winds.

Kerala received 123% more rain in August 2019 than the state as a whole experienced over a lengthy period of time. The amount of rainfall in August 2018 was 96% more than the long-term average. Kozhikode (176%), Wayanad (110%), Malappuram (176%), Palakkad (217%), Thrissur (127%), and Ernakulam (140%) were the most severely hit districts in North and Central Kerala, receiving more than 100% more rain than usual in August. From August 1 to August 31, 2019, there was more over 1000 mm of rain in 7 out of 14 districts from Kasargode to Thrissur.

Rescue and Relief:

The state government launched rescue and relief efforts right away. On August 8th, 2019, an emergency operations centre was launched with the deployment of federal and state forces.

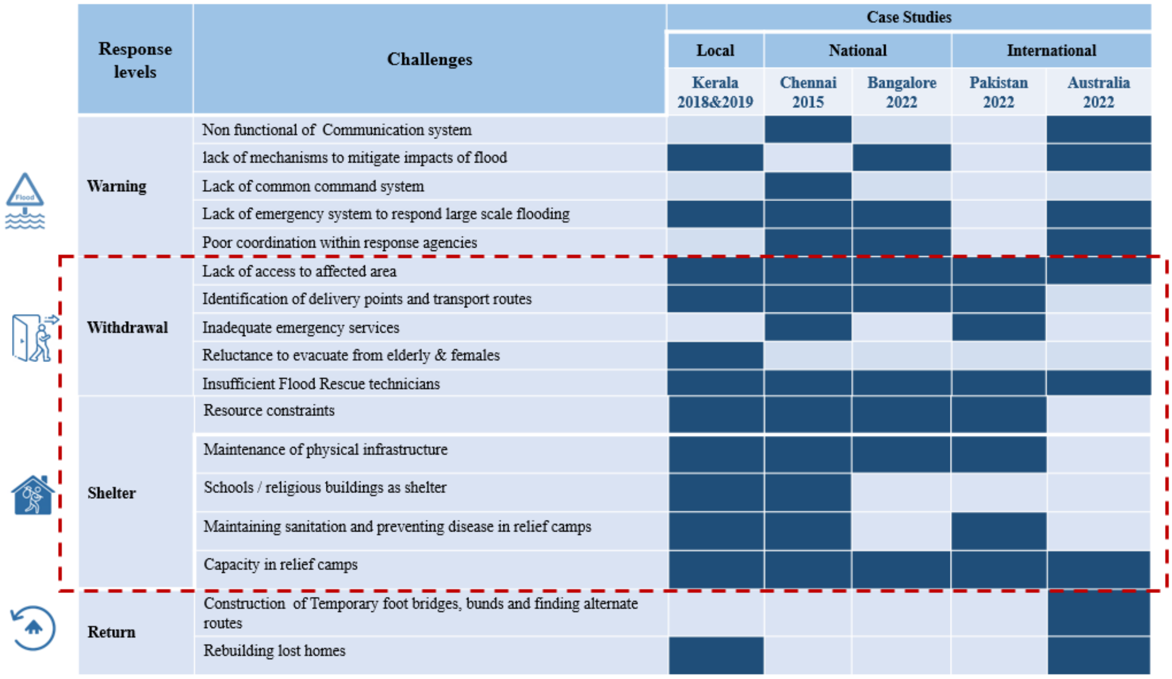
- The actions carried out in relation to the monsoon disaster in the state were evaluated by the Hon'ble Chief Minister, as well as Chairperson SDMA, on August 8th, 2019. On the following days, he also double-checked the situation from the State Emergency Operations Centre.
- A full-fledged control room comprising members of the NDRF, Army, Air Force, Coast Guard, ETF, MRC, Kerala Police, Fire & Rescue services, and other forces was added to the 24x7 Emergency Operations Centre.
- On August 9, 2019, the State Executive Committee met to discuss the state's overall flood condition. The SEC convened the following days (10th and 11th August) to address the crucial activities that needed to be carried out in the affected areas, particularly Malappuram & Wayanad.
- The Hon'ble Chief Minister, together with Revenue Ministers and senior officials, visited the landslide-affected villages and camps on August 13 to inspect the situation.
- Managers of the camp were given instructions about the provision of food and non-food things in the camp.
- The website www.keralarescue.in was relaunched in order to enable improved supply chain management of goods and services.
- Each district improved its District Emergency Operations Center by hiring more personnel to operate there around-the-clock.
- Public announcements were made, and evacuations happened right quickly.
- Dam operations were closely observed, and the public regularly received updates on the discharge of dam water.
- On August 10th, 2019, KSDMA hosted the Inter Agency Group (IAG) of NGOs and Civil Society Organizations at the state level.

DISCUSSIONS AND FINDINGS

Challenges

Based on the literature review, some of the major challenges has been consolidated under each response stage and have been tabulated as shown in table 3 . From this content analysis ,it can be inferred the at majority of the challenges are falling under the withdrawal and sheltering stages of the flood response mechanism.

Table 3 Flood response challenges consolidated under each response stage



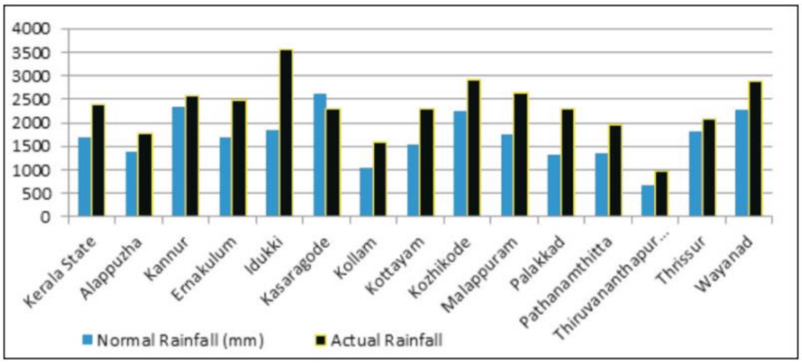
The table given below represents some of the best practices adopted by UN Hyogo Framework for Action 2005 -2015 and as per the Assam state disaster management plan with which the challenges studied in section 3.1 can be mitigated.

Table 4: Best Practices adopted in flood response ,mechanism

Case Studies	Best Practices Adopted	Challenge Mitigated
UN Hyogo Framework for Action 2005-2015	Capacity Analysis and Capacity-Building	Lack of emergency system to respond large scale flooding Insufficient Flood Rescue technicians
	Hazard Monitoring, Forecasting and Early Warning	Lack of mechanisms to mitigate impacts of flood
	Information Management and Communication	Non functional of Communication system Lack of common command system Poor coordination within response agencies
	Emergency Services and Stand-by Arrangements	Inadequate emergency services
	Incorporating Early Recovery into Preparedness Planning	Rebuilding lost homes Maintenance of physical infrastructure
Assam State	Elements of response:	Lack of access to affected area

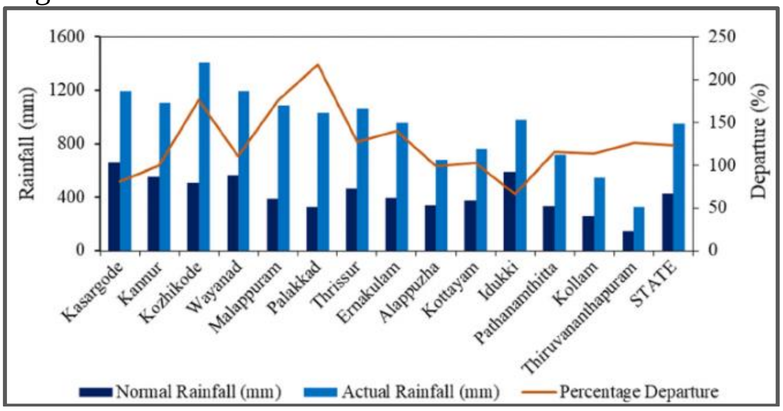
Disaster Management Plan	Before, During and After	Identification of delivery points and transport routes
	Incident Response System	Poor coordination within response agencies
	Emergency Support Functionaries	Inadequate emergency services Resource constraints Poor Sheltering

Kerala Floods



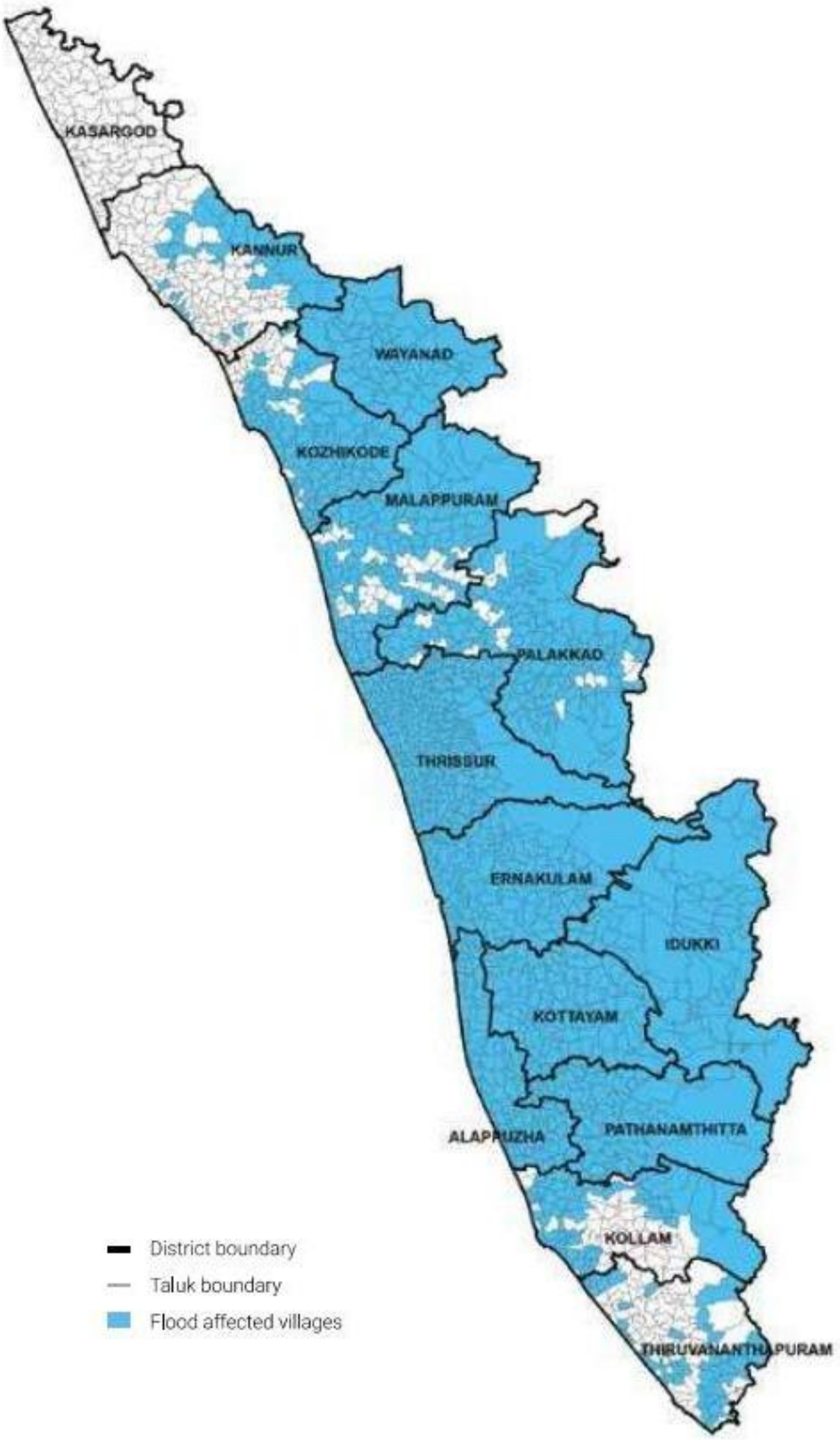
Source : National Institute of Disaster Management

Graph 1 Bar diagram of District wise Normal and Actual rainfall in Kerala Floods 2018



Source: An Appraisal of Kerala Flood-2019, Link.springer.com

Graph 2 Bar diagram of District wise Normal and Actual rainfall in Kerala Floods 2019



Source: Kerala State Disaster Management Authority

Map 1 Flood affected districts in Kerala during 2018 floods

Source : MEMORANDUM Kerala Floods – 2019

Map 2 Flood-affected districts in Kerala during 2019 floods

According to the literature review, the majority of the response and relief operations were concentrated on identifying evacuation routes and providing shelter.

Maps 1 and 2 indicate that the same urban areas of Kerala,the districts of Ernakulam, Thrissur, Kollam, Malappuram, and Kozhikode were consistently under water during the flooding events that took place in 2018 and 2019. Furthermore, it can be seen from the graphs that, in addition to the rural districts, the urban districts also saw relatively above-average rainfall in 2018, with Kozhikode receiving the most rain, followed by Malappuram, Ernakulam, Thrissur, and Kollam. The district that received the most rainfall during the 2019 floods stayed the same (Kozhikode), followed by Malappuram, Thrissur, Ernakulam and Kollam.

Framework

A need to prepare the actions and activities executed during the withdrawal and sheltering stages of the flood response mechanism has been found after studying the current challenges and issues, as well as the response and relief measures implemented during the significant flooding events in Kerala. Additionally, this planning stage should be included in pre-disaster preparedness since it makes it easier for decision-makers to locate shelter options and evacuation routes early on, lowering the danger of flooding that would otherwise occur if the same were planned haphazardly during the hazard. As a result, a framework is being proposed that would highlight various factors that must be taken into account while preparing for the withdrawal and sheltering stage.

The critical factors for the withdrawal and sheltering stage as identified from the study include spatial, social, and institutional factors which have been shown iconographical in the figure given below:

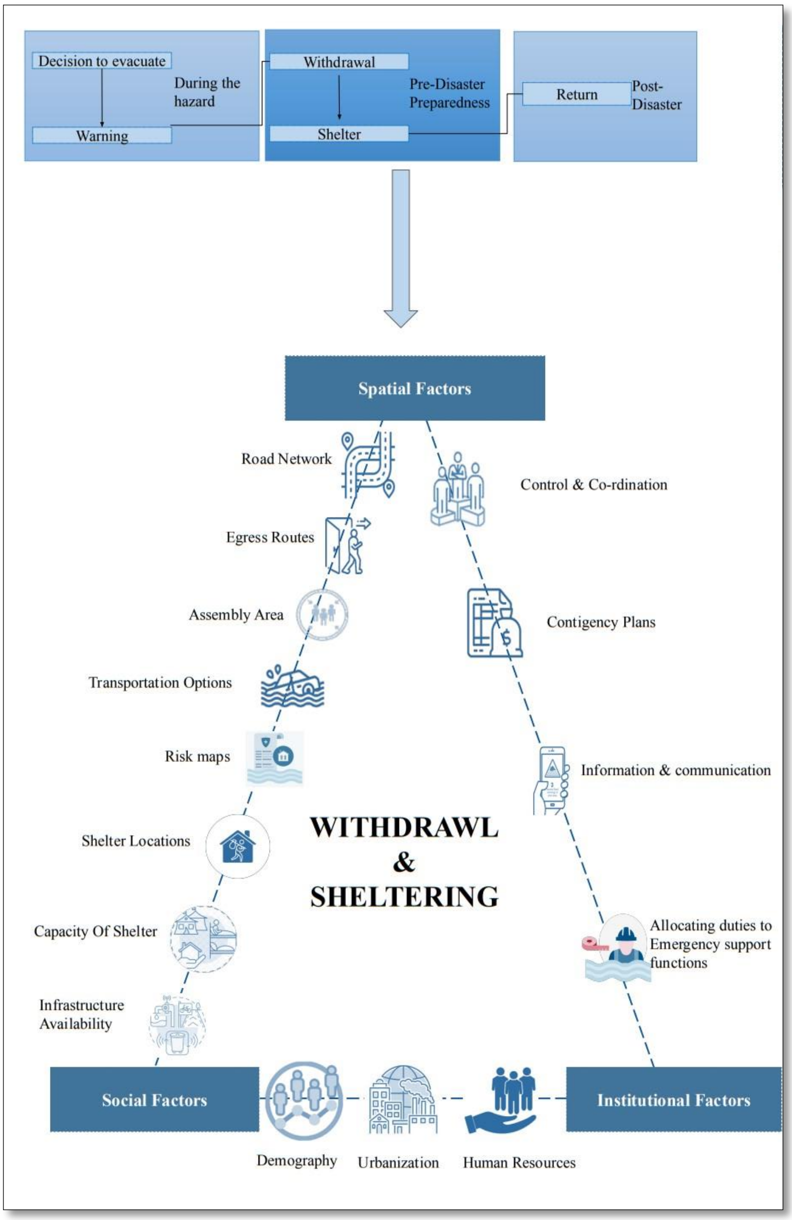


Figure 5 Framework for the flood response mechanism

CONCLUSION

The flood emergency response plan serves as a critical framework to manage floods, providing the necessary structure for emergency management functions. This study provided a generic framework based on deductive and content analysis which is a great asset for decision-makers. It serves as a practical guide for communities looking to strengthen their resilience in the face of floods. Moreover, it helps them anticipate the potential impacts of flooding and develop strategies to stay safe during these hazardous events. In short, this generic framework will assist communities in creating an effective flood emergency response plan that will enable them to manage and mitigate many potential risks.

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GEOSPATIAL EVALUATION OF LANDSLIDE INDUCED FLOODS IN CENTRAL KERALA: A THROWBACK TO 2021

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Abstract:

Kerala had catastrophic landslides and floods in 2018 and repeated in the coming years also, resulting in the loss of lives and property. In October 2021, a cloudburst occurred in middle Kerala, causing multiple devastating landslides in the districts of Kottayam and Idukki followed by flood. Kanjirappally town was flooded for the first time in history. Though the river overflowed during the flood in 2018, it did not trigger a major flood. The study focuses on how the topographic, physical, and geological factors and anthropogenic activities in the Manimala river basin influence the occurrence of landslide-induced floods. The landslide and flood susceptibility were analysed by the frequency Ratio method based on paleo flood locations in the Manimala River basin. The impact of each factor was analysed against the flood points. The findings showed that about 9.77 % of the study area is coming under a very high flood susceptible zone which covers an area of 104.338 km^2,61.15 % of the study area is in moderately flood susceptible zone having an area of about 652.993 km^2. Flood susceptibility is low for 29.08 % of the study area which covers 310.527 km^2.The flood that occurred on 2021 October 16 was triggered by the landslides that occurred on the upper course of the Manimala River basin. The Cloud burst led to landslides and this debris flow caused the blocking of natural stream channels and in turn, caused flooding in the midland region of the river basin.

Keywords:

Flood, Landslide, Cloudburst, Frequency ratio

INTRODUCTION

A flood can be defined as a rise in water level for a short duration to a peak from which the water level recedes at a slower rate (WMO, 1974). Amongst different natural calamities like cyclones, droughts, and earthquakes, the maximum damage is caused due to floods around the world (WMO, 1994). The frequency of flooding in India is more than 50% of the total number of floods occurring in Asia in each decade (Parasuraman and Unnikrishnan, 2000). India has a peculiar geographical setting that there are floods in some parts and droughts in other regions, and sometimes they co-exist. According to Central Water Commission 2010, India is the second largest food-prone country after Bangladesh with about 40 million hectares of land under food prone. Every year, flood affects an average of 7.6 million hectares of land in India.

In recent years, the number of landslides and floods in Kerala has increased significantly (Jain et al.,2021). In 2018, Kerala experienced very heavy rainfall and the most disastrous flood. Compared to the "Great floods of 1099", it is much larger than the 1924 flood, but quite reminiscent. This event was triggered by the Southwest monsoon of 2018. In a span of 30 days, 339 human lives were lost, thousands of houses were destroyed, more than 1.5 million people were moved to relief camps, large stretches of major roads were washed away five bridges were damaged. The flood in Kerala in August 2018 was reported as the fifth-biggest flood in the world in five years since 2015. The major reason for floods is Monsoon and landslides. In 2019, the Puthumala and Kavalappara landslides together caused 81 deaths (Wadhavan et al., 2020), and 66 tea estate workers perished in the Pettimudi landslide 2020 (Achu et al.,2021). In 2021, the Kootickal and Kokkayar slides caused 18 deaths (Sisira et al.,2022). Most of the landslides that occurred in Kerala are debris flow types (Kuriackose et al.,2009, Achu et al.,2021). These flows are characterized by rapid movement and long run-out distances in mountainous areas along the steep slope (Hugget 2007, Hungr et al.,2014), and these debris flows result in floods.

STUDY AREA

Manimala River basin, which spans the latitude range of 9^{0}21 to 9^{0}40' N and the longitude range of 76^{0}33 to 76^{0}58' E. (Fig 1:study area:Manimala river basin,Kerala It is one of the 4 Major rivers which do not have direct outlet to sea as these rivers (Pamba, Manimala, Meenachil, Achankovil) empty into vast Vembanadu Lake.It originates from Kolahalamedu of Mothavara hills of the Western Ghats at a height of about 1257 m above MSL. The Manimala River basin can be generally divided into three zones geologically. The western coastal zone consists of recent sand and silt, the Middle zone consists of residual laterite formed by the decomposition of Archean crystalline rocks, Eastern zone consists of charnockite rocks of the Archean group. Physiographically the river basin can be broadly classified into three distinct natural physiographic zones, viz; the lowland, the midland and the highland. The highlands are mostly reserved and protected forest with patches of tea, cardamom, coffee estates. The lumberers and the migrant settlers seeking better fortunes cleared most of the natural forest cover, originally for cassava and other hill crops cultivated together with coconut palms only to be later replaced by rubber (Hevea Brasiliensis) plantations (Kumar 2005). Cassava cultivation is known to accelerate soil erosion (Putthacharoen et al. 1998) and the land-use practises associated with it are deemed to act as a catalyst to slope failures in the region (Government of India 1956). Cobble-packed slope-terracing ignoring the natural drainage is a prevalent practise among the farmers in the region, which was identified as a reason to have increased the susceptibility to landslides.

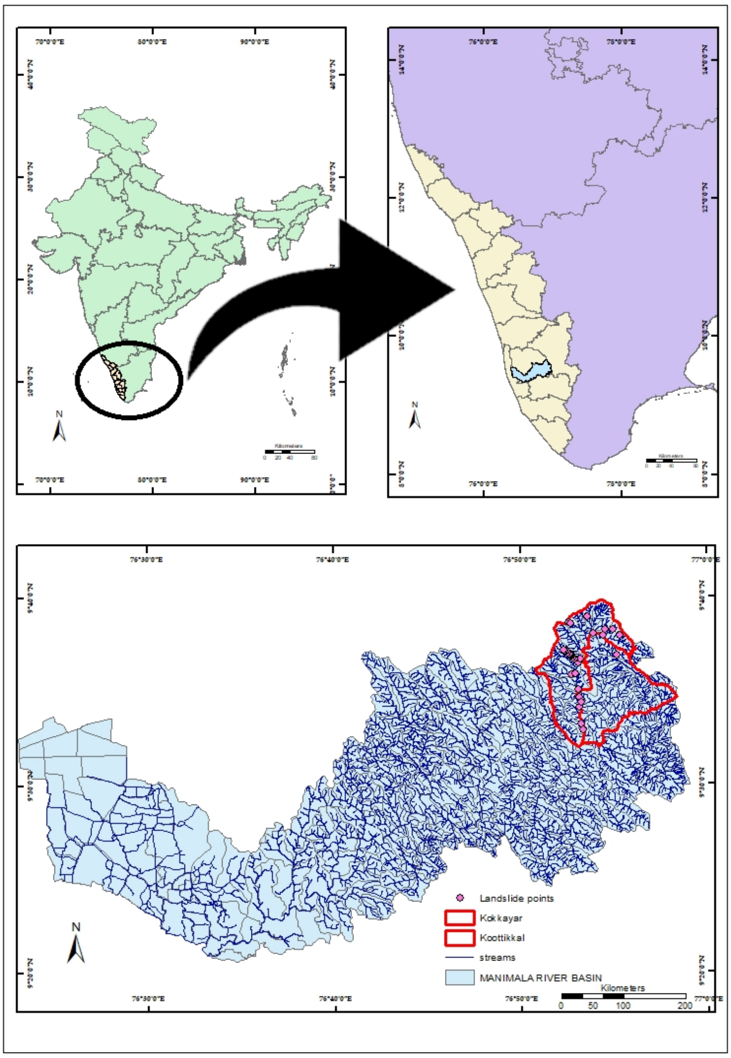

Fig 1-study area :Manimala River basin,Kerala

The basin, witnessed the worst landslide events and biggest flood in 2021. On 2021 October 16 heavy rainfall experienced in Kottayam and Idukki districts. This led to landslides and caused 18 deaths at Koottikkal and Kokkayar and the Kanjirappally town was flooded for the first time in history. Though the river overflowed during the flood in 2018, it did not trigger a major flood. Also compared to the flood in 2018, Kanjirapally experienced the worst flood in

2021 as the water level rose by 15 ft. Flood in 2021 was a repetition of the flood that occurred in 1957.

OBJECTIVES

To study the flood and landslide susceptibilities of the study area. And evaluate the effect of landslides on flood susceptibility of the area

REVIEW OF LITERATURE

Numerous studies have reported that floods are the deadliest natural hazards, affecting many regions in the world each year. In recent decades the trend in flood damages has been growing exponentially. The primary reason for natural hazards is climate change,changes in upstream land use and ever-increasing population and assets in flood prone areas. Rising sea levels have increased the risk of rising storms and coastal floods. Since floods are a very serious natural disaster and almost impossible to prevent completely (Cloke and Pappenberger, 2009), it is very necessary to create food susceptibility mapping and food vulnerability assessment through which we will be able to design some management schemes for diminishing flood risks in the future and also a useful tool to guide the governments and planners to formulate proper flood management plans.

Remote sensing data provides information that has proved to be very useful in many disaster management applications. Remote sensing data combined with GIS techniques offers an effective tool in the process of mapping areas that are prone to natural hazards. Many researchers have attempted to map flood prone areas using RS and GIS techniques. Rahmati et al., (2016) investigated the application of the frequency ratio (FR) and weights-of evidence (WofE) models for flood susceptibility mapping in the Golestan Province, Iran using several hydrogeological parameters. The validation of results indicated that the FR and WofE models had almost similar and reasonable results in the study area with an AUC of 76.47% and 74.74% for FR and WofE models respectively.

In India also various studies were carried out to map flood prone areas. Jain et al., (2005) delineated of flood-prone areas inn Koa catchment, Kahalgaon, Biharthrough the use of IRS LISS III and Landsat TM as well as DEM data using a range of image processing techniques including simple density slicing, Tasseled Cap Transformation and water-specific index. The 189 results obtained using different approaches indicated that a Normalized Difference Water Index (NDWI) based approach produced best results Biju et al., (2018) performed Flood Susceptibility Mapping through Frequency Ratio (FR) and Shannon's Entropy (SE) Models using several flood conditioning factors in Nagavathi Sub-Basin, Tami Nadu, India and resulted that the FR and SE models have almost analogous and practical outcomes with AUC of 79.40% and 78.70% respectively.

In Kerala also many researchers worked on flood prone analysis using various methods. Lakshmi et al., (2016) created a flood risk assessment map for the Karuvannur river basin in Kerala, India by using analytical hierarchy process based on various topographical and hydrological factors and the resultant risk map showed higher risk areas in the central west and south east parts of the basin.Mayaja and Srinivasa, (2016) studied flood hazard zoning using analytic hierarchy process as a case study for Pampa river basin, Kerala, India by applying to a set of geospatial factors ranging from qualitative to quantitative type and revealed that highly populated and urbanized regions located in the downstream of this river basin are more vulnerable to flood hazard. Roy et al., (2018) studied flood hazard vulnerability in Alappuzha district for year 2012 to determine the most flood prone area in the same through weighted overlay method using certain flood affecting factors and concluded that floods are natural disasters that cannot be prevented but its impacts can be controlled by appropriate planning. Pramanick et al., (2021) performed SAR based flood risk analysis in four districts of Kerala to assess the full effect of the floods in 2018 and concluded that the districts of Alappuzha and Kottayam were severely affected by floods, followed by Thrissur and Pathanamthitta. Vilasan and Kapse, (2021) prepared the flood susceptibility maps of the Ernakulam district, Kerala by integrating remote sensing data, GIS, and analytical hierarchy process (AHP), and fuzzy-analytical hierarchy process methods using various hydrogeological factors and the prepared map was validated using the receiver operating characteristic (ROC) curve method which confirms the prediction capability of the prepared maps. The very high susceptible zone constitutes around 19% of the district.

In addition to flood landslides also a great to human life. Landslide susceptibility mapping was performed at in Damrei Romel area, Cambodia using frequency ratio and logistic regression models and the frequency ratio model (86.97%) and the logistic regression (86.37%) had high and similar prediction accuracy (Lee and Sambath,2006). Aykut et al., (2007) studied Landslide susceptibility mapping for a landslide-prone area (Findikli, NE of Turkey) by likelihood-frequency ratio and weighted linear combination models. From the studies conformed that the landslides do not exist in the very 219 high susceptibility class of the both maps, 79% of the landslides fall into the high and very high susceptibility zones of the WLC map while this is 49% for the LRM map. The Himalayan region and western ghats are highly vulnerable to landslides. Pham et al., (2015) studied landslide susceptibility of a Part of Uttarakhand Himalaya, India using GIS – based Statistical Approach of Frequency Ratio Method. The study showed that the FR model indicates fairly well in the present study. Overall, the FR model is an effective method for the landslide susceptibility assessment of hilly areas. It can be applied in other areas of Himalayas for the assessment and management of landslide hazards.

The hilly terrain of the state of Kerala, a linear stretch of land with the Western Ghats running throughout its length, is a landslide-prone area. Landslides here are shallow-seated as the overburden thickness usually varies in the range of 1–5 m, with most of the region having less than 2 m overburden, and they rest unconformably on the Precambrian bedrock. Thus, a detailed study of this hazard, using the latest technology, is inevitable. The best possible method of studying these cataclysmic phenomena is through remote sensing. Geological history suggests that there is no representation of Phanerozoic above the Precambrian crystallines except a thin veneer of recent sediments (Soman, 2002; GSI, 2005). During monsoon landslide occurs in the hilly tract of Kerala, which forms a part of the Western Ghats (Anbazhagan and Sajinkumar, 2011, Sajinkumar and Rani, 2015). The prevalence of tropical climate enhanced the chemical weathering (Sajinkumar et al, 2011, Sajinkumar et al, 2015) and facilitated the formation of a thick column of soil over the Precambrian crystallines (Sundarajan and Sajinkumar, 2012) wherever the topography permitted. This big unconformity existing between the Precambrian crystallines and the overlying Recent sediment forms the slip plane for the landslides in Kerala. The typical landslide dynamic type occurring in Kerala is debris flow restricted to monsoon period (Sajinkumar and Anbazhagan, 2015). Idukki district, in central Kerala within which Munnar is located, is one of the major landslide prone areas in the Western Ghats. Considering the severity of the problem, numerous studies were carried out in the district by different organizations. Geo-informatics in Landslide Hazard Zonation (LHZ) in parts of Idukki district by Sajinkumar (2005); LHZ on mesoscale of Munnar and adjacent area by Muraleedharan (2009); district wise LHZ by Centre for Earth Science Studies (2010); study on weathering and landslides by Sajinkumar et al. (2011); early warning system by deploying deep earth sensor probes in Anthoniyar Colony, Munnar by Ramesh and Vasudevan (2012); LHZ along Thodupuzha-Idukki-Munnar road corridor by Abraham and Shaji,(2013); LHZ of a part of Idukki district by Sajinkumar and Anbazhagan, (2015) and identification of Trema orientalis- a plant species which grows profusely in landslide affected area (Sajinkumar, 2015) are the important studies carried out in this district.

METHODOLOGY

Frequency ratio, the most popular bivariate method (Korup and Stolle, 2014) is used for analysis. The primary reason for the acceptance of the frequency ratio method is its simplicity and clarity of the principles used and can have higher accuracies compared with other methods (Pradhan, 2010; Ramesh and Anbazhagan, 2015; Chen et al., 2016). The understandability of the input, calculation, and output procedures, and the ease of implementing GIS make the frequency ratio method a more acceptable tool for landslide susceptibility assessment when sufficient data is available (Lee et al., 2007). In order to prepare the landslide inventory and flood inventory maps the paleo slide and paleo flood locations were collected using GPS immediately after the catastrophic event. The frequency ratio model was used for landslide and flood susceptibility assessment with 16 factors including slope, aspect, curvature, geomorphology, geology, lineament density, precipitation, stream density, distance to streams, soil moisture, soil texture, soil depth, NDVI, built-up density, distance to watershed management works and distance from roads were considered for landslide susceptibility evaluation. And the 16 factors including slope, TWI, flow accumulation, distance from stream, stream density, road density, LULC, NDVI, geology, lineament density, geomorphology, soil texture, soil depth, precipitation and population data. By analysing these factors the landslide and flood susceptibilities of the basin are analysed, from the susceptibility maps the relationship between landslide and flood is evaluated(Fig:2 Methodology adopted for the study).

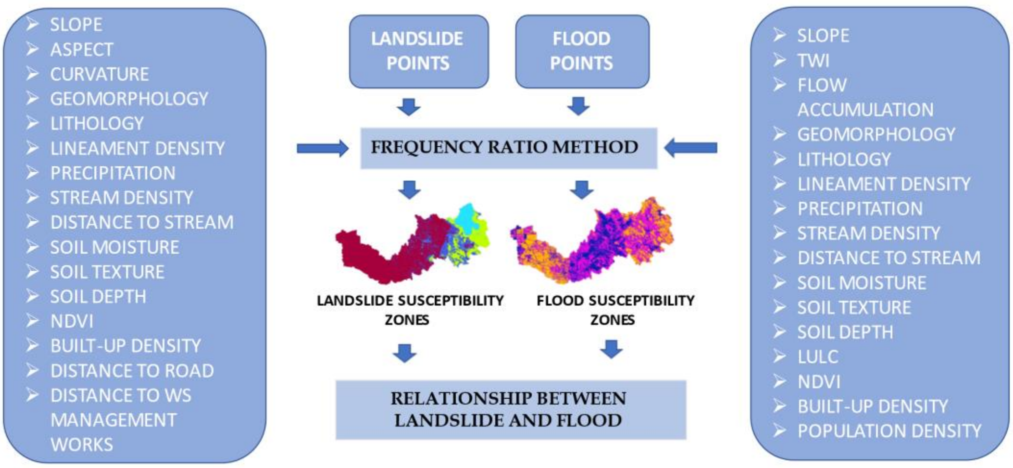

Fig 2. Methodology adopted for the study

RESULTS AND DISCUSSION

In the current study, very high probability of landslide is found in the region of slope angle greater than 17^0 where frequency greater than 3 which covers an area of about 144 km² area. Seckar et al., (2008) pointed out that majority of mass movements have occurred in hill slopes >20^0 along the western hats scraps. Aspects such as North, North-East and South-West are considered as landslide probability zones in the present study where frequency ratio higher than one. Prabhan (2010) also reported high frequency of landslides for North and North West facing areas in central part of peninsular Malaysia. The term curvature is theoretically defined as the rate of change of slope gradient or aspect, usually in a particular direction (Wilson and Gallant 2000). The influence of plan curvature on the slope erosion processes is the convergence or divergence of water during downhill flow (Ercanoglu and Gokceoglu 2002; Oh and Pradhan 2011). For this reason, this parameter constitutes one of the conditioning factors controlling landslide occurrence (Nefeslio ˘lu et al. 200 b).In the study all landslides are observed in convex or concave area ,none is observed in flat surface. The analysis with geomorphology and landslide occurrence indicates that frequency ratio is greater than one only for denudational hills .Similar 235 observations were made by Vijith and Madhu (2007) from Western Ghats of Kerala with high frequency of occurrence in denudational hills. It is widely accepted that lithological characteristics strongly effect the physical properties, such as strength and permeability of the surface and sub-surface material; and therefore, affect the likelihood of land sliding (Kamp et al., 2008). In the study area, the frequency of landslides is high in charnockite terrain and it consists of 66% (705 km²) of the total area .Spatial distribution and nature of lineaments mainly determine the distribution and intensity of landslides. The lineament density is calculated and the area with lineament density less than 0.3 promotes landslides. It covers an area of 903 Km^2.Precipitation was considered as the major climatic factor which influence landslide in the study area. In the study area precipitation greater than 2600 mm is vulnerable to landslides. Prabhan (2010) reported that more landslides are found at the region of high precipitation. Streams can play an adverse role in the stability of a slope, by undercutting due to toe erosion and by saturating the slide toe, due to increase in water infiltration (Gorum et al., 2011). Stream density and distance to stream are analysed. Land slide occurrence is high in the areas with moderate stream density (3-4) .Most of the landslides occurred within 100 m from the streams .The frequency of landslides reduces as moves away from the streams. Soil characteristics have a great impact on landslide susceptibility. Soil moisture, soil texture and soil depth are considered. Landslide frequency is higher than 1 in areas with soil moisture content is low and soil texture as clay and gravelly loam and these are very deep. In the case of NDVI, major number of landslides are found in the areas of NDVI between 0- 0.3.Building density also extracted from satellite image, the landslide susceptibility is high in areas with built up density greater than 1000.The frequency of landslides increases with increase in built up density. Anthropogenic activities have a great role in landslide susceptibility. Hence the distance from roads, quarries and watershed management works are considered. In mountainous terrain, the construction of communication network including roads and railway, often leads to the destabilization of slope and eventually land sliding (Shafique et al., 2016). The landslide susceptibility is high within a distance of 500 m from the road network, and it decreases away from the road network .Also the landslide points are within 5 km from the quarry locations. Numerous rain pits have been made in this vulnerable slope (with the good intention of collecting rain water and thereby augmenting the groundwater, and which is at times utilized for irrigation).As per Construction of interconnected surface drains: Every effort should be made to ensure that surface water is carried away from a slope (Cedergren, 1989; Holtz and Schuster, 1996). From the studies it is observed that most of the landslides are within 1500 m from the watershed management sites. Landslide susceptibility map indicate that about 5%of the study area was considered as very high landslide susceptible zone which covers about 49 km² of the total area and 4%(47km²) is considered as high susceptible zone zone. LSI is moderate for 28% of the study area (303 km²) and low for 63% of the total study area (667km²)(Fig 4: Landslide susceptibility zones of Manimala river basin).In the present study slope angle greater than 17^0 ,aspects N,NE, denudational structural hills, charnockite lithology, distance to streams, high built up density and unscientific construction of roads and watershed management works are main landslide causing factor.

Land elevation always plays an important and effective role for contriving flood susceptibility mapping (Rahmati et al. 2016a, c; Fernandez and Lutz 2010). Generally, it is observed that the tendency of flood susceptibility decreases as elevation increases, so the FR value decrease as the height of the area increases, which illustrate the high probability of flooding in low elevated area (Khosravi et al. 2016). In current study also high probability of flooding in low elevated area. The slope of a region regulates the flood occurrence as low flat plain area has a strongly association with flooding condition in the rainy season. A high number of floods occur in lower slope area as the water cannot discharge swiftly (Sarkar 2019). High slope indirectly enhances the food probability as it fosters speedy water and the area with high slope has the less time to regulate and percolate water under the ground (Jaiswal et al. 2003).In the study, about 82% of flooding occurred in the area having less than 17° of slope .Areas located close to the flow accumulation path are more likely to get flooded (Elkhrachy 2015).TWI represents the effect of topography on the location and size of saturated source areas in generating runoff in a basin (Sharif et al. 2016). In the case, the topographical wetness index (TWI) flood susceptibility is inversely proportional. The areas which are nearer to streams generally show higher flood susceptibility, here also the flood susceptibility is high in areas near to the streams. The stream density is an influencing factor for flooding. High drainage density values indicate high runoff has the lower chances for flooding and area with low drainage density has the greater chances for flooding; due to low number of drainage systems, water cannot be drained very quickly in a short period of time (Sarkar 2019).Road density is a secondary factor for flood. In the study, the high frequency ratio come under the class between 2 to 3 which have been recorded with high FR values of 1.983, which shows highly probability of flooding. Vegetated areas offer levels of protective mechanism, making land less prone to flooding. Therefore, a negative relationship exists between a flood event and vegetation density. Conversely, urban areas increase the storm water runoff due to the extensive impervious surfaces (Al-Zahrani et al. 2016). Vegetated areas generally yield high values of NDVI because of their high NIR reflectance and low visible reflectance hence, high probability for flooding occurred in areas with low NDVI values. Lithology of the study area consist of charnockite exhibits high probability for flooding. The analysis with geomorphology and flood occurrence indicates that frequency ratio is greater for pediplain, waterbody and plateau. Lineament play secondary role in the flood occurrence. Lineaments control the infiltration. Lineament characterised fault and fracture zone results secondary permeability and porosity (Yalcin and Bulut 2007; Pourghasemi et al. 2012). The soil texture of gravelly clay and gravelly loam favour for flooding.Generally if soil depth is high then rate of infiltration is high, then there is low chance for flood and if soil depth is low, the rate of infiltration is low, then there are high chances for flood. . The population density is also an influencing factor for flood. In the study, the high frequency ratio come under the class with population density less than 1500, which have been recorded with high frequency. The amount of rainfall is the most important reason for flooding in any area. Generally, the area receives annual rainfall of 2600-2800 mm. In the high-risk zone, the annual rainfall average exceeds 2600mm. But as an immediate cause on October 16, a cloud burst induced heavy rainfall of 266mm was experienced in the study area (Fig 3:Rainfall Observed in Kanjirapally rain gauge, the nearest rain gauge station of the study area). This rainfall triggered landslides on the foothills of the western ghats.

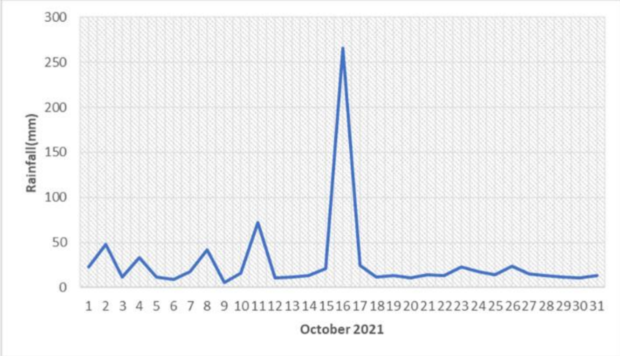

Fig 3: Hyetograph of October 2021, Observed in Kanjirapally rain gauge nearest rain gauge station of the study area

Flood susceptible zone map indicated that about 9.77 % of the study area is coming under very high flood susceptible zone which covers an area of 104.338 km2 . 61.15 % of the study area is in moderate flood susceptible zone having an area of about 652.993 km2 . Flood susceptibility is low for 29.08% of the study area which covers310.527(Fig 5: Flood susceptibility of Manimala river basin).

The Himalayan watersheds produce most of the flooding during the monsoon season (Chauhan et al., 2017; Kumar et al., 2022). Such extreme events have caused to generate numerous hazards, including landslides, flash floods, and landslide lake outburst floods (LLOFs) (Kala, 2014; Chauhan et al., 2022). Recently the same catastrophic events are observed in the Western Ghats also. Because the interactions between the synoptic-scale circulation and the hydrological cycle in mountains are highly complex and nonlinear (Maraun et al., 2011). The flood that occurred on 2021 October 16 was triggered by the landslides that occurred on the upper course of the manimala river basin. The Cloud burst observed in the study area caused the slopes to get saturated and result in an increase in pore water pressure, which further resulted in landslides. The debris flow from upland region caused the blocking of natural stream channels and in turn, caused flooding in the midland region of the river basin.

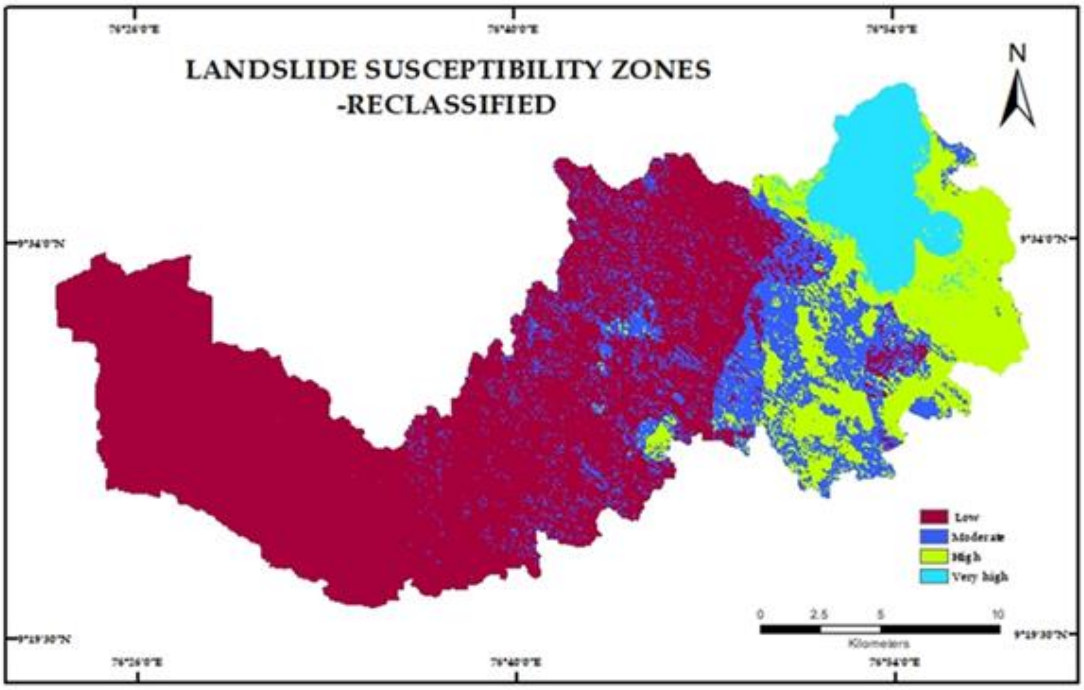

Fig 4: Landslide susceptibility zones of Manimala river basin

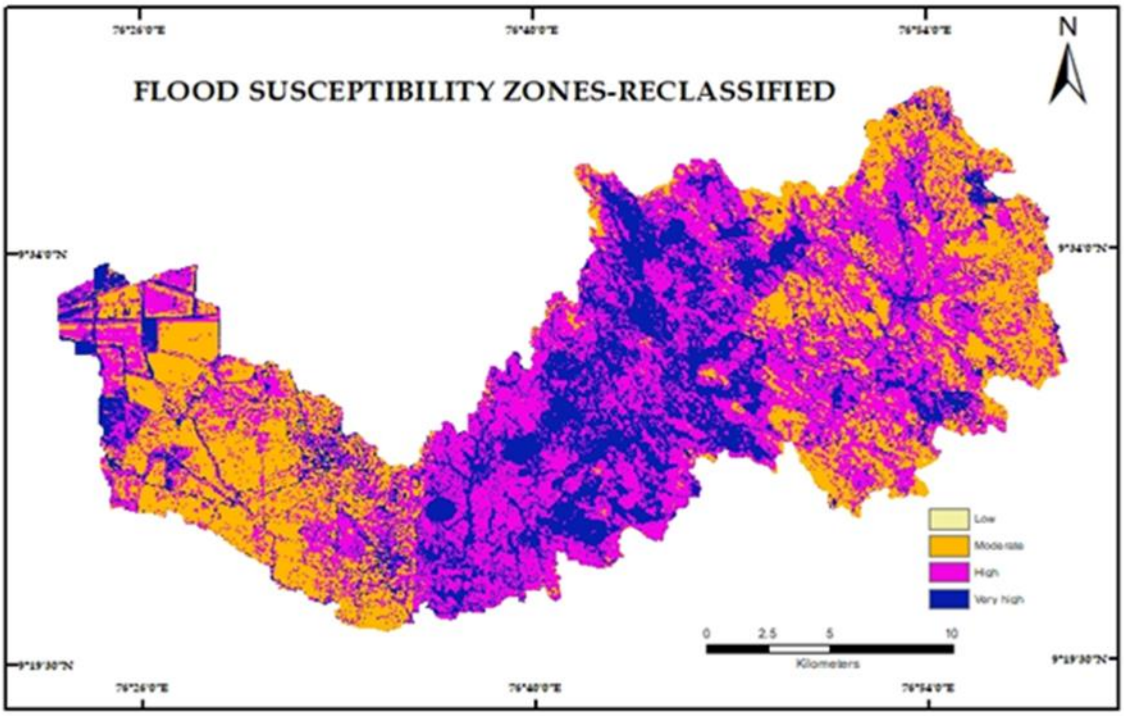

Fig 5: Flood susceptibility of Manimala river basin

CONCLUSION

Field investigations and scientific analysis have been carried out to estimate the effect of 2021 landslides on floods in the manimala river basin. Site observation and interpretation on the topographical, geological and climatological data indicated that landslide has occurred on the upper Kokkayar and pollaga sub watershed caused by the torrential rainfall observed on October 16,2021.These slides took place mostly at the hill area of the catchment with a high slope due to heavy rainfall which causes loss of compaction and cohesion strength of the soil. Rainfall with high intensity and long duration is predicted to have triggered erosion in the landslide area. The eroded materials induce flash floods carrying high concentrations of sediment and damaging various types of areas in the downstream watershed. Specifically, the results of the study indicate that two factors, namely the landslide area and heavy rainfall as the cause of flash floods in the Manimala River.

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AUTHOR CONTRIBUTIONS

Amrutha AS –Investigation, visualization, Methodology, Writing original draft

Ashly M Sabu –Investigation, Formal analysis

Abin Varghese-Conceptualization, supervision, reviewing and editing

Sreelakshmi Prakash-Methodology

Baiju KR-Expert consultant

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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GOVERNANCE FOR LANDSLIDE DISASTER RISK REDUCTION (LSDRR) FOR PUBLIC ADMINISTRATION IN AN ASPIRATIONAL DISTRICT OF GOVERNMENT OF INDIA

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Abstract:

Wayanad is the only Aspirational district in Kerala State amongst 117 district in Government of India. It is a land with pristine beauty and is situated at the southern tip of the Deccan Plateau at an altitude of 700 - 2100 meters from MSL. The district seasonally (mostly monsoon) witness Landslide and Floods due to its peculiar topography and rainfall. Amongst other disasters in Wayanad, landslides are causative factors for life loss and damage to infrastructures & lead more than 200 slides during 2018 to 2021 year. This paper focus on major achievements of DDMA Wayanad and the then District Collectors Initiatives for reducing the disaster vulnerability posed by the Landslides. The DDMA Wayanad has initiated landslide regulatory mechanism through legal provisions envisaged by the District Collector (DC) and Chairperson of DDMA by the DM Act 2005. The Landslide Hazard Zones (LHZ prepared by National Centre for Earth Sciences & of KSDMAs) in Wayanad are now under regulatory orders & under surveillance of DDMA wayanad. As the best governance and public administration for disaster risk reduction regulations / orders was made since 2015 onwards & are subjected for sequel amendments for later years, till 2019. Such, regulation was made first of its kind in India by the DDMA Wayanad. All the land coming within 500 meter from all the boundary point of the High Hazard Zone (HHZ) are subjected to be regulated. The 2019 proceedings of the DC, mainly focus on building types (Categorised into 5 types), construction of building at high hazard zone (HHZ), height regulations (multi-storied buildings), measures are established for slope cutting in such terrains more than 45 degrees of slope, removing ordinary earth at dangerous magnitudes, mining, quarrying and land developments activities at LHZ.This regulation made by the DC has achieved in reducing most of the manmade landslides in the district. In year 2022, only one incident was reported than of the previous trends and it has been occurred due to retriggering effect of previous sliding. The preparedness measures for landslide risk, the DDMA Wayanad has initiated "Community Based Rainfall Monitoring System (CBRMS)" than of conventional rainfall forecast. Totally of 156 Locations are recorded daily including 6 locations of IMD AWS. Panchayath level alerts are provided during the time of monsoon emergencies.

Keywords:

Landslide, Hazard, Zonnation, Regulation, Governance, Aspirational District.

INTRODUCTION

Wayanad is one of the Aspirational District according to NITI Aayog Government of India. It is the only aspirational district in the Kerala state. District wayanad is situated at the southern tip of the Deccan Plateau & part of the Western Ghats, with ridges, valleys, peaks, hillocks & ranges, with an altitude of 700 to 2100 meters (MSL). Bordering with Malappuram and Kozhikode districts & shares boundary with two states Tamil Nadu and Karnataka. The Nilgiri district of Tamilnadu and Mysuru, Chamarajnagar and Kodagu of Karnataka State. Wayanad ranks 12th in the state in area and its land area is least 2230 sq km (*Figure No.1*). Among the districts and 40% of its area is covered under forest. The main river in the district is Kabani, one of the east flowing rivers of Kerala. The majority of the population in Wayanad solely depend on farming as a livelihood (90s); recently (2010) tourism industry awakened paradigm shift from conventional state of practice (DDMP 2021).

The beautiful land is also vulnerable to various disasters including floods and landslides. Landslides are one amongst disaster that had posed vulnerabilities in Wayanad many times in the past. The Wayanad - Kozhikode border has been identified by National Center for Earth Science Studies (NCESS) as one of the most landslide prone areas in the state. some of the key landslides that occurred are; The Mundakkai, Kappikkalam and Valamthode landslide/debris flows are notable ones.

The Mundakkai debris flow occurred in 1984 and it claimed 14 lives apart from the loss of agricultural land. The Kappikkalam Landslide near Padinjarethara occurred in 1992 and claimed 11 lives. Landslide occurred on 23.6.2007 at Valamthode, which claimed 4 lives. Apart from this, many other Landslides of similar nature and magnitude occurred in Wayanad. One such landslide occurred at the Ambalavayal-Kumbaleri road near the Arattupara and Phantom Rock, The landslides at Puthumala and Mundakai during 2019. Such, landslide incidents are overwhelming the district towards vulnerability.

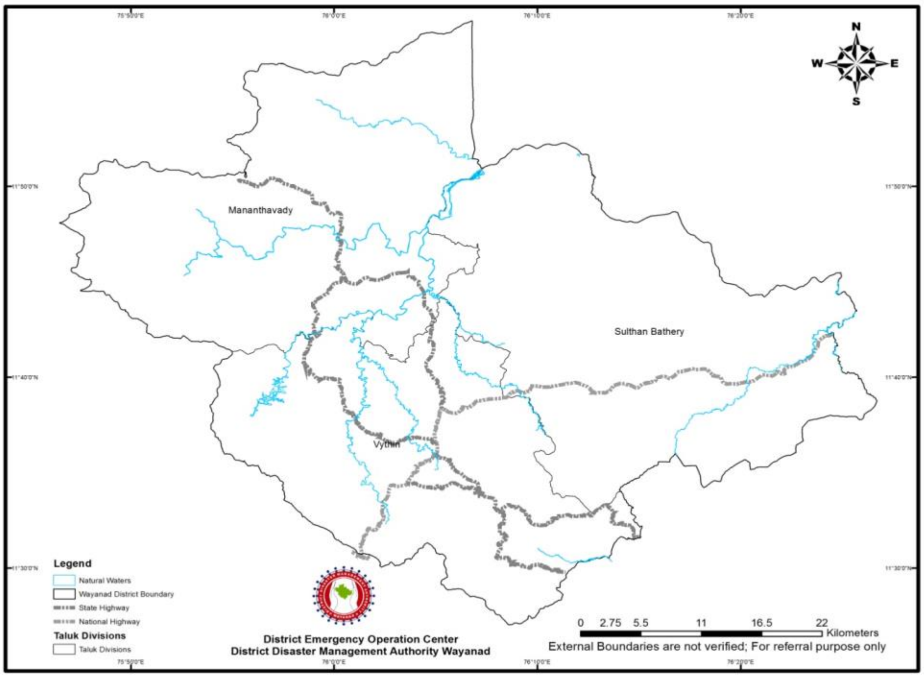


Figure 1: Action Research Area - Wayanad stating the jurisdictional limits & location Map.

In this regard, District Disaster Management Authority (DDMA) Wayanad has initiated governance strategies for disaster risk reduction of landslide (LsDRR);

MAJOR OBJECTIVE OF THE PAPER

- To sensitize the governance strategies adopted by the DDMA Wayanad for LsDRR.

METHOD & METHODOLOGY

This paper is a typical narrative paper of coherence science policy paper; where we authors has dialectally explained the actions taken for the LsDRR. The research method opted as action research. The practical implications done in the study area or the Action Research Area (ARA) Wayanad by the District Disaster Management Authority has been reflected as results whole through this paper. The Geographical Information System (GIS), Arc Map software tools (buffer tool, extraction by mask) was used to demarcate the 500 meter buffer zone from High Hazard Zone of the Landslide Hazard Zonation as a pictorial representation of the order of the District Collector during 2019.

RESULTS

Landslides are the utmost causative for vulnerabilities to people in Wayanad. Henceforth prevention of risk of Landslide stands its priority for government. As matter of concerns, DDMA Wayanad has issued orders and has taken serious steps to monitor, inspect construction activities in Wayanad. This initiative of DDMA Wayanad is the model to all other Hilly terrains in India and is First of its kind in Landslide Risk Regulations as the best practice made here by us to the Nation in alleviations of vulnerabilities posed by landslides.

Governance Strategies of DDMA Wayanad through regulatory DM orders

A. Landslide Mitigation Measures through regulatory orders.

B. Restriction of Construction, Quarrying, Mining, and land development activities

C. Landslide Early Warning

  a) Community Based Rainfall Monitoring System (CBRMS)

  b) School Based Rainfall Monitoring System as early warning measures.

  c) Benefits of CBRMS & Best Practices.

A. Landslide Mitigation Measures through regulatory orders.

The landslide Hazard Zonation (LHZ) maps of National Center for Earth Science Studies (NCESS) gave insights about the landslide prone area (Figure No.2 & 8) of the district. The landslide events occurred during 2018 has been plotted by the state authority (KSDMA) and as depicted in Figure No.3.

The DDMA Wayanad has initiated landslide regulatory mechanism through legal provisions envisaged to the District Collector and Chairperson of DDMA envisaged in the DM Act 2005. The legal affirmative points conferred under section 30(1), 30(2)(iii), 30(2)(v), 34(h), 34(m) of DM Act 2005; The DDMA Wayanad has began to issue orders since 2015 onwards, Figure No. 4. details the chronologically the orders. All the orders are publicly available at official district website, the link : https://wayanad.gov.in/en/dm-orders/.

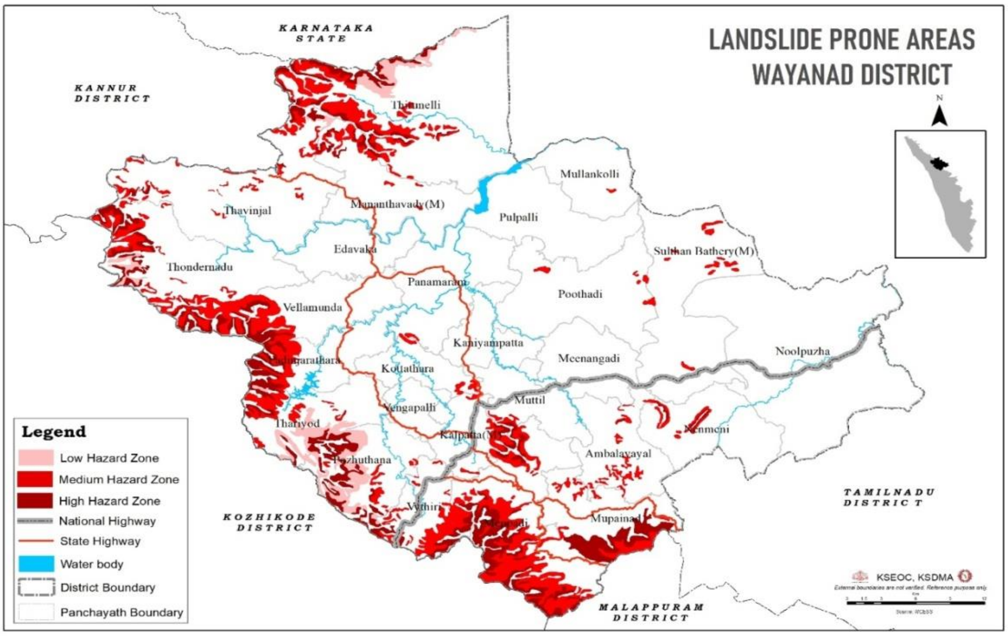


Figure 2: Landslide Hazard Zonation Map of NCESS & KSDMA.

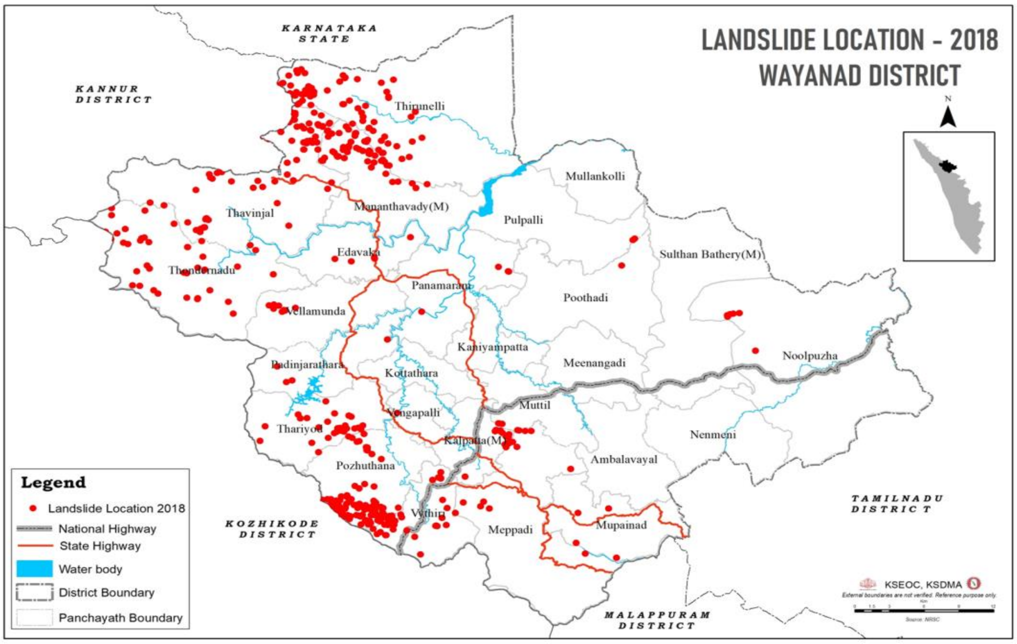
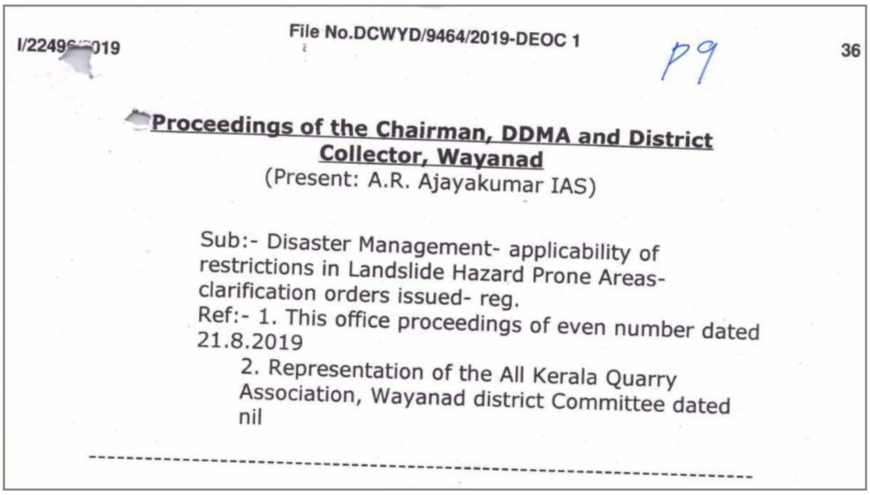


Figure 3: Landslide events during 2018.

Figure 4: Orders of District Collector & Chairperson DDMA Wayanad.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Proceedings of the Chairman, DDMA and District Collector, Wayanad
(Present: A.R. Ajayakumar IAS)

Sub:- Disaster Management- applicability of restrictions in Landslide Hazard Prone Areas- clarification orders issued- reg.
Ref:- 1. This office proceedings of even number dated 21.8.2019
2. Representation of the All Kerala Quarry Association, Wayanad district Committee dated nil

Figure 5: Snapshot of Order of then Chairman DDMA Wayanad.

The crucial order on landslide regulations and the construction regulation came into existence during the year 2019 by the order of the Proceedings of the then Chairman, DDMA & District Magistrate and District Collector Wayanad - Shri. A.R. Ajay Kumar IAS (Figure No. 5.). The order stated that; from the Landslide Hazard Zonation map of KSDMA, from the High Hazard Zone (HHZ) from its border ***the land coming under the 500 meters distance from all the boundary points of the said area are being regulated for constriction activities*** (Fig. No.6 - 10).

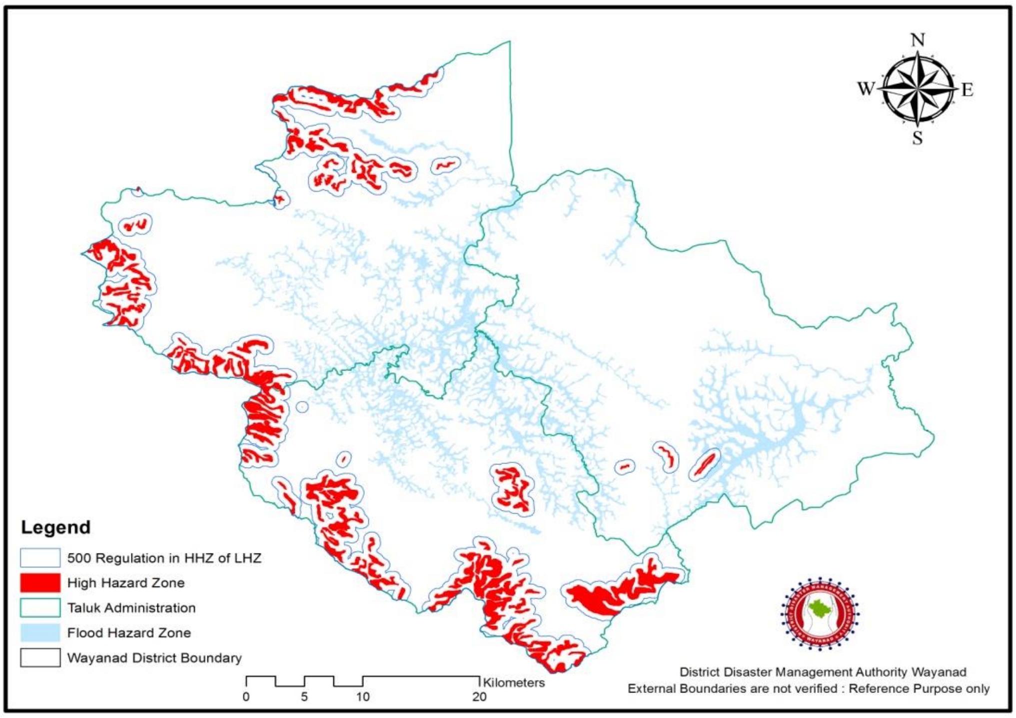

Figure 6: The 500 Meter Regulated zone from the HHZ of the LHZ.

The order stated that; from the Landslide Hazard Zonation map of KSDMA, from the High Hazard Zone (HHZ) from its border the land coming under the 500 meters distance from all the boundary points of the said area are being regulated for constriction activities (Figure No. 6 & 7).

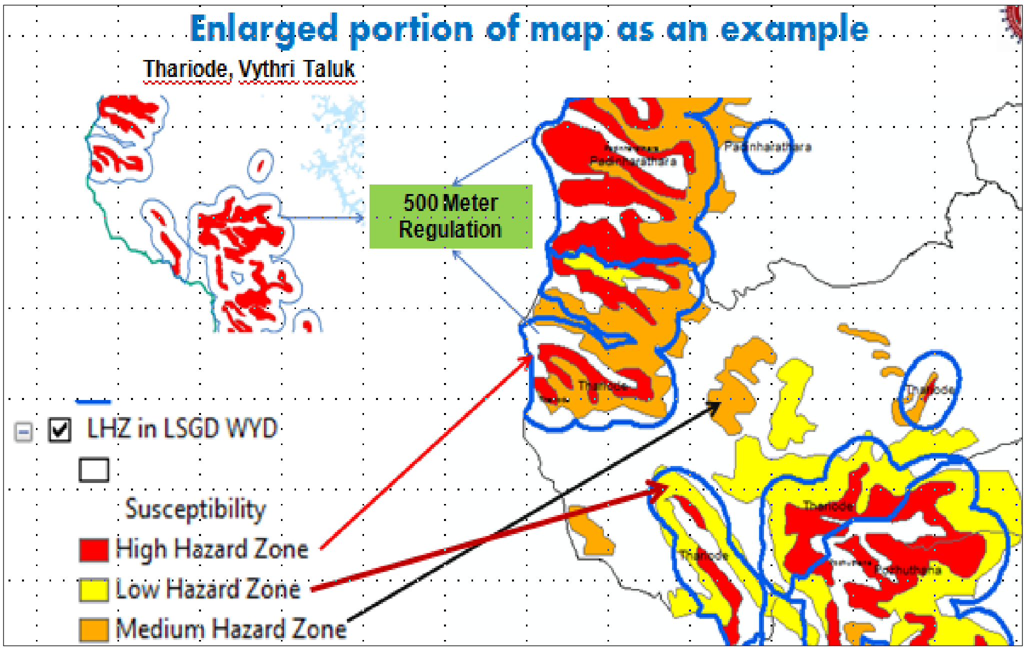

Figure 7: Enlarged portion of regulated zone from HHZ.

K. R. Baiju, Karunakaran Akhildev, Joice K. Joseph, Naveen Babu, Anithomas Idiculla, Asha Rose, Shibu K. Mani, Mahesh Mohan, and A. P. Pradeepkumar. (2023). Proceedings Volume of the 5th International Disaster, Risk and Vulnerability Conference (DRVC) January 19th – 21st, 2023. School of Environmental Sciences, Mahatma Gandhi University, Kottayam, Kerala, India – 686560. p- 1 to 447

The local community that reside in these areas cannot be disturbed to construct own residential buildings, buildings for their educational and healthcare needs, small scale industry unit buildings and buildings for their worship. At the same time all constructions with a commercial intent need be curbed to ensure the safety of the local populace also. The buildings in vulnerable locations are classified as per Kerala Panchayat Building Rules (KPBR) / Kerala Municipal Building Rules (KMBR). The Category of restrictions is as detailed as nutshell; Group A: Residential Building, Group B: Educational and Community Buildings, Group C: Medical or Hospital Buildings, Group D: Small Industrial Buildings, Group E: Other Constructions. The structural safety of buildings having more than 5 floors and situate either in Landslide Prone Area or within a radial distance of 500 meters are restricted. Height of such buildings coming under this category shall be limited to 8 meters and 2 floor levels. Quarrying and mining activities has to be restricted within the Landslide Prone Areas. No construction in the Group E category.

Refer the order in detail for understanding:
https://cdn.s3waas.gov.in/s3b73ce398c39f506af761d2277d853a92/uploads/2020/12/2020121850.pdf

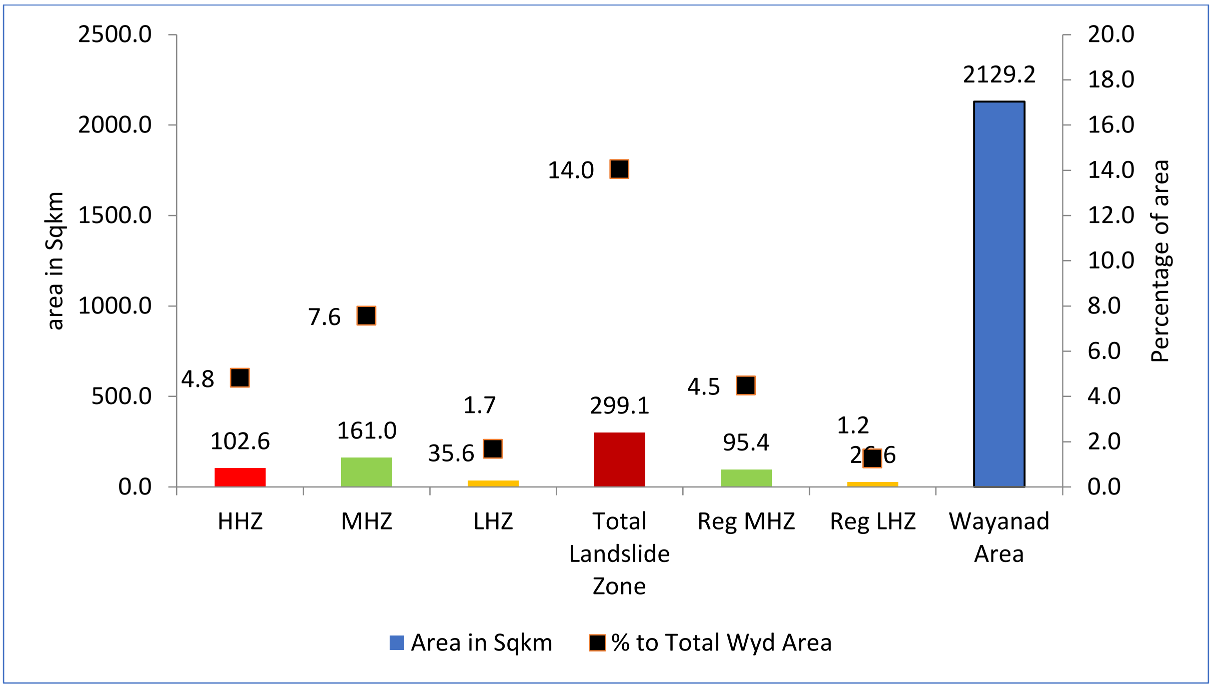

Figure 8: Overall Statistics of LHZ & Regulation

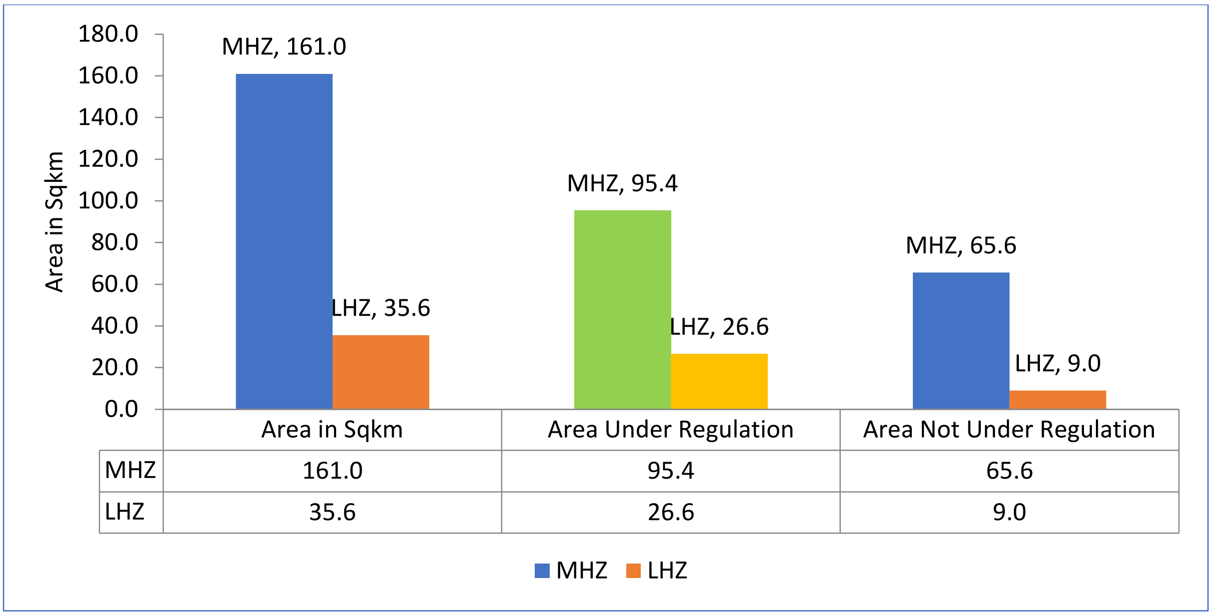

Figure 9: Area regulated & Non regulated are from HHZ fall to Medium, Low Hazard.

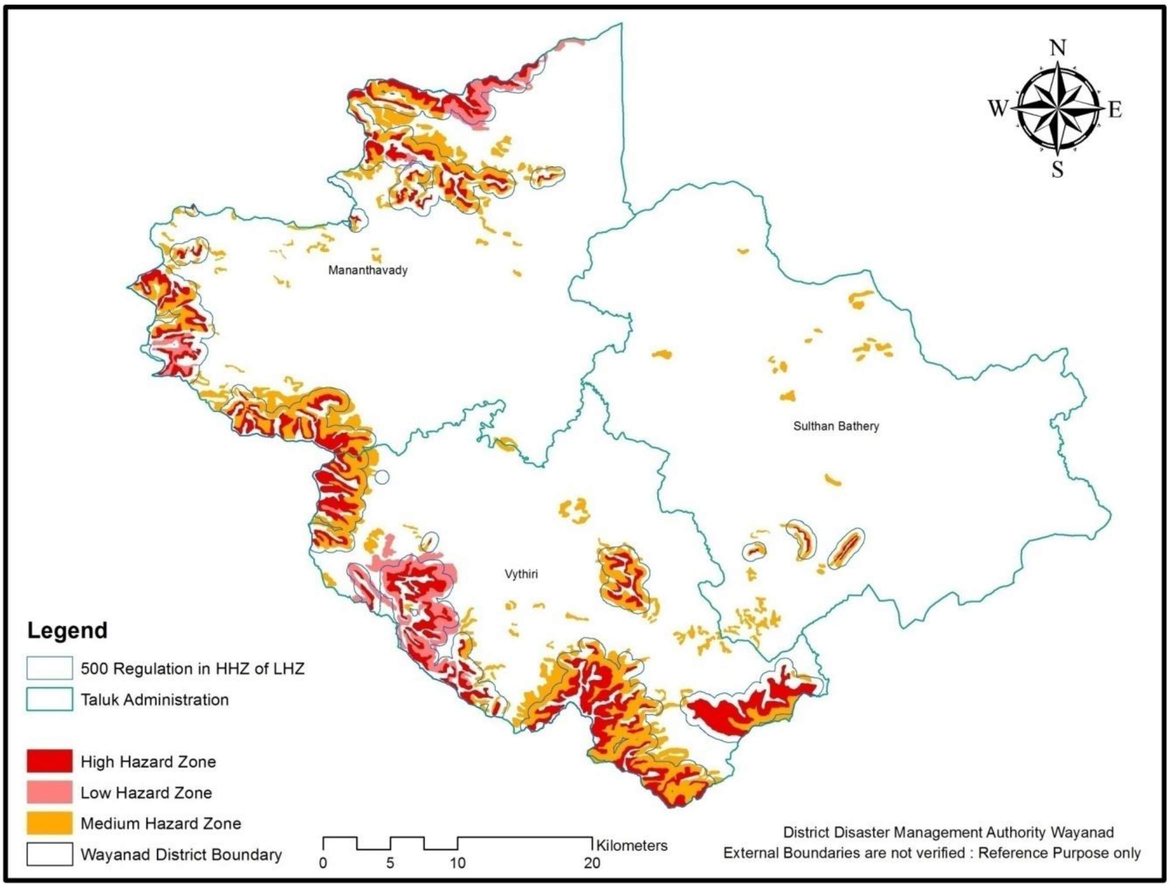

Figure 10: Map showing Landslide Hazard Zone & regulated area.

The area under regulations taluk wise is as shown in the Table No.1. The statistics of Landslide hazard zone and regulated area shown in Figure No. 8, 9 & 10. Figure No. 11. denotes the regular inspection carried by the Hazard Analyst DEOC official and other stakeholders to know the site is under regulated zone for safe construction practice. The inspection involves in sanction of necessary recommendations to the DDMA chairman to finalize the and pass the requisition of the client who is the seeker for permission for such construction as per KMBR mandates.

Table. 1: The Village & Taluk under regulation 500 meter from HHZ.

Sl.no	No. of Village	Village	Taluk	Area (Sq.km)
1	1	Nenmeri	Sulthan Bathery	1.02
2	2	Ambalavayal	Sulthan Bathery	0.14
3	1	Mannanthavady	Mananthavady	2.54
4	2	Periya	Mananthavady	0.70
5	3	Kanjirangad	Mananthavady	2.12
6	4	Thavinhal	Mananthavady	2.33
7	5	Thirunelly	Mananthavady	11.26
8	6	Thondernad	Mananthavady	12.29
9	7	Thrissileri	Mananthavady	1.30
10	8	Vellamunda	Mananthavady	4.04
11	1	Muppainad	Vythiri	10.19
12	2	Muttil South	Vythiri	0.31
13	3	Padinjarathara	Vythiri	6.24
14	4	Achooranam	Vythiri	0.92
15	5	Kalpetta	Vythiri	0.66
16	6	Kottappady	Vythiri	12.10
17	7	Kunnathidavaka	Vythiri	4.99
18	8	Pozhuthana	Vythiri	9.27
19	9	Tariyod	Vythiri	5.12
20	10	Thrikkepatta	Vythiri	2.67
21	11	Vellarimala	Vythiri	12.37

The figure number 11 A depicts the site location came for query to ensure the land falls in the High hazard Zone or not. The ground level GPS inspection resulted and reflected in the figure number 11 A. stated that the presumed location falls away from the HHZ with a distance of 99.9 meter. As per confidentiality the Figure number 11 location can't be disclosed unless until government directions.

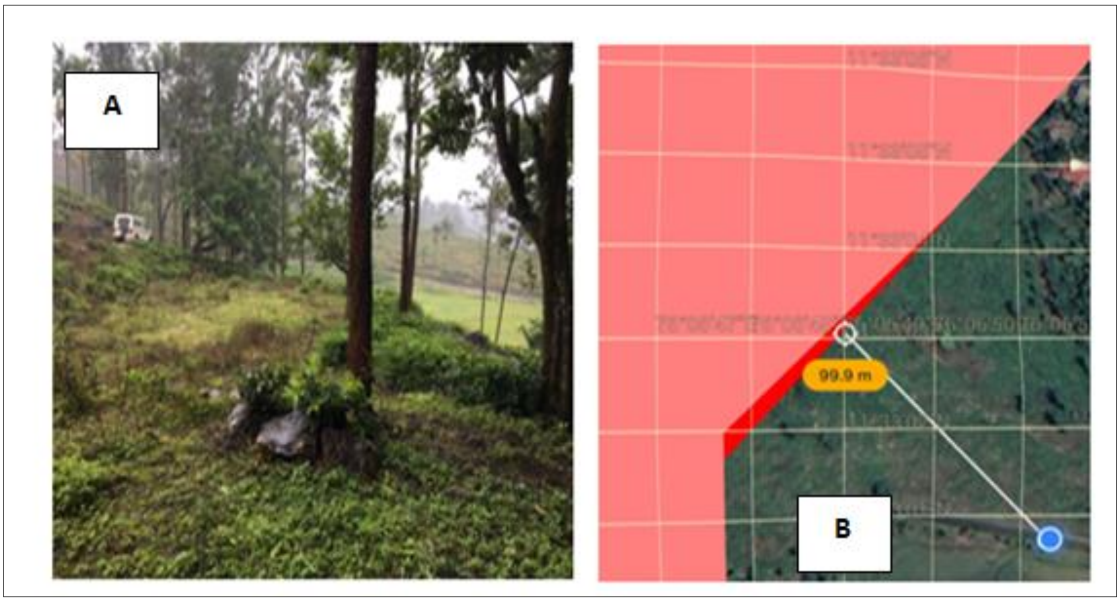

Figure 11: Example site, of regular inspection carried under HHZ by DDMA.

B. Restriction of Construction, Quarrying, Mining, and land development activities

As per the order of the District Collector File No.DCWYD/9464/2019-DEOC 1 in the light of the legally affirmative points described and in exercise of the powers conferred under sections 30(1), 30(2)(iii), 30(2) (v), 34(h) and 34 (m) of the Disaster Management Act 2005, that; The consecutive order starts from section 16 of the proceedings;

(A) The Secretaries of all Grama Panchayats and Municipalities are hereby ordered to ensure that;

i) Permission to construct buildings shall be allowed in Landslide Prone Area in Wayanad district to those buildings coming under Group A, B, C and D Height of such buildings coming under this category shall be limited to 8 meters and 2 floor levels. While calculating the height of the building and number of floors, all floors including any cellar or mezzanine floors shall be included; but the stair or lift head room, water tank and parapet wall shall be excluded. The built up area of such buildings shall not exceed 200 square meter. Any building coming under Group B, C and D in the Landslide Prone Area will be permitted based on merits after rigorous scrutiny by the Core Committee

ii) No construction coming under the Group E, mentioned in Table 1 of the order (refer the order *File No.DCWYD/9464/2019-DEOC 1)* above, shall be permitted at Landslide Prone Area, henceforth.

iii) It shall also be ensured that the construction of those buildings coming under Group B, C and D is compulsorily designed structurally to avoid the disaster of building collapse and to withstand landslide disaster. It shall further be ensured that such constructions will not result in the construction of an unsafe building.

iv) Secretaries of Grama Panchayats and Municipalities shall make sure that the above conditions are fulfilled while issuing building permits. They shall also reconsider the existing permits based on the report of Expert Committee and renew the permits only if it comply with the corrective actions suggested by the Expert Committee constituted here under.

(B) The Secretaries of all Grama Panchayats and Municipalities, the Tahsildars of Sulthan Bathery, Mananthavadi and Vythiri Taluks, The District Soil Conservation Officer and the Geologist are here by ordered that

i) No quarrying and mining activities shall be permitted at any Landslide prone area. If any such quarrying or mining is happening at any Landslide prone area, the Tahsildar shall get them closed after issuing notice within two weeks after giving them a reasonable opportunity of being heard. In any case, the final decision on the matter shall be arrived at, within one month from the date of this order.

ii) The Tahsildars and Secretaries of Grama Panchayats and Municipalities shall ensure that no quarry is functioning outside Landslide hazard prone areas without valid permits and licenses. The documents obtained by Quarrying units shall be mandatorily re-examined by the Geologist, before 20.9.2019 to ensure that all the conditions in the permit are rigorously followed. If any Quarrying unit does not follow the conditions prescribed in license or permit, as envisaged in statutes, then such units shall not be permitted to operate further.

iii) The Geologist and the District Soil Conservation Officer shall re-assess the probability of landslips or landslides within a radius of one kilometer area of all quarrying units in the district, within 3 months from the date of this order.

iv) The Geologist and the District Soil Conservation Officer shall thoroughly examine all landslips, landslides and soil piping etc that took place or present in the 1 kilometer radius of quarry area to asses the adverse impact of quarrying on the disaster situation/vulnerability in that locality.

v) The Geologist shall asses the quantity of minerals extracted, details of explosives used, number of workmen engaged and area under mining with reference to the existing quarrying/ mining permits issued, within one month form the date of this order

(C) The District Geologist, the Secretaries of all Grama Panchayats and Municipalities and Tahsildar, Vythiri/Mananthavadi/Sulthan Bathery are hereby ordered to ensure that

i) No mechanised excavation of ordinary earth shall be permitted at any Landslide prone area. In case of removal of ordinary earth fell down as part of any disaster, then the same
may be removed with the approval of Tahsildar based on the recommendation of Geologist . No cutting of earth (other than the minimum required for providing the footing/foundation of the building or construction of drinking water well or construction of the necessary sanitary and water supply constructions for the building) shall be permitted in Landslide Prone Area.

ii) All the constructions are so designed as to avoid cutting and leveling of ordinary earth to the maximum possible extent and without disturbing the natural landscape. Cutting of ordinary earth shall be permitted only in accordance with the relevant provisions contained in acts, rules and orders connected thereto. In any case, the cutting of ordinary earth to a height of more than three meters shall not be permitted, unless proper stepping is provided at each 3 meter intervals of vertical height. The horizontal measurement of each such step shall not be less than 2 meters.

(D) The Secretaries of all Grama Panchayats and Municipalities are hereby ordered to ensure that

iii) all Lodging Houses and other buildings under Group E which are registered under the Madras Public Health Act, 1939 or any other act or rule for the time being in force in the concerned Grama Panchayat or Municipality, comply with all the specific requirements contained therein, in the said rule or act, with respect to ensuring the safety of occupants and community. Any Lodging House or other building coming under Group E mentioned in Table 1, which violates any of the said provisions, shall not be permitted to continue its operation or business, without rectifying the said violation. The Secretary shall issue notice to all such Lodging Houses or other Building coming under Group E, which do not comply with such specific requirements, within two weeks positively and decide the case after giving them a reasonable opportunity of being heard. In any case, the final decision on all such cases shall be arrived at within a period of three months from the date of this order.

iv) all lodging Houses and other buildings coming under Group E which are not registered with the Grama Panchayat or the Municipality, as the case may be, are reasonably presumed to be not taking such registration, for the reason that they are not complying with the safety provisions enlisted in various statutes like the Madras Public Health Act, 1939; the Kerala Municipal Building Rules, 1999; the Kerala Panchayat Building Rules, 2010 etc. So the functioning of such un-registered Lodging Houses, can trigger disasters. Therefore, action shall be taken to close down such un-registered Lodging Houses forthwith. They shall be permitted to restart their functioning only after complying with all provisions and obtaining valid registration from the Grama Panchayat or Municipality. The Secretary shall issue notice to all such Lodging Houses within two weeks positively and take final decision on all such cases within a period of three months from the date of this order, after giving them a reasonable opportunity of being heard.

v) No lodging house or other building coming under the Group E, mentioned in Table 1 above, shall be permitted to operate in an Unsafe Building, as defined in rule 2(1)(db) of Kerala Panchayat Building Rules, 2011 and Rule 2(1)(ch) of the Kerala Municipal Building Rules 1999.

vi) Any construction proposed for a building in a land which constitute an angle of 45 degree or more with the horizontal plane or on soil unsuitable for percolation or on area shown as floodable area or in sandy beds shall be permitted only after rigorously ensuring the conditions stipulated in rule 26(3) of the Kerala Panchayat Building Rules, 2011 and Rule 23(3) or Kerala Municipal Building Rules, 1999.

(E) The Secretaries of all Grama Panchayats and Municipalities are hereby ordered that;

a). It shall be ensured that no construction or land development is done in such a way as to disturb the natural flow of any water course except the ones which are meant for disaster management operations and those which are permitted under the Kerala Irrigation and Water Conservation Act, 2003.

b). All artificially created water storage units created by blocking or altering the natural flow of water, except the ones used by the public or used by the local Self Government Institutions for water supply schemes, constructed at any Landslide Prone area shall be safely drained and demolished. No further water storage will be permitted in such artificial water bodies. It is made clear that this will not be applicable to drinking water wells and natural water bodies.

Any reference to the term "Water Course" in this order shall mean a river, stream, spring, channel, lake or any natural collection of water situated both in a private land and government lands and includes any tributary or branch of any river, stream, spring or channel.

(F) Any reference to the term "Landslide Prone Area" in this order shall include the area marked as Landslide Prone Area in the Landslide Zonation Map referred to in paragraph 6 above and all the land coming within 500 meter radial distance from all the boundary points of the said area.

(G) Order is issued under section 28 of the Disaster Management Act, to the following effect,

i) All existing buildings of Group B,C,D,E and Buildings in Group A with more than 200 square meter area situated in Landslide Prone area and Buildings having more than 5 floors and situate within either the flood prone area or Landslide Prone area or within 500 meter radial distance from any of the building collapse cases reported during the last five years shall be scrutinised by an Expert Committee, to see whether these structures pose any serious threat of disaster. The Expert Committee is hereby constituted under section 28 of the Disaster Management Act, 2005 with the following members

(H) CEO, DDMA & Additional District Magistrate (Chairman)

(I) Civil Engineering Expert from National Institute of Technology, Calicut

(J) Expert from the CWRDM, Kozhikkode

(K) Expert from the NCESS, Thiruvananthapuram

(L) District Town Planner, Wayanad

(M) District Soil Conservation Officer (Convener)

Note: For more clarification refer the website of District Administration Wayanad and section of Disaster Management Tab: https://wayanad.gov.in/en/dm-orders/

C. Landslide Early Warning in Wayanad

a) Community Based Rainfall Monitoring System (CBRMS) as early warning

Background: The origin of the community based rainfall monitoring system to the DDMA Wayanad was necessitated based upon the vulnerabilities posed by the erratic rainfall patterns and landslide susceptibility nature. The alarming issue was to be tackled down rather relaying on the 6 IMD rainfall monitoring stations and the monsoon alert message received from the KSDMA. The possible alert had only wider possibility to rely in a broader approach than that has its probability to occur rainfall in entire wayanad region was objective in nature. The actual quantum of rainfall was not known and was limited to these location only, as these 6 AWS stations can only provide coarse data for the entire district and was homogenized data that varies in ground reality.

This issue was tackled down, as the association of DDMA with HUME Center for Ecology and Wildlife Biology specialist gave better understanding & necessity of monitoring rainfall in a near real-time manner than of automated services. A memorandum of understanding was (MoU) thus signed with the center to approach and help the DDMA wayanad. The rainfall monitoring stations were extrapolated to 144 Local Self Government Department (LSGD) Panchayath wise location initially. The community people has been playing a vital role in collecting, compiling data systematically, scientifically the rainfall from the manual rain gauges installed in these 144 location entire Wayanad. The local people or the community people involvement has changed scenario of monitoring and has stood as a role model for this great initiative. People from varied field, households, homemakers, other stakeholders were amongst these 144 location who rigorously does the monitoring work in daily basis. They are taught scientific procedures, how to collect data (measure rainfall from ran gauge), where, when, and how to disseminate the collected information of rainfall to the DDMA wayanad.

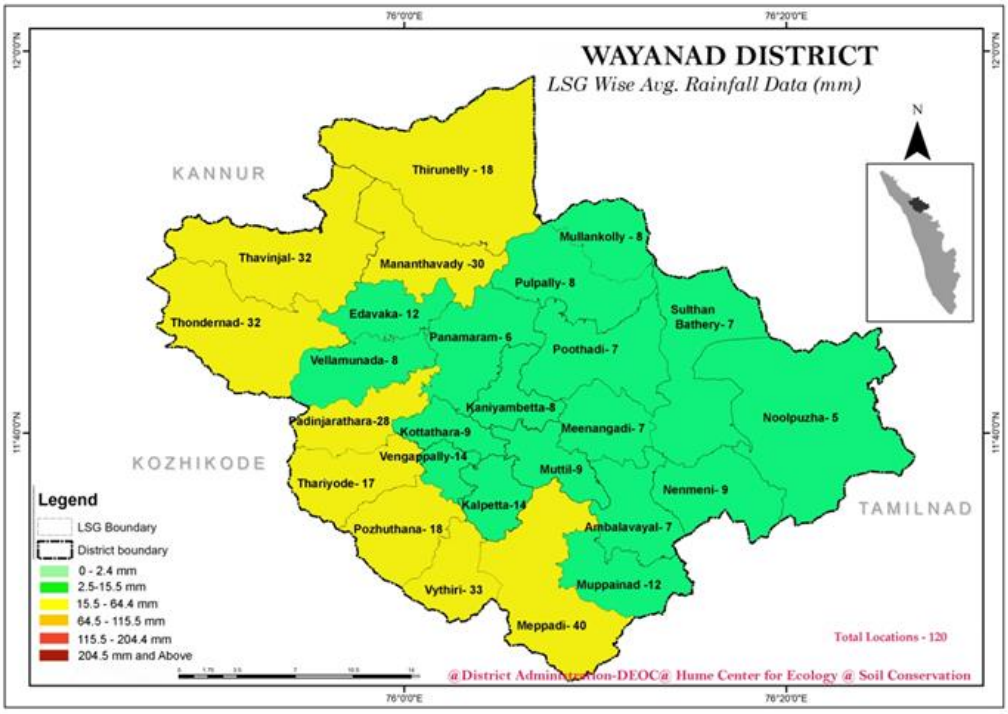

Figure 12: Rainfall Alert Maps during 2021.

To disseminate the rainfall information, the community people were pooled into social media platform WhatApp Group Named : Wayanad Weather Forecast (WWF) (Figure No.13) where they can readily share the information of local rain and temperature. These are plotted to generate rainfall (Figure No.12 ,13 & 15) and temperature maps. The locations were compiled with other rainfall monitoring stations (IMD, KSEB & Irrigation) and thus and thus DDMA Wayanad has now 156 rainfall monitoring stations (Figure No.15.).

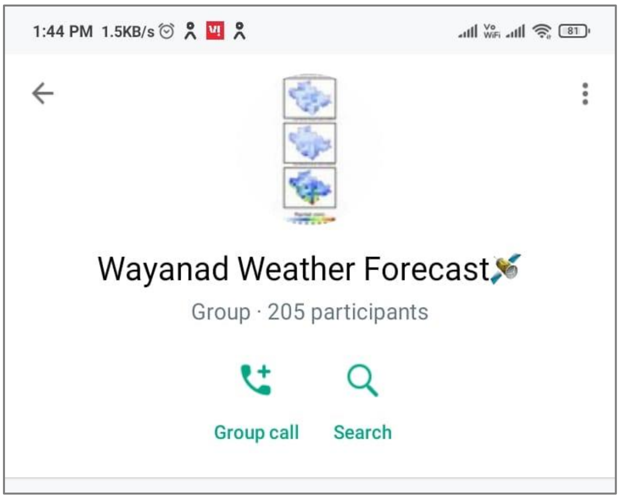

Figure 13: Wayanad Weather Forecast WhatsApp Group representation.

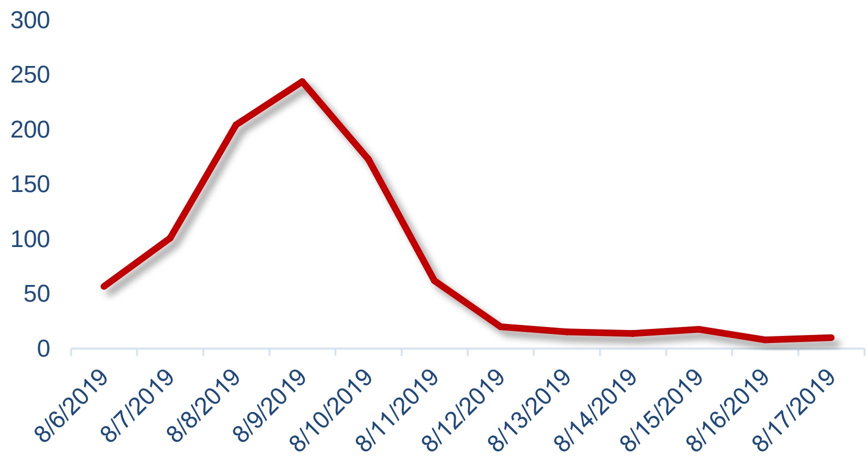

Figure 14: Example of Rainfall data received from (CBRMS - WWF) during 2019.

During the time of pre monsoon season and monsoon emergency situations the rainfall alerts are issued to the local authorities (Village offices & Panchayath offices) and various line department to be prepared and tackle the emergency situations if occurred from the DEOC the Emergency Support Function gets activated along with the Incident Response System (IRS)/Incident Response Team (IRT) as per the '*Orange Book*' of KSDMA.

b) School Based Rainfall Monitoring System (SBRMS) as early warning measures.

The project varuna or (SBRMS) is the recent initiative of the DDMA to monitor the rainfall through the School Disaster Management Clubs (SDMC). Each schools are provided with 'Manual Rain gauge' to collect the rainfall data as an activity to the DM club students. A total of 40 DM cadets from each school has mutual role to learn Disaster Management and they are provided with the scientific gist to know how to monitor/use of rainfall and help the DDMA Wayanad to assess and release warnings at times of Monsoon emergencies. This is a prospective work undergoing by all schools of wayanad. Thus a total of 198 schools were identified and having 198 rainfall monitoring system (Figure No.16.); all the schools i.e., higher secondary, high schools regardless to being government, private, aided and unaided schools are all instructed to form SDMC. The collection of rainfall is been prescribed based under the supervision of designated teachers as the Charge Officers (CO's).

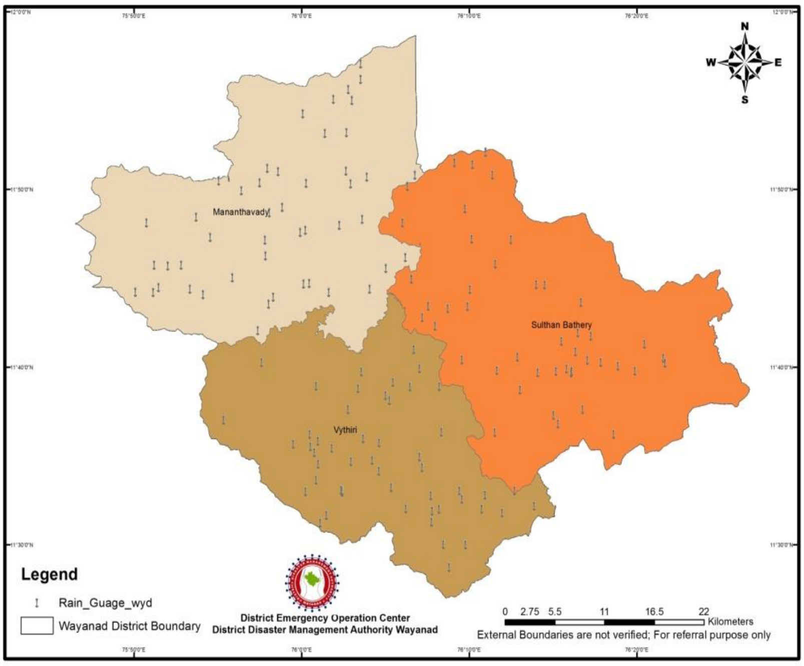

Figure 15: Community Based Rainfall Monitoring Stations (156 Locations).

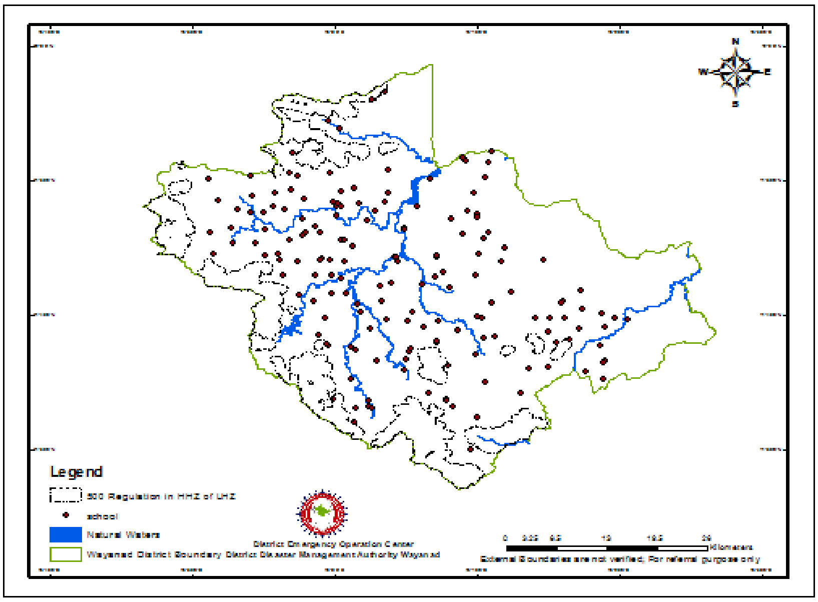

Figure 16: School Based Rainfall Monitoring Stations (Project Varuna).

Totally Wayanad DDMA will have 354 rainfall monitoring station and is a monitored by local community people & school students with other government rain gauge stations (Figure No.17). The benefits of CBRMS, it helped in saving of many life's during 8th August 2019 of Mundakai landslide incident. On the day 240 mm rainfall for 24 hours was received at the region and prolonged for two days. Totally, 34 Families were evacuated contained 177 persons. The incident might had taken away 22 persons life's if not evacuated early by the help of the data received from CBRMS. After evacuation 4 houses were fully damaged at the site of incident, on the same day of puthumala landslide incident

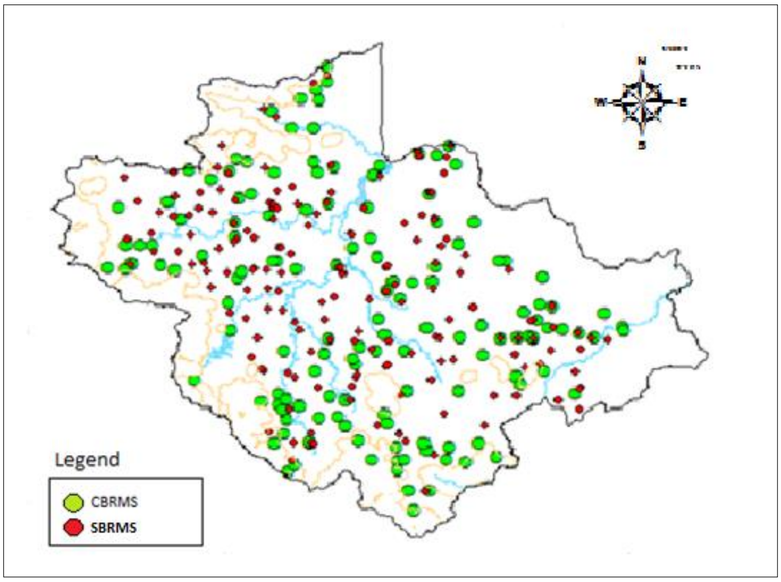

Figure 17: 354 Rainfall Monitoring Stations illustration.

https://www.newindianexpress.com/states/kerala/2020/aug/19/heres-how-wayanad-succe

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Here's how Wayanad successfully reduced monsoon havoc using micro-rainfall data

This year, Wayanad went for its own model and prepared well in advance which seems to have saved many lives.

Published: 19th August 2020 12:43 PM | Last Updated: 19th August 2020 12:43 PM

A+ A A-

Figure 18: News Report by New Indian Express

NEWS

Wayanad went for its own model and prepared well in advance which seems to have saved many lives.The landslide/flood-prone high range district took readings from 55 local stations, fixed a sealing of 1000 mm rainfall and evacuated people from places which received rain above the mark. The proof is that one among the places which received highest rainfall- Mundakai- reported a medium-scale landslide on expected lines on August 7, completely destroying four houses. But there was zero human casualty as hundreds of people in the area were already shifted to safer places.

Link of the News report:
https://www.newindianexpress.com/states/kerala/2020/aug/19/heres-how-wayanad-successfully-reduced-monsoon-havoc-using-micro-rainfall-data-2185485.html

Akhildev et al., 2023.

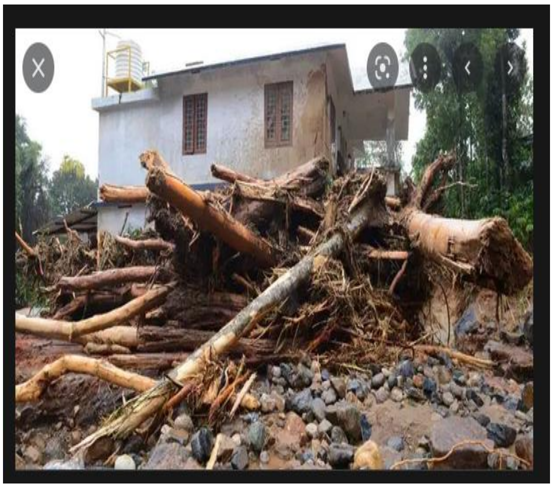


Figure 19 & Figure 20: Mundakai Landslide Incident Site 8th Aug 2019.

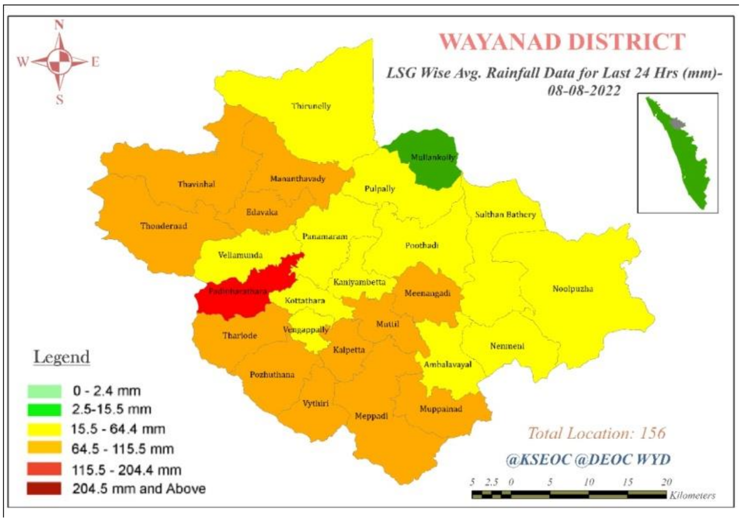

Figure 21: Rainfall Alert Maps for LSGDs during monsoon emergencies

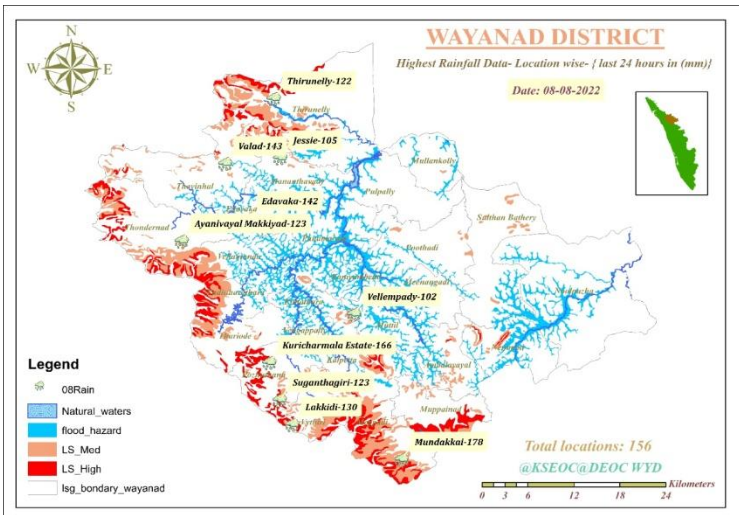

Figure 22: Rainfall Alert Maps during monsoon emergencies

c) District Emergency Operations Centre (DEOC) Wayanad

The DEOC is the nodal nerve agency of the DDMA wayanad that carries the emergency operations during the time of disaster situations in the district the Figure 23. denotes the operation procedures of the DDMA & DEOC. The DDMA & DEOC will receive the alert information from the Kerala State Emergency Operation Centre (KSEOC) the information is then passed to the local bodies and line departments through WhatsApp communication from the DEOC to take necessary actions. The Taluk emergency operations (TEOC) will be active and the officials will be alerted during the time. The Inter Agency Groups (IAG) will be notified with the alerts and they take upon the actions and be prepared to tackle down the emergency situations. Proper IRS system and IRT, ERT also simultaneously gets activated.

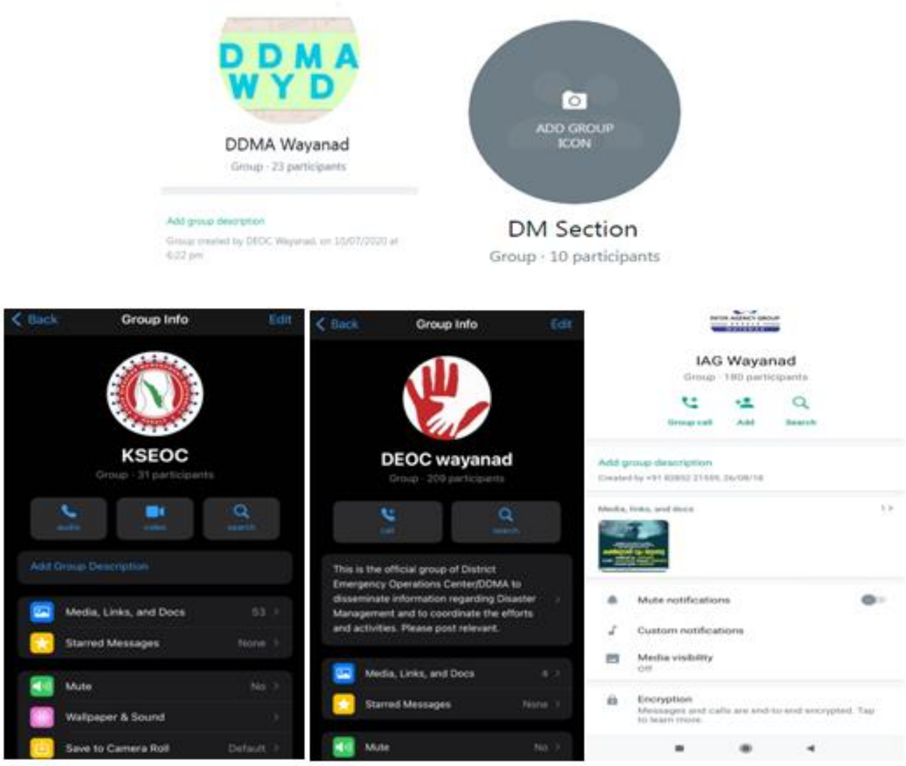

Figure 23: The DDMA & Emergency Operation with Emergency Support Function.

d) Best practice of DDMA & Government towards Landslide Rehabilitation

In wake of the Rehabilitation for 52 ~ Families ~ (Meppadi) – Rebuild Kerala Initiative, HARSHAM (Happiness And Resilience Shared Across Meppadi) project was rendered. A total of 52 families were rehabilitated and provided with Houses of 650 Sq. Feet at a cost of 6.5 Lakhs. and Rs. 4 Lakhs assistance given by the government. Houses were constructed with the assistance from NGO's; Calicut Care Foundation, Peoples Foundation, Act on, Human Rights Protection Mission, Thanal. A total of 10 Lakhs was the total cost involved for rehabilitating 1 family each (Figure No. 24).

Figure 24: HARSHAM (Happiness And Resilience Shared Across Meppadi) Project.

CONCLUSION

The novel initiatives of the DDMA wayanad and then Collectors & the Chairman DDMA has really brought out role model to other districts in the state of Kerala and other parts of the country towards hilly areas to take necessary measures as of the DDMA Wayanad has put out for the betterment of the people and has achieved in alleviating the landslide disaster risk (LsDRR) through proper governance for safer & better tomorrow in a responsible manner in arena of public administration.

ACKNOWLEDGMENT

All, the then collectors and the Chairman DDMA is hereby acknowledged to their commendable efforts made in alleviating the disaster risk posed by landslide and has institutionalized proper channel for Disaster Risk Reduction. I hereby thank our District Collector, Chairman DDMA Wayanad Smt. A Geetha I.A.S. and CEO DDMA, Shri. Shaju N.I. as my Immediate Reporting Officer (IRO) providing me necessary sanction to present this DDMA initiatives and efforts in the ILDMs International conference as a paper. Thankful to the team DM section & Junior Superintendent DM for the necessary arrangements. I thank Member Secretary, KSDMA Dr. Shekar Lukose Kuriokose for rendering this opportunity.

REFERENCE/BIBLIOGRAPHY

No scientific literature were accorded in this running text of the paper. Henceforth, typical scientific referencing in APA style is not been cited. Provided the source of some internal documents of DDMA wayanad has to been referenced as listed below.

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IDENTIFICATION OF RAIN SHADOW REGION IN ATTAPPADY BY USING COMPOSITE APPROACH OF REMOTE SENSING, GEOGRAPHICAL INFORMATION SYSTEMS, AND ANALYTICAL HIERARCHY PROCESS: A CASE STUDY OF PUDUR PANCHAYAT.

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Abstract:

Climate of the region is determined by various climatic controls, especially the physical barrier of the region. Mountains and other land barriers are likely to cause orographic precipitation and rain shadow effects. The term rain shadow denotes that the decrease in precipitation on the leeward side of a topographical obstacle as compared to regions of windward slope of the barrier. The climate of both sides is entirely different one, especially in the case of rainfall and temperature distribution. Orographic barrier plays an important role in the rainfall distribution over the Western Ghats regions of South India, especially in the Pudur Panchayat of Attappady Taluk of Kerala. The Pudur Panchayat differs from the rest of Attappady Taluk area mainly because of the rainfall characteristics and its peculiar geographical location and physiography. Average rainfall in the Western region of Pudur Panchayat is 3000mm/year whereas the Eastern region gets less than 600 mm/year. The dryness in the eastern section has been linked to the rain shadow effect of the physical barrier. This rain shadow effect creates a micro climate region with unique climatic feature. To identify rain shadow region of Pudur Panchayat of Attappady Taluk in the Palakkad district of Kerala, used the composite approach of Remote Sensing, Geographical Information Systems, and Analytical Hierarchy Process-based multi-criteria analysis. Based on the result of the study the whole area of the Pudur Panchayat is divided mainly into two categories; wet climate zone (50.01 percent) and rain shadow region (49.99 percent). The rain shadow regions are situated in the eastern part of the Pudur Panchayat.

Keywords:

Rain shadow region; Orographic precipitation; Geographical Information Systems; Analytical Hierarchy Process.

INTRODUCTION

The physical barrier of the region has important role in determine the climate of the region. Mountains and other land barriers are likely to cause orographic precipitation and rain shadow effects. Orographic effect brings not only the initiation and intensification of precipitation on the windward side of mountains and hills but also the relative deficit of precipitation on the lee side and leads to the creation of the "rain-shadow region". Rain-shadow region is a microclimate region with distinctive climate feature. Rain shadow development has noticed the various part of the world. It is also found in the leeward side of Western Ghats of Peninsular India because of its peculiar geographical location and physiography. There is a drastic difference in the rainfall distribution between the western and eastern side Pudur Panchayat of Attappady Taluk of Kerala. Therefore, the main objective of this study is to identify and demarcate the rain shadow region of the Pudur Panchayat of Attappady Taluk of Kerala, India by using composite approach of remote sensing, geographical information systems, and analytical hierarchy process.

STUDY AREA

The research area, Pudur grama Panchayat situated in the Attappady taluk of Palakkad district of Kerala and lies in between the Nilgiri hill ranges in the North and Vellinkiri hill ranges in the South both having a height of over 1200 meters. Pudur grama Panchayat is one of the grama Panchayat of Attappady taluk. Pudur and Padavayal are two villages of Pudur grama Panchayat. Pudur grama Panchayat located between 11°3'50.90''N to 11°16'17.16''N and 76°23'16.37''E to 76°43'58.08''E and the total geographical area is 370.26 Km^2. Physically Pudur grama Panchayat is a plateau with 750 – 1000 meters rising from the undulating mid lands. This area is flanked by mountain ranges, the Nilgiris in the north, and extension of the Western Ghats in the south and the east and merges with the plains of Coimbatore and its general slope is towards north-east. The eastern side of Panchayat shares the border with Tamil Nadu.

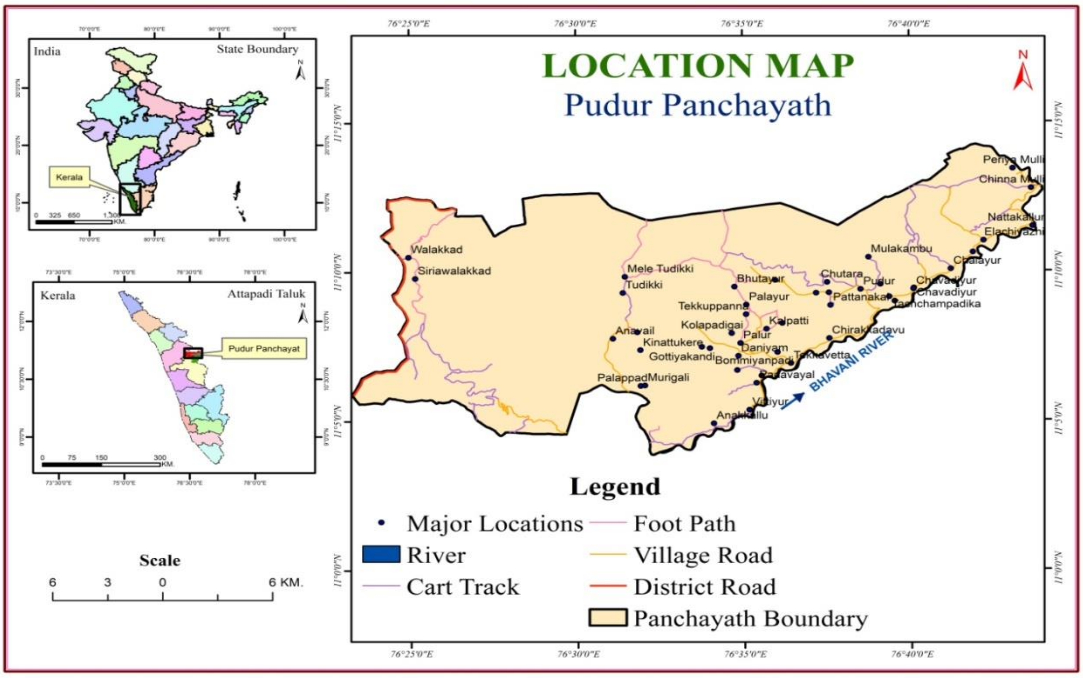

Figure 1 Study Area

K. R. Baiju, Karunakaran Akhildev, Joice K. Joseph, Naveen Babu, Anithomas Idiculla, Asha Rose, Shibu K. Mani, Mahesh Mohan, and A. P. Pradeepkumar. (2023). Proceedings Volume of the 5th International Disaster, Risk and Vulnerability Conference (DRVC) January 19th – 21st, 2023. School of Environmental Sciences, Mahatma Gandhi University, Kottayam, Kerala, India – 686560. p- 1 to 447

OBJECTIVE

The main objective of the present research is

- To identify and demarcate the rain shadow region of the Pudur Panchayat of Attappady Taluk of Kerala, India by using composite approach of remote sensing, geographical information systems, and analytical hierarchy process.

REVIEW OF LITERATURE

Orographic effect brings not only the initiation and intensification of precipitation on the windward side of mountains and hills but also the relative deficit of precipitation on the lee side (Atkinson, 1983; Smith, 1979). A region of low precipitation in the lee of topography is "rain-shadow". Therefore, the rain shadow development is the function of both topography and atmospheric state. (Sobel et al., 2003 and (Abdulrazak et al., 1995) found that the amount of rainfall on the windward slopes is higher than leeward slopes of the mountains due to the blocking of winds carrying moisture from nearby water bodies. Recent studies have shown that the magnitude of the rain-shadow effect varies significantly from storm to storm, location to location and year to year (Leung et al., 2004; Siler et al., 2013). The frequency and magnitude of the distribution of rainfall amounts varies across the mountain barrier and bring climatic changes on both sides of the barrier. The term rain shadow denotes the decrease in precipitation on the leeward side of a topographical obstacle and explains that the maximum of orographic precipitation falls on the windward side and decreases beyond the summits. Quantifying the orographic rain shadow effect requires two precipitation zones namely regions of orographic enhancement and regions of depletion (Malaby et al., 2007). Stockham et al., (2018) attempted to quantify the magnitude of the rain-shadow effect by using rain gauge observational data Diffenbaugh et al,(2005) used Regional Climate Model (RCM) output to examine anomalies in lee-side mean annual precipitation in the orographic rain shadow regions .

The Western Ghats of Peninsular India interacts with the southwest monsoon and creates a varied climate pattern in the Peninsular India (Gunnell, 1997). As a result, state of Kerala which located in windward side of the Western Ghats is a subject to high rainfall, while the majority of state of Tamil Nadu is located in the rain shadow zone (Sahu, 2018). Pudur Panchayat of the Attappady Taluk which lies in the Western Ghats of Kerala experiences Orographic effect because of its peculiar geographical location and physiography. There is a drastic difference in the rainfall distribution between the western and eastern side of Attappady Taluk (Manikkandan, 2016**).**The dryness in the eastern side can be attributed to the rain shadow effect of the mountains

MATERIALS AND METHODS

To identify the rain shadow zone, multiple satellite images were garnered from different web-sources and used them as data sources and prepared the parameters for the study .Ten thematic layers were mainly prepared for this study, viz. Rainfall, Elevation, Land use Land cover, Relative humidity, Temperature, Wind speed, Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), Soil Moisture Index (SMI),and Temperature Vegetation Precipitation Dryness Index (TVPDI) as the effective factors. The data needed was obtained from https://disc.gsfc.nasa.gov/earthdata, ALOS DEM (12.5 Meter

Resolution), NASA POWER | Data Access Viewer, and https://earthexplorer.usgs.gov/-Landsat 8 OLI/TIRS C1 Level-1, Path 144, Row: 052, Dated on 27-January, 2020.The thematic layers were mapped by digitizing and the data has been processed by using various GIS tools. The AHP model applied in this study to determine weights and ranks of different parameters for the rain shadow index model.In this method, each factor assigned rank on a scale of one to nine by assessing each element based on Saaty's scale (Table 1).After the preparation of ten thematic maps, demarcated rain shadow region by weighted overlay analysis in the GIS.

Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) method was used in this study for identification of the rain shadow region.AHP method was developed by Saaty (1990) The AHP model applied in this study to determine weights and ranks of different parameters for the rain shadow index model.In this method, each factor assigned rank on a scale of one to nine by assessing each element based on Saaty's scale (Table 1)

Table 1 Saaty's scale (1980) for pairwise comparison of parameters

Intensity of Importance	Scaling
Extreme importance	9
Very to extremely strong importance	8
Very strong importance	**7**
Strong to very strong importance	6
Strong importance	5
Moderate to strong importance	4
Moderate importance	3
Equal to moderate importance	2
Equal importance	1

Source: Saaty's scale (1980)

Preparation of thematic layers

Ten thematic layers were prepared to demarcate the rain shadow zone. The major parameters used for the demarcation of rain shadow zone and steps involved are elaborated below:

Rainfall: The amount rainfall is an important component in determining whether or not a location is in the rain shadow. Rainfall data from the Tropical Rainfall Measuring Mission (TRMM) was used for this study and the data was interpolated using the spatial analysis IDW tool by GIS

Temperature, Wind Speed and Relative Humidity: Temperature (in degrees Celsius), wind speed (m/s), and relative humidity (in percent) were all acquired from NASA Power Data Access website. Sample points/areas of interest were randomly selected from both inside and outside the study area and interpolated data using the spatial analysis IDW tool.

Elevation: Elevation has an important role in the distribution of climatic elements, especially in rainfall. The relief image was generated from the Advanced Land Observation Satellite (ALOS)data (12.5 meter) using the classify method in Arc GIS platform.

Soil Moisture Index (SMI):SMI is a direct indicator of dryness of the land surface. The soil moisture index is based on empirical parameterization of the relationship between land surface temperature (LST) and normalized difference vegetation index (NDVI) The SMI has been retrieved directly according to (Moawad, 2012) using LST as follow (Equation 1);

$$SMI=\frac{(LSTmax-LST)}{(LSTmax-LSTmin)}\text{.........Eq.1}$$

Where, SMI is the Soil Moisture Index, LST max, LST min are the maximum, minimum and value of the retrieved LST respectively. LST and the NDVI were calculated from Landsat-8 Operational Land Imagery (OLI) data.

Land Surface Temperature (LST)

LST, the skin temperature of the ground, is identified as a significant variable of micro climate and radiation transfer within the atmosphere (Suresh et al, 2016). Landsat-8 OLI data having Thermal Infrared Sensor (TIRS) with two bands (band 10 and band 11 with 100 m resolution) which is useful in providing more accurate surface temperatures. Single Window Algorithm (Suresh et al, 2016) has been adopted (Equation-2) to generate LST from Landsat-8 OLI data for the study area.

LST= BT/1+W*(BT/p)*In(e)).............. Eq.2

Where, BT isthe at satellite temperature, W is the wavelength of emitted radiance (11.5µm) p is*C/S (1.438*10∧ -2mk) h = Planck's Constant (6.626*10 ∧ -34JS) s = Boltzmann Constant (1.38*10 ∧ -23J/K) C = Velocity of light (2.998 *10 ∧ 8 m/s) p = 14380.

Normalized Difference Vegetation Index (NDVI)

Normalized difference vegetation index is one of the most prominent vegetation indices used in image processing to investigate the green cover of photosynthetic plants. The following is the mathematical formula (Equation 3) for calculating NDVI:

$$NDVI = (NIR - RED) / (NIR + RED) \text{ ...... Eq.3}$$

NDVI values are vary on a scale with an upper limit of +1 and a lower limit of -1, When the higher the value on the NDVI scale, the surface vegetation is more photosynthetically active. Negative NDVI values are used to represent non-vegetated environments such as ice, lake bodies, and rocks (i.e., values less than 0).

Temperature Vegetation Precipitation Dryness Index (TVPDI)

Remote Sensing data-based dryness methods are widely used in dryness assessments due to the large coverage range and high temporal resolution. TVPDI is a simple, operational and efficient dryness index through constructing a 3D space (P, NDVI and LST) according to the Euclidean distance method. It is used to represent the surface dryness-wetness status (Wei et al., 2020). TVPDI has been calculated by applying Wei et al., (2020) proposed method.

$$\text{Normalized LST (NLST)} = \frac{LST-LSTmin}{LSTmax-LSTmin}\text{ ....Eq.4}$$

$$\text{Normalized NDVI (NNDVI)}=\frac{NDVI-NDVImin}{NDVImax-NDVImin}\text{........... Eq.5}$$

$$\text{Normalized P(NP)} = \frac{P-Pmin}{Pmax-Pmin}\text{....................... Eq.6}$$

$$TVPDI=\sqrt{(NLSTmax-NLST)^2+(NNDVI-NNDVImin)^2+(NP-NPmin)^2}\text{.. Eq.7}$$

Where, NLST, NNDVI, and NP represent the normalized LST, NDVI, and P represent the annual mean values, and NLSTmax, NNDVImin, and NPmin represent the driest status.

Land Use Land Cover (LULC)

LULC data for the year 2015 was also created using Landsat-8 OLI data. The seven-fold classification approach of the National Remote Sensing Centre (NRSC)-Level-1 was used. Before the creation of land use data, data was pre-processed, such as preparing multispectral data (24 meters) with the band composite tool and converting the multispectral data to 15-meter resolution data using the ERDAS Imagine platform's resolution merge analysis. Google Earth Web Application and Survey of India (1: 50,000) topo sheets were used for LULC preparation.

Rain shadow index and Computation of priority scores for the thematic layers

To demarcate the rain shadow region in the GIS environment, the relative degree of influence of each parameter on the rain shadow region was computed as the priority score and AHP was employed to generate the priority score. The AHP model was applied to determine weights and ranks of different parameters for the rain shadow index model. The formula for calculating the rain shadow index is:

$$RS = \sum_{i=1}^{n} Wi * Ri*100 \text{……………………Eq.8}$$

where RS is the Rain Shadow, Wi is the weight of each parameter, and Ri is the rank of rating of the classified values under a parameter.

The analytical hierarchy process consists of two major parts. The first section is the main classification scheme of all the parameters where according to the importance of each parameter values are given and weights are calculated The second section is constructed by categorizing all the parameters into subcategory .In the pair wise comparison matrix, the rows follow the inverse value of each factor and its significance with other. After that, weighted arithmetic mean methodology has been employed to calculate the weights in the pairwise comparison matrix. The values in the pairwise comparison is normalized to acquire the normalized values in the standard pairwise comparison matrix (Equation. 8). Later, the weights of all the parameters are determined by mean row method in the standard pairwise comparison matrix.

Table - 2. Sub-criteria of each parameter and the pair wise comparison Matrix and their weights

Sl.No	**Factors**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**CR**	**Weight (Ri)**	**Rain shadow Index** $= \sum_{i=1}^{n} Wi *$ Ri*100
1	**Rainfall (in mm)**											**0.091**		
	650	1											0.29	8.12
	700	1/2	1										0.19	5.32
	800	1/3	1/2	1									0.15	4.2
	900	1/4	1/3	1/2	1								0.11	3.08
	1000	1/5	1/4	1/3	12	1							0.08	2.24
	1250	1/6	1/5	1/4	13	1/2	1						0.07	1.96

	1500	1/6	1/6	1/5	14	1/3	1/2	1					0.05	1.4
	2000	1/7	1/7	1/6	15	1/4	1/4	1/3	1				0.03	0.84
	3000	1/8	1/8	1/7	16	1/5	1/6	1/5	1/3	1			0.02	0.56
	>3000	1/9	1/9	1/8	17	1/7	1/8	1/7	1/5	1/5	1		0.01	0.28
2	**Elevation**											**0.095**		
	<500	1											0.41	7.79
	500-1000	1/2	1										0.37	7.03
	1000-1500	1/3	1/5	1									0.16	3.04
	>1500	1/4	1/7	1/5	1								0.06	1.14
3	**Wind Speed (10 Meter)**											**0.085**		
	1.88-1.92	1											0.52	8.32
	1.92-1.96	1/3	1										0.30	4.8
	1.96-1.99	1/5	1/5	1									0.13	2.08
	1.99-2.06	1/7	1/7	1/5	1								0.05	0.8
4	**Relative Humidity**											**0.038**		
	<76.29	1											0.49	5.39
	76.29 – 78.11	1/2	1										0.30	3.3
	78.11 – 79.90	1/4	1/3	1									0.16	1.76
	79.90 – 81.17	1/7	1/5	1/5	1								0.05	0.55
5	**Temperature**											**0.037**		
	23.08-23.17	1											0.40	3.2
	23.17-23.28	1	1										0.32	2.56
	23.28-23.40	1	1/3	1									0.23	1.84
	23.40-23.47	1/7	1/5	1/5	1								0.05	0.4
6	**LST**											**0.051**		
	14.61-19.33	1											0.53	3.71
	19.33 – 21.55	1/3	1										0.31	2.17
	21.55 - 24.24	1/5	1/5	1									0.11	0.77
	24.24 – 31.79	1/7	1/7	1/3	1								0.05	0.35
7	**NDVI**											**0.007**		
	-0.10 – 0.2	1											0.33	1.65

	0.2 – 0.4	1	1										0.32	1.6
	0.4 - 0.5	1	1	1									0.28	1.4
	> 5	1/3	1/5	1/5	1								0.07	0.35
8	**Land Use Land Cover**											**0.096**		
	Agricultural Land	1											0.46	1.38
	Plantation	1/3	1										0.22	0.66
	Builtup	1/5	1/3	1									0.16	0.48
	Scrub & Wasteland	1/7	1/5	1/3	1								0.09	0.27
	Forest	1/8	1/7	1/5	13	1							0.05	0.15
	Water	1/9	1/8	1/7	15	1/5	1						0.02	0.06
9	**SMI**											**0.017**		
	<0.36	1											0.42	0.84
	0.36-0.50	1/2	1										0.26	0.52
	0.50-0.61	1/3	1/2	1									0.16	0.32
	0.61-0.71	1/4	1/3	1/2	1								0.10	0.2
	0.710-0.96	1/5	1/4	1/3	12	1							0.06	0.12
10	**TVPDI**											**0.015**		
	0.41-0.75	1											0.50	0.5
	0.75-0.90	1/3	1										0.27	0.27
	0.90-1.03	1/5	1/3	1									0.13	0.13
	1.03-1.17	1/7	1/5	1/3	1								0.07	0.07
	1.17-1.47	1/9	1/7	1/5	13	1							0.03	0.03

Source: Primary

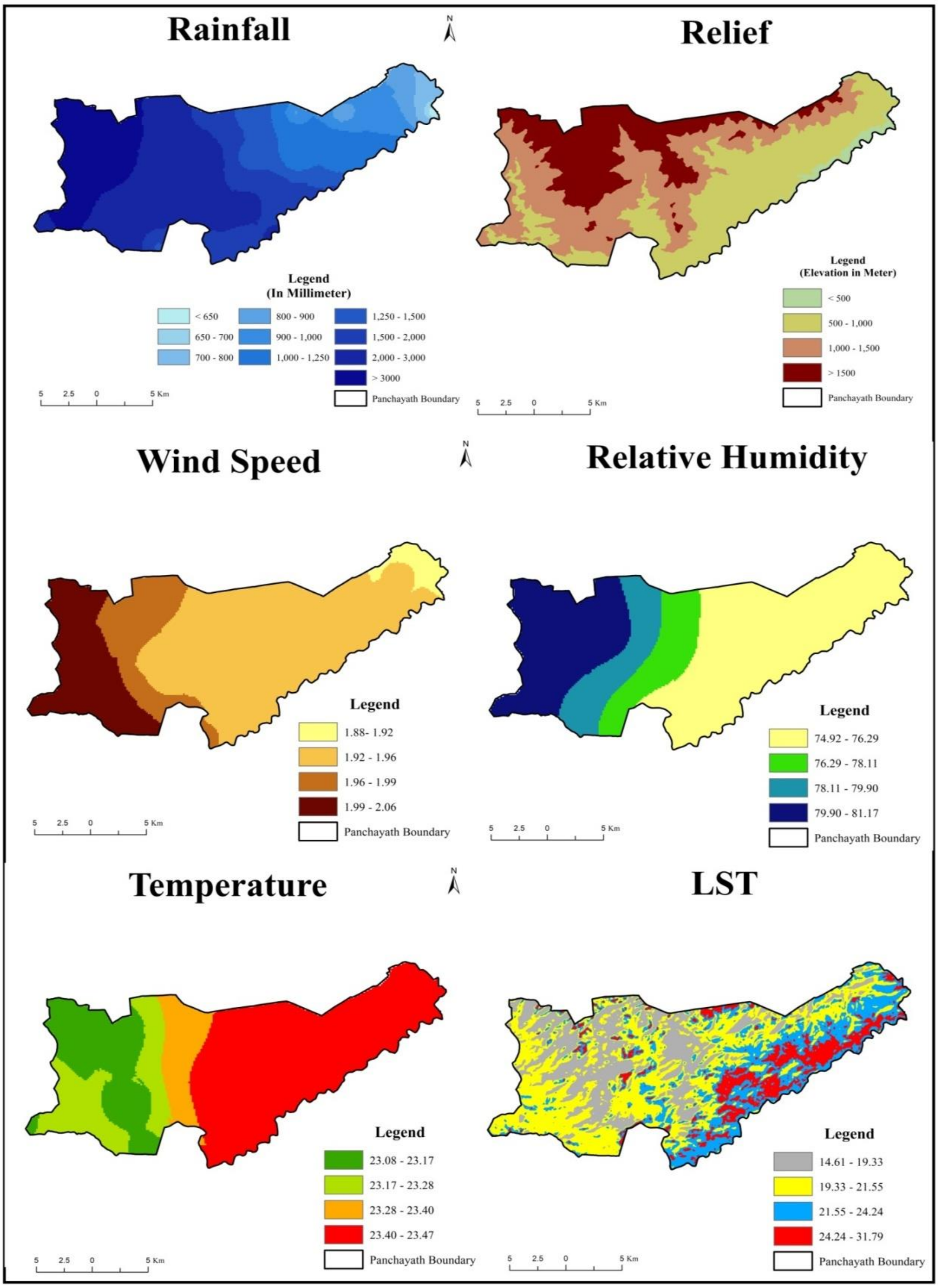

Figure2 .Map showing the rainfall distribution, relief, wind speed, relative humidity, temperature and land surface temperature of the study area

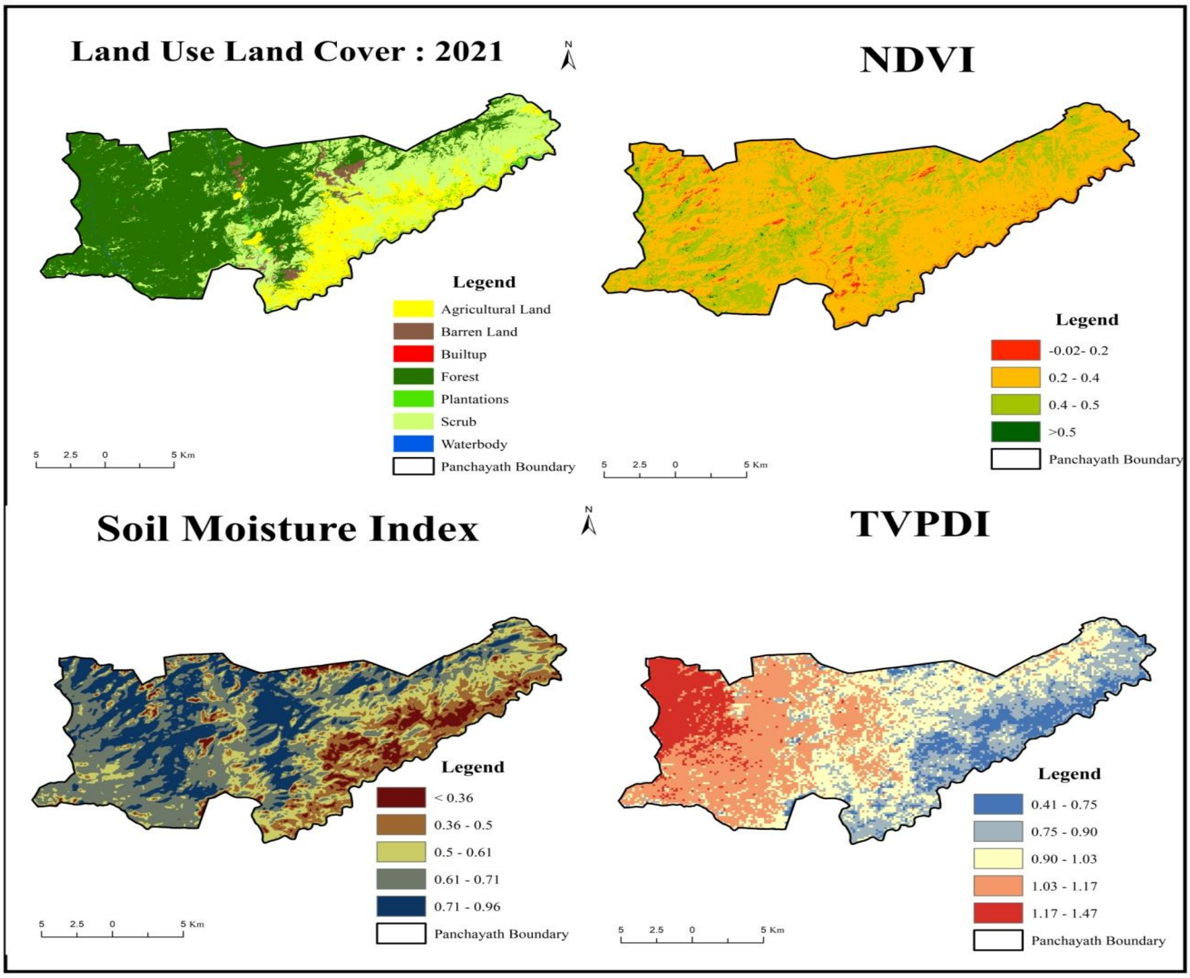

Figure 3. Map showing LULC NDVI, SMI and TVPDI of the study area

Demarcation of Rain Shadow Region

Through the composite approach by using remote sensing, GIS, and AHP based multi-criteria analysis, demarcated rain shadow region of Pudur panchyat of Attappady taluk, Palakkad district, Kerala. First selected ten parameters which are directly connected with rain shadow formation and gave weightage to each parameter according to Analytic Hierarchy Process and prepared ten thematic maps and demarcated rain shadow region by weighted overlay analysis.

Table 3: Pudur Panchayath -Rain Shadow Region

Name	Area in Km^2	Area in %
Rain Shadow Region	185.08	49.99%
Wet Region	185.18	50.01%
Total	**370.26**	**100**

Source: Primary

The result shows that Pudur panchyat categorized into two zones, rain shadow region and wet region, accounting for 49.99% and 50.01% of the total study area, respectively.

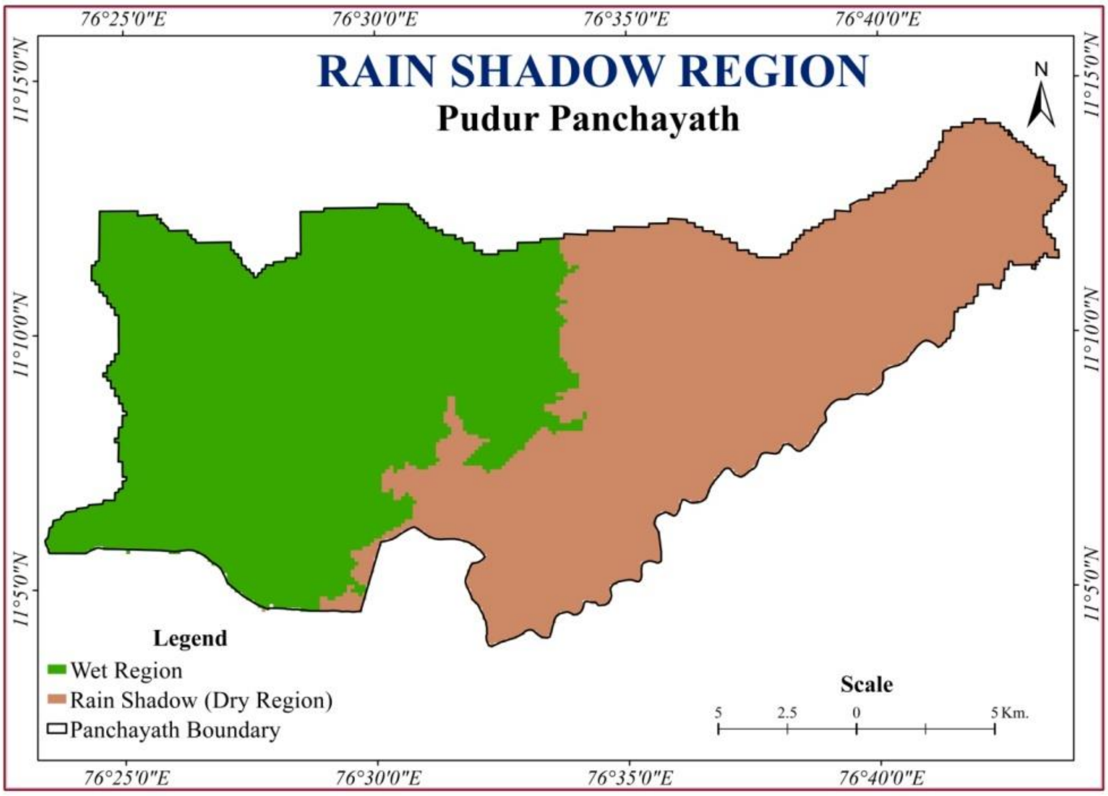

Figure - 4. Rain Shadow Region

RESULTS AND DISCUSSION

Orographic barrier plays an important role in the rainfall and temperature distribution and creation of rain shadow region in the lee side. This rain shadow effect creates a micro climate region with unique climatic feature. To demarcate rain shadow region is more complicated process. In this study, first selected ten parameters which are directly connected with rain shadow formation and gave weightage to each parameter according to Analytic Hierarchy Process and prepared ten thematic maps and demarcated rain shadow region by weighted overlay analysis. The rainfall results indicate that Pudur Panchayat receives rainfall from both the NE and SW monsoon season. The average rainfall varies from 220 mm in NE season and 309 mm in the SW monsoon season. The average rainfall is 2096 mm for the 20 years data. The eastern part receives rainfall below 650mm, while western side rainfall is above 3000mm. In the study area, temperature varies from 23.08^0 to 24.87^0. The average temperature is 23.59^0 Celcius temperature. The temperature is higher in the south and eastern part of the study area. The maximum wind speed in the research region is 2.71 mph, while the minimum wind speed is 1.88 mph. Due to the effect of mountain barrier, the wind speed has been dispersed in the western margin area and hence the complete eastern portion showing the uniform wind speed. . From the study area, it is well evident that, the relative humidity gradually decreases from western part (81.17) to the eastern part (74.91). In the eastern part of the study area, relative humidity is low with 74.91% when compare with western part due to mountain range effect. In the study area, the elevation divides the region into two sections: western side of the windward, which receives a lot of rain, and eastern side of the leeward, which receives less rain. The central and eastern parts have relatively low relief features and north and west parts have high relief. This undulating topography affects the rainfall distribution of the study area. The TVPDI value ranges from 0.40 to 1.47 in this study area. The western parts have thick vegetation with good rainfall and vice versa in the eastern part. Therefore the decreased amount of rainfall and the associated features of vegetation and also low TVPDI index value found in this eastern part. Soil Moisture (SM) is a direct indicator of dryness of the land surface. SMI value for the study area varies from .36 to 0.96. Increases value depicting high moisture content in the NW and low value in the southern part of the study area. .LST showed a low (14 Degree Celcius) in the vegetative covered area and a high LST value (31 Degree Celcius) in the area with barren land and low vegetative area.For rain shadow region having less rainfall, less vegetation cover and high surface temperature, The area with good rainfall and high vegetation shows a high positive NDVI value in the west side but low NDVI value found in the east part, whereas the negative value was observed in the barren land. Majority of the study area covered by forest vegetation followed by agricultural area and scrub .

This research focuses on the delineation of rain shadow zones in Pudur panchyat of Attappady utilising varying resolution satellite data and AHP approaches and the findings suggest that this method is suitable for delineation of rain shadow locations and rainy regions. Results of study showed that rain shadow zones cover approximately 50% of the study area. The high rain shadow regions are located in the eastern and south western parts. This study also proves that the application of remote sensing data such as TRMM, Landsat Imagery and ALOS DEM data are efficient ones for measuring rainfall and spatial demarcation of rain shadow regions. This study result also suggests that the AHP method can be used for demarcation of rain shadow regions. The majority of households especially tribe in Attappady Block rely on agriculture as their primary source of income, and the majority of them are unable to harvest as a result of the drought. The demarcation of rain shadow region of Pudur panchyat of Attappady will help the administrators to take the proper decisions and adopt strategies to make rain shadow regions more resilient and to convert them as harvest land.

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CONCLUSION

The physical barrier of the region has important role in determine the climate of the region. An orographic effect brings not only the initiation and intensification of precipitation on the windward side of mountains and hills but also the relative deficit of precipitation on the lee side and makes lee side as "rain-shadow" region. Through the composite approach by using remote sensing, GIS, and AHP based multi-criteria analysis, demarcated rain shadow region of Pudur panchyat of Attappady taluk, Palakkad district, Kerala. The result shows that Pudur panchyat categorized into two zones,rain shadow region and wet region, accounting for 49.99% and 50.01% of the total study area, respectively. This study concludes that one of the major reasons for the decrease in rainfall in the eastern part of the study area is the rain shadow effect. This study also proves that the application of remote sensing data such as

TRMM, Landsat Imagery, and ALOS DEM data are efficient ones for measuring rainfall and spatial demarcation of rain shadow regions.

AUTHORS CONTRIBUTION

SURESH.P, Assistant Professor, Department of Geography, Govt. College Chittur, Palakkad, came up with the idea, done a significant role in selecting the study area, contributed to the research, data collection and creating the paper.

Dr.RICHARD SCARIA, Assistant Professor, Department of Geography, Govt. College Chittur, contributed in methodology, analysis and back ground work of the paper.

Dr. DHANYA VIJAYAN, Research Scientist, Leibniz Centre for agricultural Landscape Research, Mincheberg, Brandenburg, Germany, contributed in ordering the paper, rectifying the errors and providing necessary suggestions.

DECLARATION OF NO CONFLICT OF INTERESTS

The authors declare that there is No Conflict of Interests between authors, affiliated organization, and any of the funding agencies in this paper and this work not published elsewhere.

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LINKING POVERTY AND VULNERABILITY: A CASE STUDY OF THE WORKERS IN GAVI

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Abstract:

Poverty, increased population density, climate change, change in land use patterns, and lack of access to safe land leads to disaster and human vulnerability around the world. Vulnerability of a community often generates poverty traps. Vulnerability may increase or decrease in response to policies and investments, external shocks, stresses or opportunities and aggregate effects of people's daily actions. At the same time, it is to be highlighted that the different groups or households in the same location may experience very different levels of vulnerability. The present study analyses the poverty and vulnerability of the resident workers of Gavi, one of the ecotourism destinations managed by the Kerala Forest Development Corporation (KFDC). The study addresses the issues of underdevelopment, marginalization, gaps in establishment of infrastructural facilities, social and cultural backwardness, apart from the core vulnerability issues of the community and developing suitable strategies for sustainable livelihoods of the resident workers. A Sustainable Livelihood Framework (SLF) that provides a structure for poverty analysis is used, to conceptualize livelihoods in a holistic way, capturing the complexities of livelihoods and coupling them with the constraints and opportunities they are subjected to. As people-centric, it has considered the assets (pentagon-human, social, natural, physical and financial) that poor people needed in order to sustain an adequate income to live. The social vulnerability of the workers towards regional climate conditions was analyzed by looking at the exposure, sensitivity and adaptive capacity and the multidimensional poverty index was worked out based on the incidence and intensity of poverty. The Community Based Vulnerability Index of 2.63 indicated high levels of poverty. All the settlements were classified as having high levels of susceptibility to poverty. They are exposed and sensitive to wild animal conflicts, changing weather patterns, unclean drinking water and sanitation facilities, climate change-related factors, the growth of invasive alien plant species, reduced cardamom production and low wages. Adaptive capacity is observed to be low despite the existence of Kudumbasree and other local social groups. Lack of women empowerment and the poor internet facilities along with less transportation services have rendered them with low scope of socio-economic development. The need for a holistic approach in understanding the problems and the prospects of the region with the active participation of all stakeholders is mandatory for improving the well-being of the local population in the region and to go in par with the Sustainable Development Goals.

Keywords:

Vulnerability, Poverty, Exposure, Sensitivity, Sustainable Livelihood Framework, Sustainable Development Goal

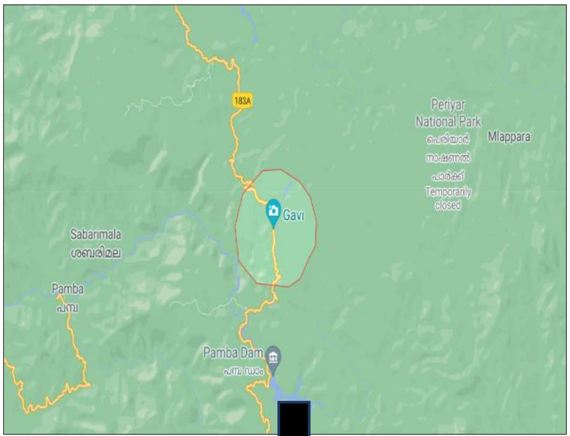
INTRODUCTION

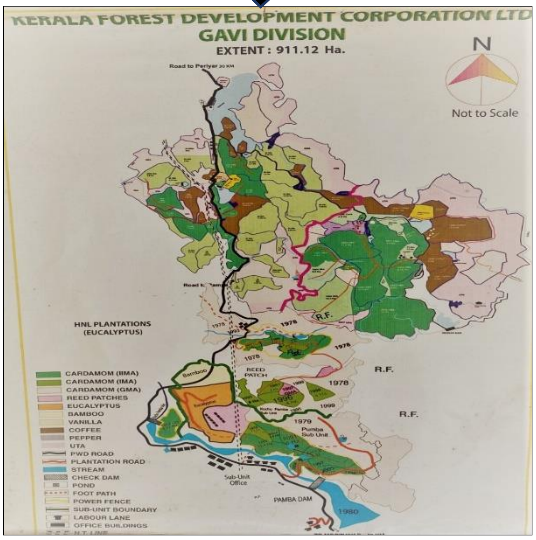
Poverty, increased population density, climate change, change in land use patterns, and lack of access to safe land leads to disaster and human vulnerability around the world. Poverty is a state where people are deprived of resources, capabilities, choices, security and power necessary for maintaining cultural, economic, political and social rights. Vulnerability of a community to poverty is determined by the risk of becoming or remaining poor. Vulnerability may increase or decrease in response to policies and investments, external shocks, stresses or opportunities and the aggregate effects of people's daily actions. At the same time, it is to be highlighted that the different groups or households in the same location may experience very different levels of vulnerability. Carrying out a socio-economic study provides an elaborate picture with broad highlights and intricate detailing with respect to a community's problems as well as prospects. The socioeconomic component incorporates various facets related to prevailing social and ethnic or cultural conditions like the quality-of-life attributes and privileges that can be afforded by the members of the respective community. The economic status includes income, educational attainment, and financial security of the study region. It helps us in understanding the opportunities existing for the respondents as well as the issues which hinder their path to progress and development. Vulnerability and poverty analysis helps understand the exposure, sensitivity and adaptive capacity of the respondents and develop community-specific strategies for capacity building and site-specific strategies for sustainable development. In this backdrop, the present study addresses the issues of underdevelopment, marginalization, gaps in the establishment of infrastructural facilities, social and cultural backwardness, apart from the core vulnerability issues of the community and developing suitable strategies for sustainable livelihoods of the resident workers.

STUDY AREA

The present study is carried out in Gavi, one of the ecotourism destinations managed by the Kerala Forest Development Corporation (KFDC). Gavi (9°26′25.72″N and 77°9′37.25″E), is part of Seethathode Panchayath in Ranni Taluk and lies in close proximity with Periyar Tiger Reserve. Endangered species including the Nilgiri Tahr and Lion-tailed macaque are often sighted on the outskirts of Gavi (KFDC). The living standards of the plantation workers in Gavi is in a deplorable state with poor access to facilities for education, medicine, housing and so on. A government lower primary school in Tamil medium is also functioning at Gavi for the education of children. However, due to the lack of high school facility and transportation facility, many children are forced to discontinue their studies post primary grade. A dispensary with minimum facilities and basic medicines is functioning in the estate with the service of a residential duty nurse. The inequality comparisons, measurement in pro-poor growth, working out poverty indexes, determinants of poverty, reduction policies and international comparisons are all considered as tools to measure, escribe, monitor, evaluate, and analyze poverty (Haughton and Khandker, 2009). Climate volatility deepens poverty vulnerability in developing countries. Extreme weather events may have an impact on poverty by reducing agricultural production and boosting the pricing of basic commodities crucial to poor households in developing nations. With the frequency and intensity of catastrophic climatic events expected to increase in the future, informed policy planning and analysis will necessitate knowledge of nations and populations most vulnerable to rising poverty (Ahmed, 2009). The lack of involvement of primary stakeholders can increase the socioeconomic dependence of local communities on the ecosystem thus causing commercial threats. This may be incompatible to conserving the biological diversity of the region (Anitha and Muraleedharan, 2006). Due to a lack of proper medical infrastructure, unavailability of medicines and lack of emergency care, the patients are forced to travel at least 26 kms to avail the aforesaid services. Malnutrition and dropout from educations are the other major issues.

Free electricity and water are provided in the labor lines. However, during summer, water shortage acts as a potential hurdle in realization of day-to-day livelihood options. Human wildlife conflict is a regular occurrence in all the 3 settlement areas in Gavi. Socio economic assessment often identifies and evaluates the potential socio-economic and cultural impacts of an ecosystem on the lives of the dependent communities.





Map 1. Study

Here, there are three settlements in Gavi, namely who are the Srilankan repatriates, Gavi, Meenar and Kochupamba (Table.1). There are 162 households in Gavi, out of which 59 are located in Gavi proper, 39 in Meenar and 64 in Kochupamba.

Table 1. Household wise distribution in different settlements in Gavi

Sl.No.	**Division-** Gavi	**Total households: 162**
1.	Gavi	59
2.	Meenar	39
3.	Kochupamba	64

METHODOLOGY

The study largely depends on primary data supplemented by secondary data wherever required. The socio-economic aspects of livelihood, household production system and dependency index, components of parameters of vulnerability index and indicators of multidimensional poverty index, among others were collected from the resident Gavi workers, through focus group discussions and field survey by simple random sampling technique. Socio-economic status analysis of respondents was analyzed using variables like age, gender, family size and economic status; educational attainment and occupational pattern. To assess the vulnerability level of folk to drought impact, a conceptual framework was developed based on the IPCC (2001) definition of vulnerability, where vulnerability is a function of exposure, sensitivity and adaptive capacity. The analysis was done based on a Community Based Vulnerability Assessment (CBVA) index (Thapa and Baral, 2013) formulated based on the following equation:

$$V= (E) \times (S) \times (1/A),$$

Where E: exposure, S: sensitivity and A: adaptive capacity of the system.

The parameters selected are observed based on indicators. The major parameters considered include temperature, precipitation, plant changes, natural hazard, livelihood activities, physical information, agriculture, NTFP collection, forest and biodiversity, physical infrastructure, natural resources, wild animal threats, seasonal changes, water scarcity, health aspects, human capital, natural aspects, social aspects, financial aspects, and so on (Table 2).

Table 2. Parameters selected for vulnerability assessment

Exposure	Sensitivity	Adaptive capacity
1.Temperature: Longer Summer, Shorter Monsoon, Weather variation	1.Agriculture and food security: Crop failure, Inability to cultivate	1. Human: Purchase of vehicles for transportation, Women empowerment activities
2.Indicator plants: Invasive alien species, changes in flowering time, Tree mortality	2. Cardamon collection: Changes in harvesting time, Reduction in quantity harvested	2.Natural KFDC supply of water Afforestation activities, Choosing other income generation activities than agriculture/ plantation.
3.Physical information: Plant diebacks, Depletion of water level in wells, streams etc.	3.Health problems: Heat exhaustion, other physical issues	3.Financial Regular visits to bank
4.Wild animals: Wild animals venturing into settlement area, wild animal attacks, territorial disturbance	4.Water resource: Drinking water shortage	4.Social Visits by representatives/authorities, club/association activities
		5.Physical Telecommunication, ICT, sanitation facilities

Multidimensional Poverty Index (MPI): The MPI is a very useful methodology that facilitates in incorporating alternative indicators, cutoffs and weights that are suitable in regional, national, or subnational contexts. Regional or national MPIs are analyzed by adapting the method upon which the global MPI is based to better address local realities, needs and the data available. Their goal is to assess multidimensional poverty levels in particular regions in the components most relevant and feasible locally. Adjusted headcount ratio (M_0) also known as the MPI relates to both the incidence of poverty (the percentage of the population who are poor) and the intensity of poverty (the percentage of deprivations suffered by each person or household on average). $M_0 = H \times A$, ie., multiplying the incidence (H) by the intensity (A).

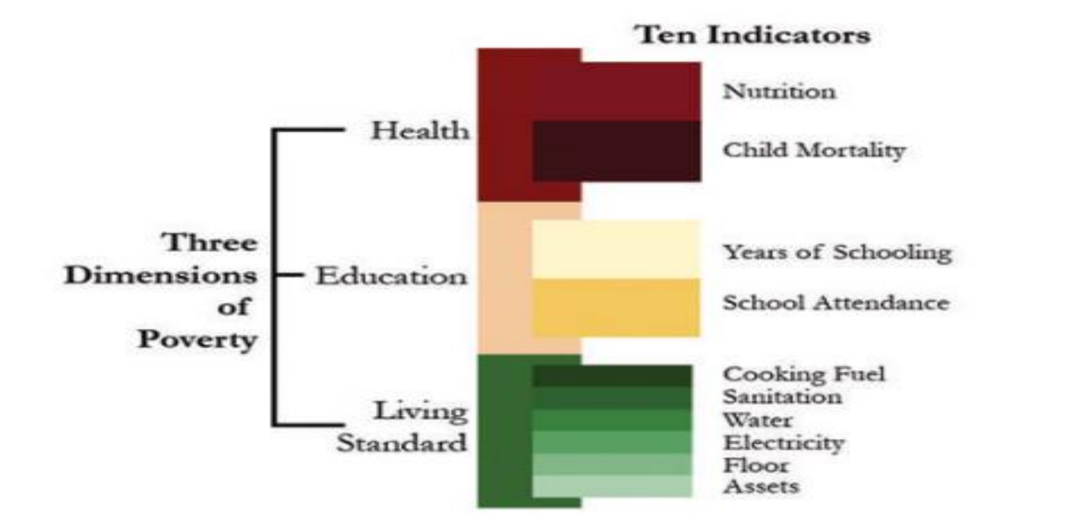


Figure 1. Composition of MPI (Source: OPHI, 2011)

Ten indicators make up the MPI, that include two for health, two for education, and six for living standards (Figure 1). Within the education dimension, the MPI uses two indicators that complement each other: one looks at completed years of schooling for household members, and the other looks at whether children are attending school. For health aspects, the first indicator looks at the nutrition of household members. Malnutrition can have a long-term impact on a child's cognitive and physical development. The data on child mortality is used in the second indicator, as m malnutrition plays a role in the death of children. Further, six indices of living standards are considered by the MPI. Clean drinking water, improved sanitation, and the use of clean cooking fuel are three standard Millennium Development Goals indicators relating to health and living conditions that are particularly important to women (OPHI,2011).

The study uses a sustainable livelihood framework (SLF) that provides a structure for poverty analysis, which is an effort to conceptualize livelihoods in a holistic way, capturing the complexities of livelihoods and coupling them with the constraints and opportunities they are subjected to (Figure 2). The SL framework is flexible and can be adapted to meet the specific needs of different organizations or contexts. It links socioeconomic and ecological considerations in a cohesive, policy-relevant structure and acts as a powerful tool for identifying the key drivers of poverty, the factors that push people into poverty, and the potential interrupters or factors that provide pathways out of poverty. It puts people at the center of development. The vulnerability looks into the external environment in which people live and often have a direct impact upon people's asset status and the options that are open to them in pursuit of beneficial livelihood outcomes. This includes trends, shocks (such as illness or death, conflict, weather), and seasonality (of prices, production cycles and so on).

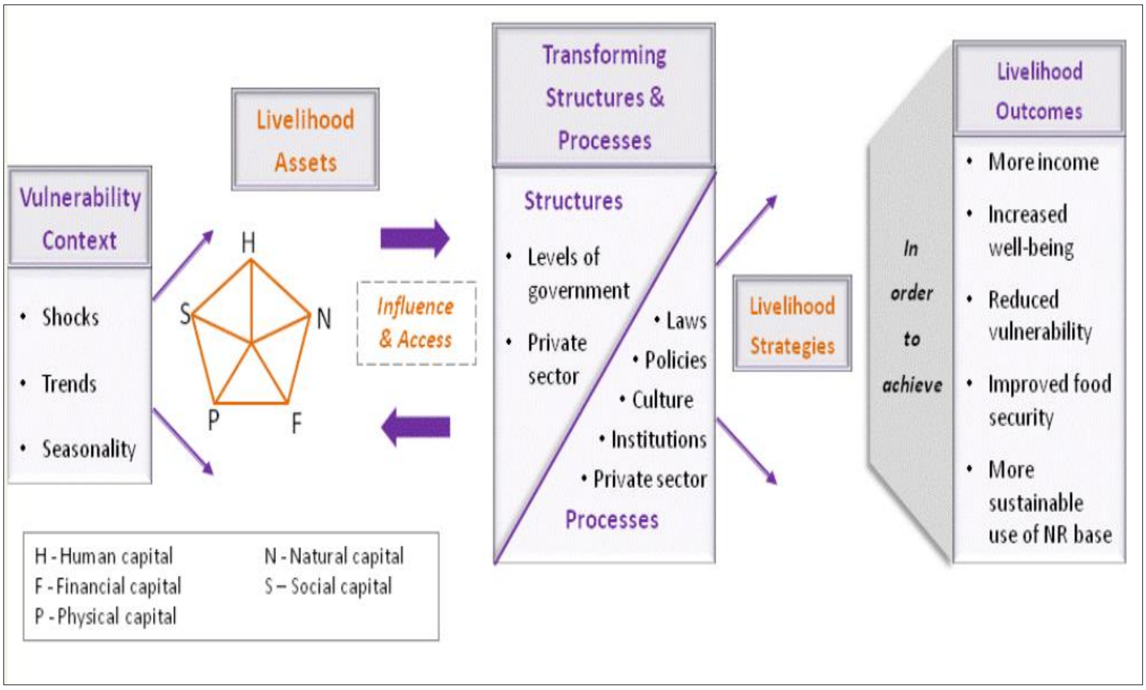


Figure 2: Sustainable livelihood framework (Source: DFID,1999)

The vulnerability factors have a direct impact on the possibilities that poor people have to earn a living now and in the future. The transforming structures and processes include the institutions and policies that affect the lives, from public and private entities to national policies and local culture. Rather than understanding poverty as simply a lack of income, the sustainable livelihoods approach considers the assets that poor people need in order to sustain an adequate income to live. The asset pentagon revolves around the five capitals-Human capital represents the skills, knowledge, the ability to work and good health. Social capital are the social resources that people draw on to make a living. Like human capital, social capital has an intrinsic value; good social relationships are not simply a means, they are an end in themselves. Natural capital are the natural resource stocks that people can draw on for their livelihoods, including land, forests, water, air and so on. Physical capital is the basic infrastructure that people need to make a living, as well as the tools and equipment that they use. In addition, the financial capital includes the savings and regular inflows of money.

The more assets any household has access to, the less vulnerable they will be to negative effects of the trends and shocks as described above, or to seasonality, and the more secure their livelihood will be. Asset endowments are constantly changing; therefore, pentagons are constantly shifting. All these capabilities, assets and activities are required for a means of living and brings into light the impact on the livelihoods of the poor people. People's access to different levels and combinations of assets is probably the major influence on their choice of livelihood strategies. Transforming Structures and Processes can reinforce positive choices and a baseline study on the socio-economic status of the workers can provide a strong background for the same.

RESULTS AND DISCUSSION

Socio-economic assessment of KFDC Plantation Workers

The demographical analysis comprises the characteristics of the respondents like age, gender distribution, religion, family size and dialect. Almost all the households follow a joint family system, with the retired parents staying with the married children. An average household size of 6 members was observed. Out of the 577 respondents surveyed, majority of them belonged to working age group of 18 to 60 years, ie., 69.0 percent. Among the three settlements, Kochupamba had more working age group respondents forming 65.3 percent. There were 11.3 percent of aged persons and 19.8 percent of total respondents were below 18 years of age. In all the three settlements, adult population were more than the younger age group. Kochupamba had the highest sex ratio (number of males per 100 females). Gavi with 100 males and 95 females shows the least value among the three settlements. Majority of the respondents (97.1 percent) belonged to Hinduism. 91.3 percent were native Tamil speakers, and the rest comprising of 8.7 percent spoke Malayalam as their native dialect. Among the respondents, 64.1 households were reported as coming under Below Poverty Level category. Majority of them faces acute poverty, underdevelopment, and lack even standard basic facilities to live. Only 9.0 percent had APL cards and 24.8 percent were AAY cardholders. Meenar had poorer conditions, where many households have complained about poverty and indebtedness.

Table 3. Demographic and Economic Factors

Variable	Classes	Settlements						Total	
		Meenar		Kochupamba		Gavi			
		Frq	%	Frq	%	Frq	%	No.	%
Age	<18 years	31	22.6	52	21.2	31	15.9	114	19.8
	18-60 yrs	98	71.5	160	65.3	140	71.8	398	69.0
	>60 years	8	5.8	33	13.5	24	12.3	65	11.3
	Total	137	100.0	245	100.0	195	100.0	577	100.0
Gender	Male	71	51.8	136	55.5	100	51.3	307	53.2
	Female	66	48.2	109	44.5	95	48.7	270	46.8
	Total	137	100.0	245	100.0	195	100.0	577	100.0
Religion	Hindu	137	100.0	234	95.5	189	96.9	560	97.1
	Christian	0	0.0	2	0.8	6	3.1	8	1.4
	Muslim	0	0.0	9	3.7	0	0.0	9	1.6
	Total	137	100.0	245	100.0	195	100.0	577	100.0
Dialect	Tamil	137	100.0	209	85.3	181	92.8	527	91.3
	Malayalam	0	0.0	36	14.7	14	7.2	50	8.7
	Total	137	100.0	245	100.0	195	100.0	577	100.0
Economic Status	APL	12	8.8	19	7.8	21	10.8	52	9.0
	BPL	96	70.1	115	46.9	159	81.5	370	64.1
	AAY	26	19.0	103	42.0	10	5.1	139	24.8
	Nil	3	2.2	8	3.3	5	2.6	16	2.1
	Total	137	100.0	245	100.0	195	100.0	577	100.0

The educational status among the residents shows 18.4 per cent had achieved primary education, whereas 54.8 per cent gained secondary education and only 11.8 per cent were successful in pursuing graduation or higher level education. The increased rates of dropout is mainly because of difficulty in transportation to the educational institutions from Gavi. Illiteracy persisted in the settlements, where 87 respondents lacked even primary level schooling (Table 4). However, with many households arranging means of educating the children by accommodating them in hostels nearby far away educational institutions, the younger generation are getting more educational facilities and opportunities.

Table 4. Educational Attainment

			Educational Attainment				
			Primary	Secondary	Higher studies	Illiterate	Total
Settlements	Meenar	Frequency	39	75	10	13	137
		Percentage	28.5	54.7	7.3	9.5	100.0
	Kochupamba	Frequency	28	146	23	48	245
		Percentage	11.4	59.6	9.4	19.6	100.0
	Gavi	Frequency	39	95	35	26	195
		Percentage	20.0	48.7	17.9	13.3	100.0
Total		Frequency	106	316	68	87	577
		Percentage	18.4	54.8	11.8	15.1	100.0

Source: Primary data

The occupational pattern shows 29.1 percent among them were permanently employed in KFDC, while 9.0 percent did allied activities in KFDC and 5.5 percent had retired from KFDC work. A total of 61 respondents pursued other occupations like driving, catering, fencing and manual work among others.

Table 5. Occupational Distribution

			Occupation						
			KFDC Permanent	Allied work (KFDC)	Retired (KFDC)	Others	Unemployed	Student	Total
Settlements	Meenar	Frequency	45	15	12	3	38	24	137
		Percentage	32.8	10.9	8.8	2.2	27.7	17.5	100.0
	Kochupamba	Frequency	61	17	8	38	67	54	245
		Percentage	24.9	6.9	3.3	15.5	27.3	22.0	100.0
	Gavi	Frequency	62	20	12	20	40	41	195
		Percentage	31.8	10.3	6.2	3.0	38.0	24.0	137
Total		Frequency	168	52	32	61	145	119	577
		Percentage	29.1	9.0	5.5	10.6	25.1	20.6	100.0

Source: Primary data

Work participation ratio is defined as the percentage of total workers to the total population. From the study it is evident that Gavi shows highest value in work participation rate, followed by Kochupamba (70.06 percent) and Meenar (Table 6).

Table 6. Work Participation Ratio	
Meenar	64.10 %
Kochupamba	70.06 %
Gavi	73.08 %

Source: Primary data

The satisfaction of the respondents from the wage shows that majority of the participants were neutral in their opinion about wage satisfaction. However, 11.1 percent expressed their dissatisfaction regarding the current level of wages. The present daily wage amount of about 400 Rupees per day is not sufficient to successfully meet all their livelihood needs. This has forced many respondents to take bank loans (Table 7).

Table 7. Respondents Distribution based on Satisfaction from Wages

			Satisfaction from wages						
			High	Moderate	Low	Not at all	Can improve	No opinion	Total
Settlements	Meenar	Frequency	4	12	20	1	1	99	137
		Percentage	2.9	8.8	14.6	0.7	0.7	72.3	100.0
	Kochupamba	Frequency	3	16	25	12	2	187	245
		Percentage	1.2	6.5	10.2	4.9	0.8	76.3	100.0
	Gavi	Frequency	0	5	19	5	3	163	195
		Percentage	0.0	2.6	9.7	2.6	1.5	83.6	100.0
Total		Frequency	7	33	64	18	6	449	577
		Percentage	1.2	5.7	11.1	3.1	1.0	77.8	100.0

Source: Primary data

Most of the households receive a monthly income of Rs.10000 to Rs 50000. This is because, there are multiple working members in most of the households. Women in the settlements are usually engaged in either plantation work or activities like tailoring, teaching, and the like. 42.6 percent of households received less than Rs 10000 as monthly income. Meenar had more households who earned between Rs 10000 and Rs 50000 than Gavi or Kochupamba. All the adult members had bank accounts and most of the retired members frequently visits banks or ATMs for collection of pension. However, they all responded as having little to no savings after their daily expenses (Table 8).

Table 8. Monthly Income Distribution

			Monthly Income				Total
			<10000 Rs	10000 Rs - 50000 Rs	>50000 Rs	No income	
Settlements	Meenar	Frequency	10	26	0	3	39
		Percentage	25.6	66.7	0.0	7.7	100.0
	Kochupamba	Frequency	31	30	0	3	64
		Percentage	48.4	46.9	0.0	4.7	100.0

	Gavi	Frequency	28	19	1	11	59
		Percentage	47.5	32.2	1.7	18.6	100.0
Total		Frequency	69	75	1	17	162
		Percentage	42.6	46.3	0.6	10.5	100.0

Source: Primary data

Women Empowerment

Most of the respondents (97.4%) disagreed on having any activities or general support for upliftment of women. Only 2.6 percent among the respondents supported the idea of women empowerment and agreed upon taking the same measures While some of the households were keen on their girl child studying and securing jobs, majority were reluctant to send them for higher studies. Considering girls as financial burden and discouraging their interests in pursuing higher education were also observed. (Table 9).

Table 9. Women Empowerment Measures Taken

			Women Empowerment Measures Taken		Total
			Yes	No	
Settlements	Meenar	Frequency	0	137	137
		Percentage	0.0	100.0	100.0
	Kochupamba	Frequency	4	241	245
		Percentage	1.6	98.4	100.0
	Gavi	Frequency	11	184	195
		Percentage	5.6	94.4	100.0
Total		Frequency	15	562	577
		Percentage	2.6	97.4	100.0

Source: Primary data

Vulnerability Assessment of KFDC Plantation Workers:

Exposure

The first criterion considered is temperature, which includes indicators like as prolonged summers, heat waves, and shorter and cooler monsoons, all of which are based on the respondents' impressions. The second parameter is indicator plants, which includes signs such as the appearance/ absence of species, changes in flowering time, and increasing tree mortality, all of which are based on the respondents' perceptions. Physical information is the third parameter, and indicators such as frequent plant diebacks and water level depletion in water bodies are obtained based on respondents' impressions. The fourth criterion is wild animals, which is based on evidence such as increased wild animal attacks on livestock, changes in their territorial distribution, and an increase in wild animals detected near communities.

Table.10. Average Exposure Index for Community							
Settlements		Parameters and Score Index Values				Average Exposure Index	Level of Exposure
		Temp.	Indicator Plants	Physical Information	Wild Animals		
Meenar (N=39)	Index Value	2.42	2.24	2.58	2.67	**2.47**	High
Kochupamba (N=64)	Index Value	2.48	2.37	2.68	2.78	**2.57**	High
Gavi (N=59)	Index Value	2.69	2.06	2.37	3.15	**2.56**	High
Total (N=162)	Index Value	2.53	2.22	2.54	2.86	**2.53**	High
Source: Primary data							

According to the CBVA measure, exposure levels of 2-4 are considered high. Meenar has the lowest exposure level of the villages at 2.47. The settlement is more vulnerable to disturbances in water level depletion, territorial distribution disturbances, invasive alien species and extended periods of summer. Invasive alien species and water depletion in water bodies are more common in Kochupamba, which has a 2.57 (highest) exposure level. Temperature indications are less common in Kochupamba. Gavi with an exposure level of 2.56, is least exposed to indicator plants parameters and heat waves (Table 11).

Table 11. Exposure parameters and indicators				
Parameter	Indicator	S1	S2	S3
1.Temperature:	i. Extended periods of summer	2.84	2.42	2.98
	ii.Heat waves	1.82	2.28	2.00
	iii. Shorter and colder monsoon/winter.	2.61	2.76	3.11
2.Indicator plants	i.Appearance/disappearance of species	2.67	2.68	2.47
	ii.Changes in flowering time	2.05	2.32	1.86
	iii.Increased incidences of tree mortality	2.02	2.12	1.86
3.Physical information	i. Frequent Plant diebacks	2.23	2.39	2.13
	ii.Depletion of water level in water bodies	2.94	2.98	2.61
4.Wild animals	i.Increased incidences of wild animal attack	2.00	2.15	2.30
	ii.Change in their territorial distribution	2.92	3.21	3.52
	iii.Wild animals spotted near settlements increasingly	3.10	3.00	3.64
Source: Primary data, S1: Meenar, S2: Kochupamba, S3: Gavi				

Sensitivity

The characteristics that indicate the sensitivity of the people to drought consequences are discussed here. Agricultural factors such as crop failure and harvesting time variations, NTFP collecting variances in harvesting time and quantity reduction, and health issues such as heat stress and water scarcity are considered (Table 12).

Table 12. Average Sensitivity Index for Community

Settlements		Parameters and Score Index Values				Average Sensitivity Index	Level of Sensitivity
		Agri.	Natural disaster	Health Problems	Water Resource		
Meenar (N=39)	Index Value	2.22	2.25	1.82	2.74	**2.25**	High
Kochupamba (N=64)	Index Value	3.04	2.38	2.07	2.39	**2.47**	High
Gavi (N=59)	Index Value	2.44	1.88	1.79	2.03	**2.03**	High
Total	Index Value	2.56	2.17	1.89	2.38	**2.25**	High

Source: Primary data

Gavi, with an average sensitivity level of 2.03, is the least sensitive of the three repatriate villages. Agricultural failure and lack of proper water resources affect it the most, while heat exhaustion and other diseases affect it the least. Reduction in cardamom harvesting and natural disasters like storms or wildfire are major problems in Kochupamba (with highest sensitivity rate of 2.47). The settlement of Meenar has more respondents being sensitive to water scarcity and less responsive to heat exhaustion and harvesting time (Table 13).

Table 13. Sensitivity parameters and indicators

Parameter	Indicator	S1	S2	S3
1.Agriculture:	i. Reduction in cardamom quantity harvested	2.30	3.21	2.11
	ii.Changes in cardmom harvesting time	2.15	2.87	2.77
2.Natural Disaster	i.Wildfire	2.12	2.45	1.84
	ii.Disappearing of springs	2.38	2.32	1.93
3.Health Problems:	i.Increase in Heat Exhaustion and other ailments in summer.	1.82	2.07	1.79
4.Water Resource:	i.Drinking water shortage:	2.74	2.39	2.03

Source: Primary data, S1: Meenar, S2: Kochupamba, S3: Gavi

The residents of Gavi, depend on well, pipeline, river, pond and canal. Most of them (51.9 percent) make use of pipeline. During summers, they depend on rivers, ponds or canals. However, over the recent years, water scarcity is less compared to the past. The authorities can ensure to provide clean drinking water through establishment of water purifiers or by encouraging rain water harvesting. A total 12.3 percent population depend on both well and pipeline (Table 14).

Table 14. Available water sources

			Available water sources						Total
			Well	Pipe line	Well and Pipeline	River	Pond	Canal	
Settl	Meenar	Frequency	27	4	8	0	0	0	39
		Percentage	69.2	10.3	20.5	0.0	0.0	0.0	100.0

	Kochupamba	Frequency	3	32	6	8	14	1	64
		Percentage	4.7	50.0	9.4	12.5	21.9	1.6	100.0
	Gavi	Frequency	5	48	6	0	0	0	59
		Percentage	8.5	81.4	10.2	0.0	0.0	0.0	100.0
Total		Frequency	35	84	20	8	14	1	162
		Percentage	21.6	51.9	12.3	4.9	8.6	0.6	100.0

Source: Primary data

For drinking water also the respodents mainly depend on pipeline (44.4 percent). They also depend on well (40.7 percent), especially in Meenar (84.6 percent). None of the respondents in Meenar depend on river for drinking water (Table 15).

Table 15. Drinking water sources

			Drinking water sources					Total
			Well	Pipe line	Well and Pipeline	River	Bore well	
Settlements	Meenar	Frequency	33	3	3	0	0	39
		Percentage	84.6	7.7	7.7	0.0	0.0	100.0
	Kochupamba	Frequency	8	38	3	8	7	64
		Percentage	12.5	59.4	4.7	12.5	10.9	100.0
	Gavi	Frequency	25	31	2	1	0	59
		Percentage	42.4	52.5	3.4	1.7	0.0	100.0
Total		Frequency	66	72	8	9	7	162
		Percentage	40.7	44.4	4.9	5.6	4.3	100.0

Source: Primary data

Adaptive Capacity

The community's adaptive capacity must be strengthened if it is to be resilient. Parameters of human, natural, economic, social, and physical elements are evaluated under adaptation capacity. Meenar has the lowest adaptation potential, as it is influenced most by financial factors such as frequent bank visits. Reducing gender inequality, women empowerment and other initiatives have been more helpful to the respondents. Gavi has lesser adaptive capacity due to a lack of natural as well as ICT initiatives and capacity building strategies. Kochupamba also scores least in terms of physical indicators like ICT or telecommunication facilities, while having the greatest adaptability (2.23) to financial, human and social characteristics such as successful worker empowerment efforts and improved forest conservation mechanisms (Table 16).

Table 16. Average Adaptive Capacity Index for Community							
Settlements	Parameters and Score Index Values					Average Adaptive Capacity Index	Level of Adaptive Capacity
	Human aspects	Natural aspects	Financial aspects	Social aspects	Physical aspects		
Meenar (N=39)	2.31	2.21	2.15	2.26	1.59	**2.10**	High
Kochupamba (N=64)	2.26	2.55	2.64	2.14	1.60	**2.23**	High
Gavi (N=59)	2.11	1.89	3.49	2.07	1.31	**2.17**	High
Total (N=162)	2.22	2.21	2.76	2.15	1.50	**2.16**	High
Source: Primary data							

The indicators and parameters for adaptive capacity are as given below (Table 17)

Table 17. Adaptive capacity parameters and indicators				
Parameter	Indicator	S1	S2	S3
1.Human aspects:	i.Temporary Migration:	1.89	1.98	1.57
	ii. Other activities	2.00	2.21	1.59
	ii.Gender equality and Women Empowerment:	3.05	2.59	3.18
2.Natural aspects:	i.Panchayath water supply:	2.58	3.37	1.76
	ii.Afforestation:	1.92	1.78	1.91
	iii. Shifting to poultry/ cattle rearing	2.15	2.50	2.01
3.Financial aspects:	i.Regular visits to bank for necessary purposes:	2.15	2.64	3.49
4.Social aspects:	i.Empowerment initiatives and service providers:	2.25	2.18	2.25
	ii.Forest Protection Cell:	2.28	2.10	1.89
5.Physical aspects:	i.Rainwater harvesting	1.76	1.46	1.33
	ii.Access to ICT facilities:	1.41	1.67	1.16
	iii.Telecommunication facilities:	1.61	1.68	1.44
Source: Primary data, S1: Meenar, S2: Kochupamba, S3: Gavi				

Meenar has a low average exposure index of 2.47, a low average sensitivity index of 2.25, and the lowest adaptive capacity score of 2.10. This also explains its moderate level of vulnerability among the three settlements. Among the three communities, Kochupamba exhibited the most drought exposure (2.57) and sensitivity (2.47). Therefore, with an index value of 2.84, it is the most vulnerable settlement despites its relatively higher adaptive capacity. Gavi is the least vulnerable settlement. This is due to Gavi's lower sensitivity level which allowed it to withstand more drought-related damage. The settlement's resilience grew as a result of its strong social and financial adaptability. Kochupamba, on the other hand, has a far lower adaptive capacity than it really required (Table 18).

Table 18. Community Based Vulnerability Index of Community

Settlements	Average Exposure Index	Average Sensitivity Index	Average Adaptive Capacity Index	Vulnerability Index	Vulnerability Level
Meenar	2.47	2.25	2.10	**2.64**	High
Kochupamba	2.57	2.47	2.23	**2.84**	High
Gavi	2.56	2.03	2.17	**2.39**	High
Total	2.53	2.25	2.16	**2.63**	High

Source: Primary data

The region is affected by natural disasters like wild fire (especially in Kochupamba where grassy hills are situated nearby), storms and heavy rains. During summers, due to water scarcity the plantation workers have to venture about 2 kms to collect water from a forest stream. Thus, a mild onset of drought indicators can also be noted. However, due to lack of awareness, about 90.7 percent respondents have not noticed any natural disasters near the settlements (Table 19).

Table 19. Natural disasters observed

			Natural disasters observed		Total
			Yes	No	
Settlements	Meenar	Frequency	0	39	39
		Percentage	0.0	100.0	100.0
	Kochupamba	Frequency	10	54	64
		Percentage	15.6	84.4	100.0
	Gavi	Frequency	5	54	59
		Percentage	8.5	91.5	100.0
Total		Frequency	15	147	162
		Percentage	9.3	90.7	100.0

Source: Primary data

Considering the whole vulnerability index, plantation-dependent Sri Lankan repatriates in Gavi are in a vulnerable state, which merely qualifies (since all the index values are merely above 2, when 2-4 values denote high vulnerable level) to the 'higher' level. A strong point is that despite almost many of the basic facilities like housing, sanitation, electricity, water, transportation and banking facilities being provided by the KFDC and the government, the respondents are living in a miserable condition with poorly maintained cottages, damaged toilets, unclean settlements and dirty drinking water. So more than the provision of these facilities, quality and standard of the facilities must be reviewed and improved.

Multidimensional Poverty Index

Here, the intensity of poverty (average deprivation score of the multi-dimensionally poor people) represents the percent of households with poverty score greater than 0.333, which equals to 0.37 percent. Based on multidimensional headcount ratio (0.08), which is the ratio between the number of people who are multidimensionally poor and the total population, we can see, Kochupamba is having highest multidimensional head count ratio and for Meenar, it is the least. Now, based on intensity and headcount ratio, MPI was calculated which showed that Kochupamba is the most multidimensionally poor settlement among the three. The total value was found to be 0.031.

It must be noted that since the KFDC and the government provide the basic facilities like electricity, sanitization, primary education or health dispensary at Gavi, many of the respondents cannot be considered as qualifying the criteria for being multidimensionally poor. However, the condition of the facilities provided are miserable which makes them suffer a lot. So, a proper review of the amenities provided must be considered for better implementation of the facilities. Here, 8 percent of the residents in total three settlements are MPI poor. They lack at least a) all of the signs of a single dimension or b) a mixture of dimensions, such as living in a family with a starving person, no clean water, a dirt floor, and inadequate sanitation. Therefore, the poor in this area are disadvantaged in 37% of the weighted indicators on average. The MPI indicates the proportion of the population that is multidimensionally poor, adjusted for the severity of deprivation. The MPI can also be interpreted as the proportion of weighted deprivations experienced by the poor in a society as a percentage of the total potential deprivations experienced by the society. If everyone in a society was deficient in all of the indicators studied, the MPI would be 100 per cent. Since, they are deprived in 37 per cent of the weighted indicators on average, that society is deprived in just 3 per cent of the total potential deprivation.

As far as the sanitation facilities are concerned, the toilets are mostly in dilapidated condition. Over the years of use, many toilets had lost doors, pipe facility and roofs. The sustainable development goal of clean water and sanitation is far from reach for the community. It’s a major issue in Kochupamba and Gavi where women have to go out at nights to use these toilets. Since there have been incidents of wild animal sightings near the settlements, this is a major issue. About 24.0 percent have responded as having poor sanitation facilities. Some respondents even depend on open defecation, which is seriously harmful to health (Table 20).

Table 20 Access to sanitation facilities

			Access to sanitation facilities		Total
			Yes	No	
Settlements	Meenar	Frequency	39	0	39
		Percentage	100.0	0.0	100.0
	Kochupamba	Frequency	45	19	64
		Percentage	70.3	29.7	100.0
	Gavi	Frequency	39	20	59
		Percentage	66.1	33.9	100.0
Total		Frequency	123	39	162
		Percentage	75.9	24.1	100.0

Source: Primary data

Lack of ICT facilities is a major problem in the settlements. With many children requiring laptops and mobile phones for educational purpose, the absence of internet connectivity has made their situation worse. Most of the respondents use basic model cell phone for calling purpose alone. A majority of 95.7 percent households have mobile phone access (Table 21).

Table 21. Mobile phone use

			Mobile phone use		Total
			Yes	No	
Settlements	Meenar	Frequency	37	2	39
		Percentage	94.9	5.1	100.0
	Kochupamba	Frequency	63	1	64
		Percentage	98.4	1.6	100.0
	Gavi	Frequency	55	4	59
		Percentage	93.2	6.8	100.0
Total		Frequency	155	7	162
		Percentage	95.7	4.3	100.0

Source: Primary data

The people in Gavi can use social media sites only when they go to the nearby towns. Even if there is a primary school functioning in Gavi, basic computer literacy is not provided there due to the lack of internet connectivity. This has also led many students and job seekers to move to far away towns in Idukki, Kottayam or Tamil Nadu. Here, only 36.4 percent households have any member using social media sites (Table 22).

Table 22. Social Networking Sites

			Social Networking Sites		Total
			Yes	No	
Settlements	Meenar	Frequency	23	16	39
		Percentage	59.0	41.0	100.0
	Kochupamba	Frequency	17	47	64
		Percentage	26.6	73.4	100.0
	Gavi	Frequency	19	40	59
		Percentage	32.2	67.8	100.0
Total		Frequency	59	103	162
		Percentage	36.4	63.6	100.0

Source: Primary data

Majority of the households are electrified (91.8%). In Meenar all the households have electricity connection. However, in Kochupamba and Gavi, a few houses do not have access to electricity. Apart from this, some areas of settlements are also lit with tube lights or electric fencing is done to restrict wild animals from entering the settlements (Table 23).

Table 23. Electricity facilities available					
			Electricity		Total
			Yes	No	
Settlements	Meenar	Frequency	39	0	39
		Percentage	100.0	0.0	100.0
	Kochupamba	Frequency	62	2	64
		Percentage	96.9	3.1	100.0
	Gavi	Frequency	58	1	59
		Percentage	98.3	1.7	100.0
Total		Frequency	159	3	162
		Percentage	98.1	1.9	100.0
Source: Primary data					

The already damaged roofs and floors, destroyed toilets, wild animal attacks on cattle, dirty water sources and poor medical facilities along with a lack of facilities like telecommunication, ICT, etc adds to the poor situation of the respondents. Most of these conditions cannot be included in the standard MPI index, which has led to such a lower MPI score of just 0.031. The following table (Table 24) shows the MPI calculation for KFDC plantation workers

Table 24. Multidimensional Poverty Index for Gavi				
Category	**Meenar**	**Kochupamba**	**Gavi**	**Total**
Household size	39	64	59	162
Total individuals	137	245	195	577
Education				
No one has completed five years of schooling	2	4	9	15
At least one school age child not enrolled in school	0	0	1	1
Health				
At least one member is malnourished	0	15	12	27
One or more children have died	0	0	1	1
Living standards				
No electricity	0	0	1	1
No access to clean drinking water	0	3	4	7
No access to adequate sanitation	0	19	20	39
House has dirt floor	24	51	35	110
Household uses "dirty" cooking fuel	39	63	36	138
Household has no car and owns at most one bicycle, motorcycle, radio, refrigerator, telephone and TV	25	15	35	75
Is the household poor? [c ≥ 1/3 = 0.333]	1	9	6	16
Censored score Ci [k]	1	9	6	16
Q [Number of people multidimentionally poor]	1	34	14	49
Multidimensional headcount ratio [H]	0.0072	0.13877	0.07179	49/577 =

= q/n	9			0.08492
Intensity of poverty [A]	0.335	0.363	0.39457	18.201/49 = 0.37144
MPI = H x A	0.002442	0.50374	0.02832	0.03154
Source: Primary data				

The MPI analysis highlights the fact that the community is yet to reach a decent standard of living as there is poverty existing among the workers in Gavi.

CONCLUSION

The present study is based on analyzing the socio-economic conditions of KFDC plantation workers of Gavi, based on the parameters of health, education and living standards, through evaluating their exposure, sensitivity and adaptive capacity levels. The multidimensional poverty index was 0.031, indicating that community in Gavi totally is deprived in just 3 per cent of the total potential deprivation. However, despite this low MPI score, they are not having a good quality of life. The low MPI is mainly due to the availability of the basic facilities like electricity, sanitisation, housing and medical centre. However, the standards of these facilities available are very poor, and the residents are forced to use those damaged toilets, old cottages with cracked walls and asbestos roof and inefficiently working medical center. There have been increased incidences of cancer patients in Kochupamba and Meenar, possibly due to living in asbestos roofed houses over the years. Under MPI, living standards, health and educational aspects are evaluated. Living standards in Gavi is in a miserable condition. Electricity is available in all the three settlements. However, a few households still lack power supply. Similarly, even though public toilets are built in all the three settlements, they are in damaged conditions. Also, during nights, women will have to use these toilets which lack proper doors and roofs. Reconstruction of toilets and septic tanks is an immediate need. Wild animal attacks on cattle, especially in Kochupamba where Tiger sightings and attacks are a usual thing, strict measures need to be taken to install electric fencing and regular night patrolling. Through monitoring and enhancement of resilience only the problems of man-animal conflict can be rectified. Also, construction of forest ponds can ensure water availability for animals in forest, thereby reducing the chances of them venturing out of the forest. In the estate, a dispensary with meagre facilities is operating with the assistance of a duty nurse. Only minimal drugs are accessible, which are given to patients free of charge when they are in need. Patients are compelled to travel at least 26 kilometres due to a lack of sufficient medical infrastructure, unavailability of drugs, and lack of emergency care. Malnutrition and school dropout are two more big issues in this area. Workers' children and dependents attend schools and colleges far locations, such as Vandiperiyar (27.5 kilometres) or Kottayam (121.1 kilometres), among others. At Gavi, a government lower primary school in Tamil language is also operating for the education of repatriate children. However, many children are compelled to drop out of school after fourth grade due to a lack of high school facilities and school bus service. There is a significant rate of dropout among school-aged children, which is symptomatic of their social deprivation.

Community based vulnerability index of 2.63 indicates high levels of poverty. Invasive species have been found to be on the rise in the Gavi community, posing a threat to cardamom production. This invasive plant species, also known as "Kambi Pullu," draws the nutrients necessary for Cardamom from the soil. People's perceptions of a longer summer season, shorter and cooler monsoons, and an increase in heat waves represent a visible climate change scenario. During the summers, surrounding springs and streams dried up, indicating that the water table had been depleted. During the summer, inhabitants confront a significant water deficit. Wild animal sightings and territorial distribution disturbances have increased in the Gavi village. Even though no humans have been injured, wild animals are attacking cattle and inflicting property damage. In the settlements, there was a lack of skill based and empowerment efforts. Despite the existence of self-help groups such as kudumbasree and other clubs in the settlement, empowerment programmes and capacity building initiatives were weak. It was discovered that, even though the population had overall low adaptive capacity, all social, physical, and natural capacity-building measures were poorly applied. The need for a holistic approach in understanding the problems and the prospects of the region with the active participation of all stakeholders is mandatory for improving the well-being of the local population in the region. This will further help to go in par with the Sustainable Development Goals of no poverty, zero hunger, good health and wellbeing, quality education and gender equality.

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SOIL EROSION QUANTIFICATION IN CHALIYAR RIVER BASIN, KERALA, USING REVISED UNIVERSAL SOIL LOSS EQUATION (RUSLE)

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Abstract:

Soil erosion is an environmental problem and adverse hydro-geologic phenomenon consisting of the detachment and transportation of surface soil particles from their initial location to the nearby location for subsequent accumulation. This necessitates quantification of soil erosion under both retrospective and future scenarios for efficient conservation of soil resources. In the present study Revised Universal Soil Loss Equation (RUSLE) based soil erosion estimation framework at an unprecedentedly high spatial resolution (30×30m) to quantify the average annual soil loss in Chaliyar River Basin, Kerala was used. The input parameters were derived by using the observed rainfall data, soil characteristics, and topographic characteristics derived from the digital elevation model (DEM) and satellite imageries. This approach was evaluated in the river basin, wherein the different RUSLE inputs, viz., rainfall erosivity (R factor), soil erodibility (K factor), slope length and steepness (LS factor), cover management (C factor), conservation practice (P factor) factors have the magnitude of 321.06 to 890.729 MJ mm ha-1 y-1, 0 to 0.3-ton ha¯1 MJ¯1mm¯1, 0 and 79.4958, 0.0029 to 1.864, 0 to 1 respectively. The estimated soil erosion of the Chaliyar river basin ranged between 0 to 6758.36 t ha¯1 y¯1. Compiling the results from the study, it can be concluded that the 2.9709 km² (0.12%) area falls in the high potential erosion risk zone where the high hazard zone is in the areas of higher elevation. The outcomes of this study will serve as a valuable tool for decision-making while implementing management policies to prevent further erosion.

Keywords:

Chaliyar, Soil erosion, RUSLE, Climate change.

INTRODUCTION

The soil erosion process gets accelerated by considerable human activities across many places of the globe (Gabriels and Cornelis, 2009). Moreover, poor land-use practices also lead to a considerable increase in soil erosion (Arnáez et al., 2015). Soil erosion caused by water is the loss of top fertile surface soil as a result of erosive rainfall and consequent runoff (Ganasri and Ramesh, 2016). It is considered to be the riskiest form of soil degradation (Alexandridis et al., 2015).

Soil erosion which occurs in a watershed boundary is caused by four factors: climate, the characteristics of soil, the topography of the area, and Landover vegetation. There are several types of soil erosion a) Sheet erosion in which water passes over a soil with gentle and smooth slope, it follows along a sheet of more or less uniform removal of soil from all parts of the area having a similar degree of slope, b) Splash erosion occurs when the falling raindrops splash on the soil and beat the bare soil into the flowing mud, c) Rill erosion takes place when the removal of soil by runoff water with the information of shallow channels that can be smoothed out completely by normal cultivation. Rills develop as a result of the concentration of runoff water where the silt-laden runoff water starts flowing along the slope through small finger-like channels, d) Gully erosion is the removal of soil along drainage lines by surface water runoff, when surface water runoff increases and attains more velocity on slopes which enlarges rill into gullies, e) Stream bank erosion mainly occur when the stream and river change their course by cutting bank and depositing the sediments on the other, f) Sea-shore erosion mainly caused by the loss or displacement along the coastal line due to the action of the wave. The landforms can create and destroyed by erosion. Soil erosion is one of the major problems in the river basin, because the eroded sediments are deposited in the river basin results in increased sedimentation in the basin (Boggs, 2006). Soil erosion by rainfall and surface water flow is generally affected by five factors: Rainfall erosivity, soil erodibility, topography, surface coverage, and support practices in humid regions, soil erosion is of little concern in well-established forests and paddy fields, however bare lands such as logging forests, construction areas, and upland crop fields on slopes are exposed to a high risk of soil erosion. Studies have reported that soil erosion can be affected by the impact of climate change. Climate change affects the rate of soil erosion directly through the change in precipitation and temperature pattern and eventually altering the runoff, biomass production, infiltration rate, soil moisture, and land use (Li and Fang, 2016).

The erosion phenomenon consists in the detachments of individual soil particles from the soil mass which are transported by erosive agents such as water and wind (FAO, 2015). It moves the soil particles of the most upper layer of the ground from one plot to another plot. Further, soil erosion is a complex and progressive phenomenon that has been increasing around the twentieth century all over the world (Singh and Panda, 2017). It is estimated that 75 billion metric tons of soil is removed by wind and water in annually (Diyabalanage et al., 2017). Moreover, FAO stated that global soil erosion by water is 20–30 Gt (gigatons) year−1 (FAO, 2015). In addition to that, two billion hectares had been eroded by human intervention in globally. By this, water erosion has contributed to 1100 million hectares (Ganasri and Ramesh, 2016). Water erosion in the tropical region is comparatively high due to the annual distributed rainfall coupled with other factors which are prevailing to the rill and inter-rill erosion (FAO, 2015). Accelerated water erosion has become a leading soil degradation scenario in the tropical region because of the human activities (Diyabalanage et al., 2017). Hence, global soil erosion by water has reached an alarming level and it should be addressed sustainably.

Sustainable management of land and water resources warrants formulation of effective and appropriate erosion prevention measures, which in turn, rely on assessment of soil erosion rate. Field survey based conventional soil erosion assessment methods are not cost effective and time-consuming task. Thus, several erosion models have been developed, and they can be categorized into three groups such as empirical, conceptual and physical (Devatha et al., 2015). Each model has its own attributes and application scope with the data that has been used to run the model (Ricker et al., 2008; Rahman et al., 2009; Wijesundara et al., 2018). Universal Soil Loss Equation (USLE) is an empirical soil erosion model which was formulated by the United States Department of Agriculture (USDA) in 1978 to conjecture amount of soil loss in long-term basis (Abdo and Salloum, 2017). Furthermore, it focuses on inter-rill and rill erosion from cropland by water with the effects of some attributes of geology, climatology and topographical features. USLE was updated as The Revised Universal Soil Loss Equation (RUSLE) (Renard, 1997). RUSLE was originally developed to assess soil erosion of gently sloping agricultural land (Wischmeier and Smith, 1978). Hence, in recent years many researchers across the world adopted RUSLE. Some of them aligned to the watershed to compute the magnitude of the soil erosion associated with agricultural activities (Prasannakumar et al., 2012).

STUDY AREA

Chaliyar is the one among the 44 rivers in Kerala. Chaliyar River drainage basin is cored by Precambrian Peninsular Shield which lies between Murat and Kabini basins in the north and Kadalundi basin in the south. This inter-state river has a total drainage area of 2,923 km^2 out of which 2,536 km^2 lies in Kerala State and the rest 387 km^2 area falls in Tamil Nadu. It is bound by latitudes 11º 06’07” N and 11º 33’35” N and longitudes 75º 48’45” E and 76º 33’00” E falling in Survey of India (SOI) degree sheets 58A and 49M. The basin comprises parts of four districts viz. Kozhikode district cover an area of 626 km^2 in the northwest, Wayanad district over an area of 112 km^2 in the north, Malappuram district spreads over an area of 1784 km^2 in the east and south and Nilgiri district of Tamil Nadu over an area of 378 km^2 in the northeast. Chaliyar River forms the third largest river in Kerala rising in the Elambaleri hills in the Wayanad plateau. Six major streams Chaliyarpuzha, Punnapuzha, Kanjirapuzha, Karimpuzha, Iruvahnipuzha and Cherupuzha constitute the Chaliyar River drainage system. Other important tributaries are Kurumanpuzha, Pandipuzha, Maradipuzha, Kuthirapuzha and Karakkodupuzha. Most of these rivers have their origin in the Nilgiri hills in the east and Wayanad hills in the north, where they form a number of rapids and waterfalls. The river joins the Lakshadweep Sea south of Kozhikode near Beypore after flowing over a distance of about 169 km^2 in the name Beypore River. The watershed is predominantly agricultural lands (74.26 %) and forests (14.21 %). The remaining area comprises urban areas, rocky areas and water bodies. The basin enjoys a tropical humid climate with sweltering summer and high monsoon rainfall, on an average about 3000 mm of rainfall occurs annually in the basin. The principal rainy seasons are the southwest (June-September) and northeast (October-November) monsoons in India. The pre-monsoon months (March-May) are characterized by major thunderstorm activity and the winter months (December-February) by minimal cloudiness and rainfall. Summer (southwest) monsoon (June-September) accounts for a major part of the average annual rainfall (> 300 cm), whereas the winter monsoon (October-January) accounts for about 50-60 cm rainfall. Temperature in the region ranges between 23° and 37°C.

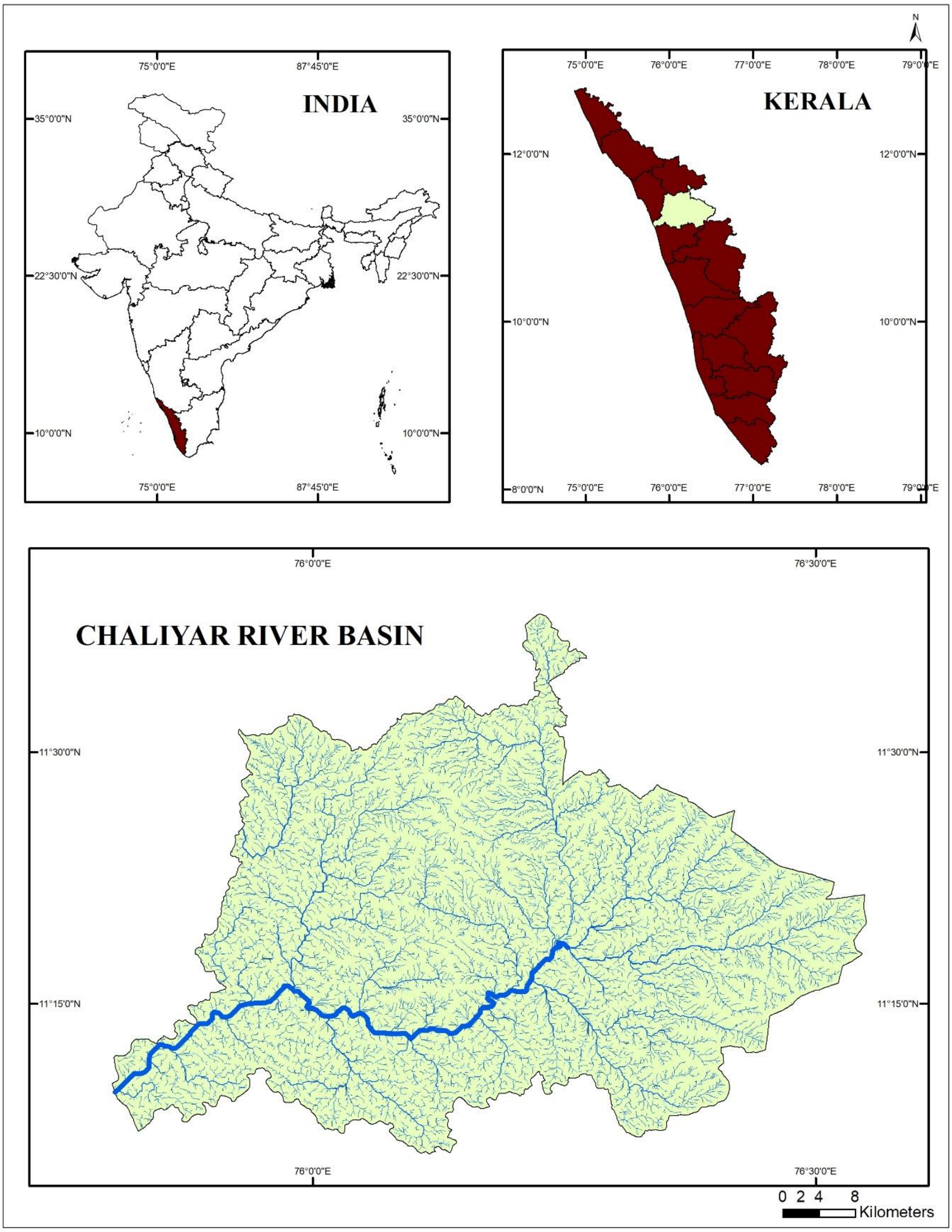


Fig 1.1 Location map of the study area

OBJECTIVE
To quantify soil erosion in the Chaliyar river basin using RUSLE method

REVIEW OF LITERATURE

Various approaches and equations for risk assessment or predictive evaluation of soil erosion by water are in vogue in the international research scenario (Saha and Pande 1993; Angima et al., 2003; Yue-qing et al., 2009; Kim Y., 2014; Bekele and Gemi, 2021). The soil erosion models used in regional scale include USLE/RUSLE, WEPP, SEM-MED, ANSWERS, LISEM, EUROSEM, SWAT, SWRRB, AGNPS, etc. Each model has its own characteristics and application scopes (Boggs et al., 2001; Lu et al., 2004; Lim et al., 2005; Thomas et al., 2018, Prakash et al., 2022).

Numerous works have been done on the soil erosion using different types of models across the world. Most of these works applied to the mountains and plateau areas. The soil erosion models are too diversified globally. Lu et al., (2004) prepared soil erosion risk map in Rondonia, Brazilian Amazon by RUSLE using LANDSAT images. Lim et al., (2005) has used the RUSLE model, in which they have developed a GIS-based sediment assessment tool for effective erosion control (SATEEC) to estimate soil erosion and yield within a watershed. Fu et al., (2006) modelled the impacts of no-till practice on soil erosion and sediment yield with RUSLE, SEDD and Arc View GIS. Terranova et al., (2009) studied the soil erosion risk scenarios in the Mediterranean environment of Italy using RUSLE. Demirci and Karaburun (2012) estimated soil erosion using RUSLE in GIS framework Buyukcekmece Lake watershed, Turkey. Kim, (2014) assessed the soil erosion by using RUSLE and GIS in San Marcos Sub basin, USA. Bekele, M. (2021) done Geographic information system (GIS) based soil loss estimation using RUSLE model for soil and water conservation planning in Anka-Shashara watershed, southern Ethiopia. Mengie et al., (2022) assessed soil loss rate using GIS–RUSLE interface in Tashat Watershed, Northwestern Ethiopia.

Large number of studies on soil erosion were reported in India. Pandey et al., (2007) identified critical erosion prone area in the agricultural watershed in Jharkhand using USLE, GIS and Remote Sensing. Kumar and Kushwaha (2013) analysed the soil erosion risk based on RUSLE-3D using GIS in Shivalik, Uttarakhand, in which high resolution satellite data of IKONOS and IRS LISS III were integrated in Land and Water Information System image processing. Dash et al., (2021) assessed soil erosion vulnerability using RUSLE which is a case study of Altuma catchment of Brahmani River basin, Odisha, India.

In Kerala also large numbers of studies were reported on soil erosion modelling using RUSLE method. Prasannakumar et al., (2011) had done wrk on the spatial prediction of soil erosion risk in Siruvani river watershed in Attapady valley of Kerala using RUSLE, GIS and Remote Sensing. Anjana and Ajith (2016) prepared soil erosion of Kuttyadi river basin using RUSLE. Thomas et al., (2018) used RUSLE to predict the long-time average annual soil loss and to identify the critical erosion/ deposition prone areas in a tropical mountain river basin, viz., Muthirapuzha River Basin, in the southern Western Ghats. Prakash et al., (2022) estimated annual soil loss in Chalakkudi river basin of southern India using RUSLE model and AHP techniques.

METHODOLOGY

In the present study, soil loss was estimated using the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997). The soil erosion assessment is based on a quantitative approach.

Data sets used

Satellite image (band 3, band 4, and band 5) of Landsat 8 (OLI/TRS) was downloaded from USGS Earth Explorer (https://earthexplorer.usgs.gov/). Aster DEM was taken from (https://earthdata.nasa.gov/). Soil textures were collected from benchmark soils of Kerala. The rainfall data were used for estimating the value of runoff in the study area. The data were collected from GES DISC (https://disc.gsfc.nasa.gov) with spatial resolution 0.1° × 0.1 °. Digital elevation data was collected in raster format from ASTER DEM with the spotted resolution of 30m. (https://earthexplorer.usgs.gov/). Various thematic layers were prepared for the study area are Boundary and Land use and Land cover (polygon feature).

Analysis performed

RUSLE- based annual soil loss estimation

The RUSLE represents how both physical and anthropogenic or semi-anthropogenic (land use/land cover) affect rill and inter-rill soil erosion caused by raindrops and surface runoff (Renard et al. 1997). In this study, RUSLE model was used to compute the long-term average annual soil loss and five factors were analysed using the following empirical equation. Eq. 1

$$\mathbf{A = R \times K \times LS \times C \times P} \quad \ldots\ldots\ldots\ldots\ldots \textbf{(Eq. 1)}$$

were,

A = predicted average annual soil loss per unit area (t ha¯1 y¯1)

R = rainfall -runoff erosivity factor (MJ mm ha¯1 h¯1 y¯1)

K = soil erodibility factor (ton ha¯1 MJ¯1mm¯1)

LS = slope length-steepness factor (dimensionless)

C = cover-management factor (ratio of soil loss from a specified area with specified cover and management to that from the same area in tilled continuous fallow) (dimensionless)

P = conservation support practice factor (dimensionless)

Rainfall Erosivity (R)

The rainfall erosivity factor is an index that measures the erosive force of a specific intensity of rainfall and is defined as a function of rainfall volume, intensity, and duration (Renard and Freimund, 1994). The value of rainfall erosivity factor used in RUSLE must quantify the effect of raindrop impact and must also reflect the amount and rate of runoff likely to be associated with the rainfall. Rainfall data from the GESDISC open data portal, were used to calculate R-factor over a ten-year period (2011-2020) using the following relationship developed by Arnoldus (1980)

$$\mathbf{R= \sum_{i=1}^{12} 1.735 \times 10^{\left(1.5 \times \log\left(\frac{pi2}{p}\right) - 0.08188\right)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(Eq. 2)}$$

Where, R is the rainfall erosivity factor (MJ mm ha¯1 h¯1 y¯1), Pi is the monthly rainfall (mm) and P is the annual rainfall (mm).

Soil Erodibility Factor (K)

The K factor is an empirical measure of soil erodibility that is influenced by intrinsic soil properties (Fu et al., 2006). It represents a variety of factors such as soil erodibility, sediment transportability, and the amount and rate of runoff. The K factor map was created using a generalised soil texture map obtained from the Kerala soil survey organisation. The corresponding K values for the soil types were determined using the soil erodibility nomograph (Wischmeier and Smith, 1978) while taking particle size, organic matter content, and permeability class into account. Soils with low soil erodibility have 0 values, while soils with high soil erodibility have high values (Goldman et al., 1986).

Table 4 Soil erodibility factor (K)

Sl No.	Textural class	K factor
1	Clay	0.29
2	Loam	0.30
3	Gravelly clay	0.26
4	Gravelly loam	0.22
5	Sandy	0.05

Slope Length and Steepness Factor (LS)

The topographic factor, also known as the slope length and steepness factor (LS), account for the effect of the site's topography on erosion. The effects of a slope length factor (L) and a slope steepness factor (S) are combined in the LS factor. The slope length and steepness that influence the surface runoff speed, the LS factor describes the combined effect of slope length and slope steepness, the slope length increases the total soil erosion loss per unit increases as a result of progressive accumulation of runoff in down slope. As the slope steepness increases, the total soil erosion also increases as a result of increasing the velocity and erosivity of runoff (Wischmeier and Smith, 1978). Renard et al., (1997) defined the slope length as the horizontal distance traversed from the origin of overland flow to the point where deposition occurs or runoff concentrates into a defined channel.

The combined LS-factor was computed for the watershed by means of SAGA using the DEM following the equation, as proposed by Moore and Burch (1986).

$$\mathbf{LS = (Flow\ accumulation \times Cell\ size/22.13)^{0.4} \times (Sin\ slope/0.0896)^{1.3}} \quad \text{.......... (Eq. 3)}$$

Were flow accumulation denoting the accumulated upslope contributing area for a given cell. LS is the combined slope length and slope steepness factor; cell size is the size of grid cell (for this study: 30 m) and sin slope is the slope degree value in sin.

Cover Management Factor (C)

The cover-management factor (C) reflects the effect of cropping and other practices on erosion rates (Chalise et al., 2019). It is the most spatiotemporal sensitive, as it follows plant growth and rainfall dynamics (Nearing et al., 2004). This factor defined as a non-dimensional number between zero and one representing a rainfall erosion weighted ratio of soil loss for specified land and vegetated conditions to the corresponding loss from continuous bare fallow (Wischmeier and Smith, 1978).

The Normalized Difference Vegetation Index (NDVI), an indicator of the vegetation vigour and health is used along with the following formula to generate the C-factor value image for the study area (Zhou et al., 2008: Kouli et al., 2009).

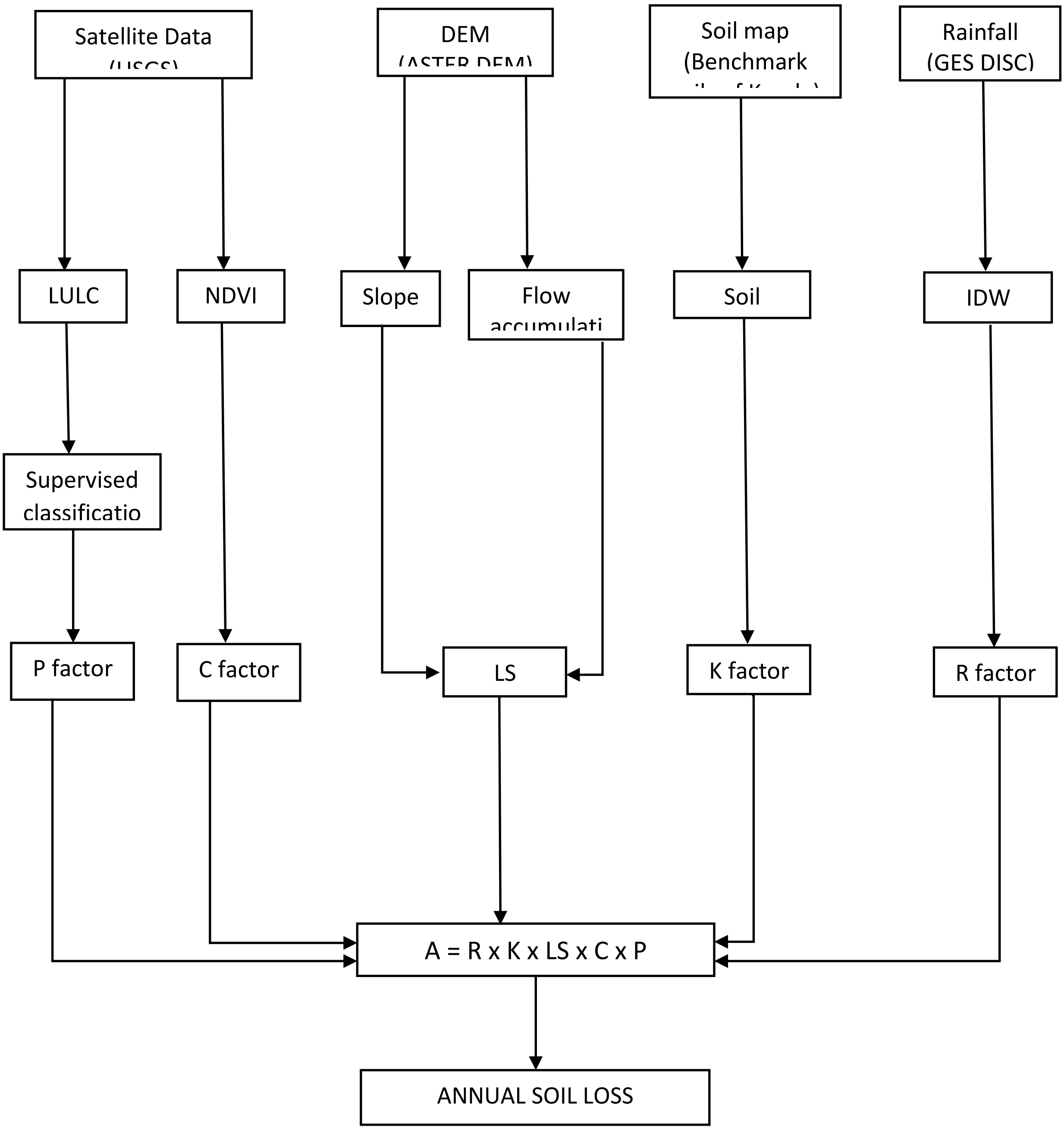
$$\mathbf{C = \exp[-\alpha\ (NDVI / \beta\text{-}NDVI)]} \quad \text{.............................. (Eq. 4)}$$

Where α and β are unitless parameters that determine the shape of the curve relating to NDVI and the C-factor. An α-value of 2 and a β-value of 1 seem to give reasonable results (Van der Knijff et al., 1999). High NDVI values and low C values are found in areas with dense and healthy vegetation.

Conservation Practice Factor (P)

The conservation practice factor (P) is defined as the fractional amount of erosion that occurs when cultivation practices such as contour cultivation, strip cropping, and terracing are used. compared to erosion that would occur without them. Improved tillage practices (e.g., crop rotation, organic fertilizing, etc.) contribute to erosion control as well. The value of P-factor ranges from 0 to 1, in which the highest value is assigned to areas with no conservation practices, and the minimum values correspond to good conservation practices. The lower the P values, the more effective the conservation practices (Prasannakumar et al., 2011). The assigned P factor value for the present study is given below (Table 5).

The overall workflow for the RUSLE is represented as a flow chart below (Figure 1)



RESULTS AND DISCUSSION

The annual soil loss in the Chaliyar river basin was estimated using RUSLE method. The results obtained are described below

Rainfall Erosivity Factor (R)

The average Rainfall Erosivity Factor (R) value for the years 2011-2020 varied from 321.06 to 890.729 MJ mm ha^{-1} y^{-1}. Highest R values are observed in the lower part of the study area. The area which is susceptible to high erosion rate is due to the high precipitation, which is highly erosive. The highest rainfall was observed in the month of July and the lowest rainfall was observed in the month of January. In Kerala especially in Chaliyar river basin, it was observed that an average annual rainfall of 3059.405 mm was obtained for last decades hence the area showed high values for R factor also.

Soil Erodibility Factor (K)

Soil erodibility factor represents susceptibility of soil to erosion and transportability of the sediment. Different soil types are naturally resistant and susceptible to more erosion than other soils and are function of grain size, drainage potential, structural integrity, organic content and cohesiveness (Prasannakumar et al., 2011). The soil erodibility factor ranges from 0 to 0.3-ton ha^{-1} $MJ^{-1}mm^{-1}$.

Slope Length and Steepness Factor (LS)

The topographic factor (LS), which combines the effects of a slope length factor (L) and a slope steepness factor (S), is very important in RUSLE because it characterizes the surface runoff speed. Slope, considered critical for identifying the zones of erosion intensity, varies from 0 to 73°. In general, as the L-factor rises, total soil erosion per unit area rises due to the progressive accumulation of runoff in the down slope direction, and as the S-factor rises, runoff velocity and erosivity rise (Prasannakumar et al., 2011). The LS value ranges between 0 and 79.4958.

Cover Management Factor (C)

The present study area, the factor values range from 0.0029 to 1.864. The cover management factor represents the effect of cropping and agricultural management practices as well as the effect of ground, trees and grass cover on reducing soil loss. The factor has an inverse relationship with NDVI (Moses, 2017).

Conservation Practice Factor (P)

The P factor represents the effect of cropping and agricultural management practices as well as the effect of the ground. trees and grass cover on reducing soil loss. Majority of the area is under mixed crops as well forest area. For the forest, there is no control practices are adopted, it has given maximum value of 1 which covers an area of 434.371 km² (17.11%). Mixed crop with large area having P factor 0.3 constitute 1613.64 Km² (63.56%).

Annual Soil Loss (A)

The estimated soil erosion of the Chaliyar river basin was ranged between 0 to 6758.36 t ha^{-1} y^{-1} (Fig. 7.2). The potential soil loss of the basin was found to be high where the slope or LS factor is high. Such areas are more susceptible to erosion and the soil loss is very high. The results were correlated with similar studies carried out in different parts of the Western Ghats. The soil erosion estimation in these studies is found to be similar and matching. The result of current study is also compared with other works, Pradeep et al., (2015) quantified the soil loss of sub-watershed of river Meenachil, namely, Kalathukadavu and Poonjar river basin found to be 4227 t ha^{-1} y^{-1}. Work done by Aswathi et al., (2022) estimated soil erosion of 5714.57 t-ha^{-1} y^{-1} for a tropical river basin in South India (Muvattupuzha River Basin). Comparative study of these works reveals that estimated soil erosion in study area is high.

Compiling the results from the study, it can be concluded that the majority of the study area, 1861.32 Km^2 (73.39%) is classified as low potential erosion risk and 2.9709 Km^2 (0.12%) area falls in highly potential erosion risk zone. The spatial pattern of classified soil erosion risk zones indicates that the areas with high and severe soil erosion, east and northern parts of the study area, while the areas with low erosion risk are in the central and south western parts of the study area.

Table 5 Area under different categories Topographic factor (LS) of the study area

Sl No.	LS Factor classes	Area	
		(Km^2)	(%)
1	0 – 2.5	1399.58	55.13
2	2.5 - 5	347.829	13.70
3	5 - 10	450.521	17.74
4	10 - 20	315.007	12.41
5	20 – 79.4958	25.9146	1.02

Table 6 Assigned P factor value for the land use and land cover

Sl No.	Land Use and Land Cover	P Factor	Area	
			(Km^2)	(%)
1	Waterbody	0	39.9429	1.57
2	Sandbars	0	0.1161	0.004
3	Built-ups	0.4	128.503	5.06
4	Mixed crops	0.3	1613.64	63.56
5	Paddy fields	0.25	57.1977	2.25
6	Exposed rock	0	64.8243	2.55
7	Forest	1	434.371	17.11
8	Grassland	0.7	25.0011	0.996
9	Tea	0.6	175.13	6.90

Table 7 Quantity of soil loss in the study area

Sl No.	Annual soil loss (t $ha-^1y^{-1}$)	Area	
		(Km^2)	(%)
1	0 – 50	1861.32	73.39
2	50 – 250	575.047	22.67
3	250 – 500	66.5604	2.62
4	500 – 1500	30.3408	1.20
5	1500 – 6758.36	2.9709	0.12

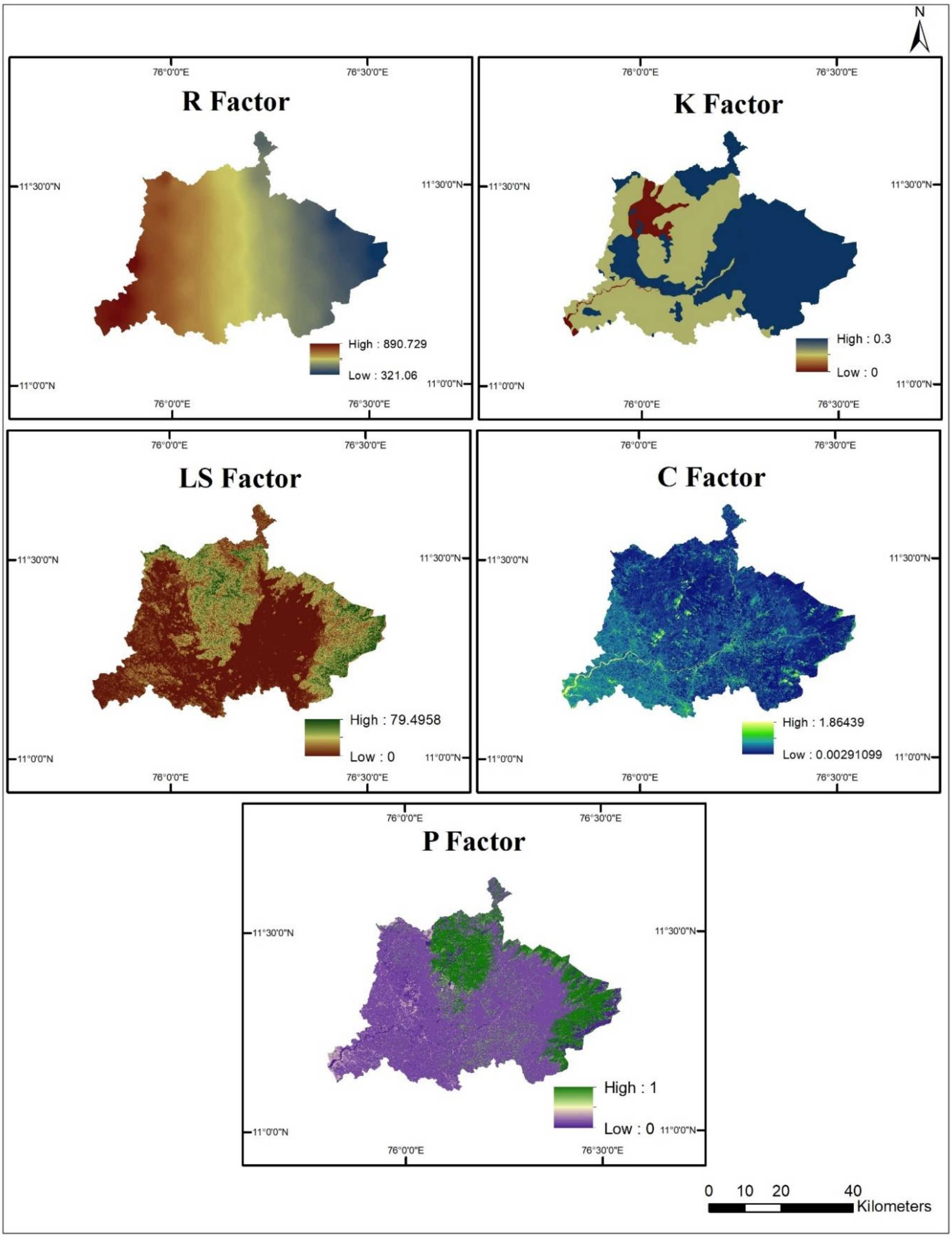


Fig. 2 Thematic factors considered for RUSLE modelling

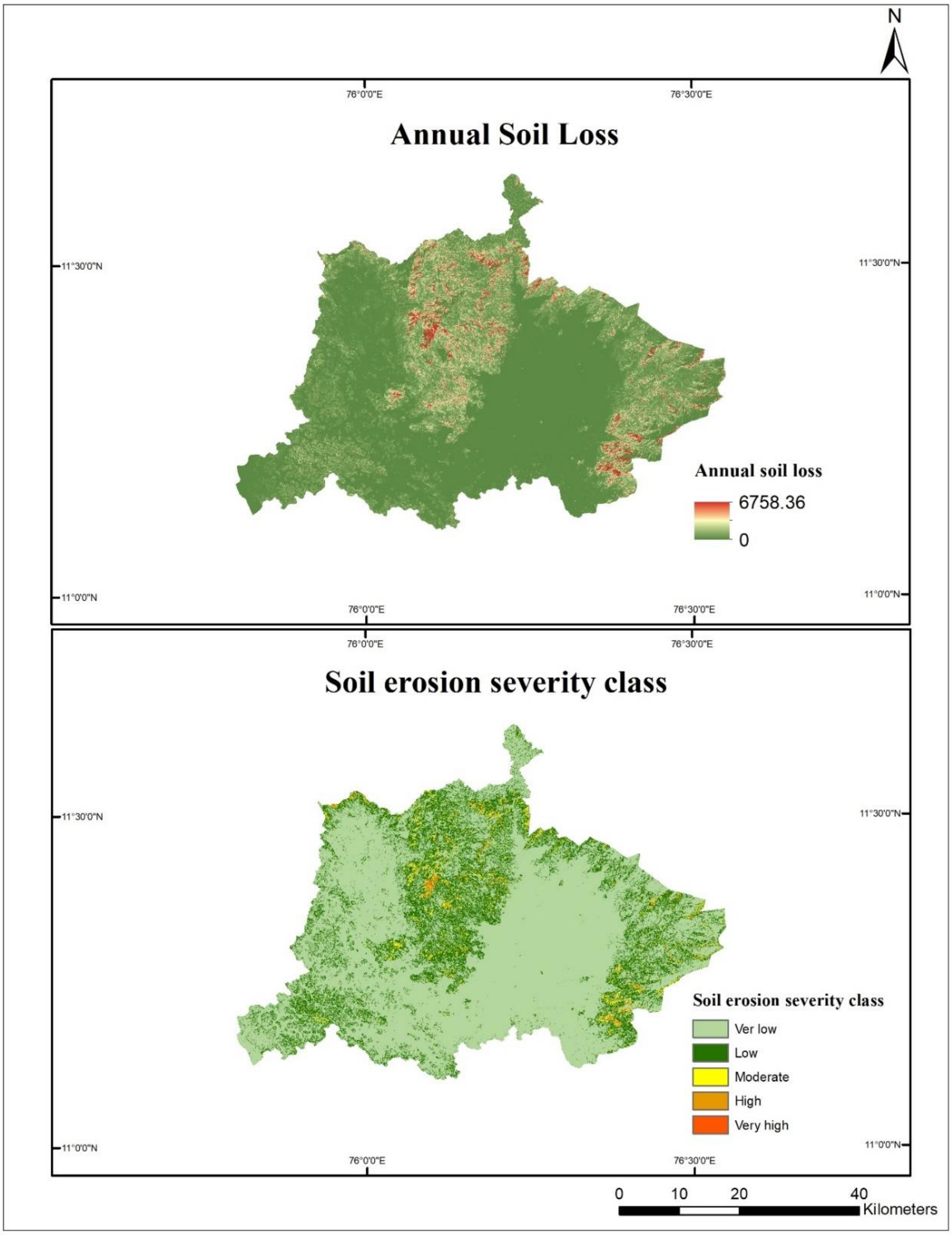


Fig. 3 Annual soil loss map of the study area

CONCLUSIONS

Soil erosion quantification assessed for Chaliyar River basin using Revised Universal Soil Loss Equation (RUSLE) considering rainfall, land use land cover, soil texture and topographic datasets. The annual soil loss is found to be in the range of 0 to 6758.36 t ha^{-1} y^{-1}. Majority of the study area comes under low to moderate erosion risk zone. High hazard zone is in the areas of higher elevation. Estimation of soil loss and its spatial distribution gives an effective control, management and sustainable land use in the river basin.

Region having higher soil erosion needs to be monitored and several measures should be technically implemented to prevent further erosion. Though the current RUSLE model helps in the estimation of soil erosion and predicts its vulnerability, micro-scale data on rainfall intensity, soil texture, and field measurements can amplify the prediction, capability and precision of remote sensing and GIS-based analysis. These findings can also be used as foundational data to aid in water and soil conservation management and land use planning.

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AUTHOR CONTRIBUTION
Delna Joy K: Investigation, Visualization, Methodology, Formal Analysis, Writing Original Draft.
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SPATIO TEMPORAL ANALYSIS OF LAND USE /LAND COVER OF INDIAN SUNDARBANS OVER DECADES

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Abstract:

Vegetation plays an important role in sustaining the ecological biota and maintaining the equilibrium of environment. Mangroves, an exclusive group of plants with remarkable ecological importance, inhabit mostly the zones washed by the back and forth movement of tides. The depletion of mangroves is a cause of serious environmental and economic concern to many developing countries including India. They are disappearing rapidly from their natural habitat due to various reasons. The World's most extensive mangrove region, the Sundarbans ecosystem, is highly biodiverse but severely stressed. Sundarbans were facing immense destruction due to super cyclones during past years. Almost every year, the Sundarbans act as a bulwark to protect the people from various natural calamities i.e., cyclones and tidal surges. This study investigates land use land cover (LULC) change of entire Indian Sundarbans mangrove over 40 years (1978 - 2021) using Landsat imagery. Supervised maximum likelihood was used to classify the study area in four time periods over 40 years (1978, 1993, 2007, and 2021). The classification was assigned to six classes: agriculture, healthy mangrove, aquaculture, plantation with built-up, unhealthy mangrove and water body. Accuracy assessment was carried out with 200 control points for each year resulting in overall accuracy of about 75%. LULC maps revealed that agriculture and water body was the predominant class in Sundarbans and least in aquaculture. A slow and steady decline in the agriculture area was recorded during the 40-year study period from 3807.69 km^2 to 2483.28 km^2 showing a 34% reduction. Mangroves gradually decreased from 1978 to 1993 but increased in 2007, while an inconsistent increase or decrease was observed for unhealthy mangroves. Healthy mangroves mostly turned sparse and some areas are filled with water. It was observed that built-up areas increased significantly, with most of the agricultural land being converted to built-up. Proper monitoring of LULC changes when applied help the relevant government bodies, agencies and environmental managers utilize the environment to the fullest.

Keywords:

LULC, Sundarbans, Remote Sensing

INTRODUCTION

Land use and land cover (LULC) change has become a central component in current strategies for managing natural resources and monitoring environmental changes (Attri et al., 2015). It plays a very important role on regional to global scales, with impacts over ecosystem functioning, ecosystem services, and biophysical and human variables such as climate and government policies (Meyer and Turner 1994). Mangroves, an exclusive group of plants with remarkable ecological importance, inhabit mostly the zones washed by the back and forth movement of tides. Communities depend on mangroves for a range of goods such as fuel wood, shellfish, palms and on ecosystem services such as maintenance of the productivity of important estuarine dependent fisheries, water quality regulation, flood reduction and shoreline stability (Acharya, 2002). The depletion of mangroves is a cause of serious environmental and economic concern to many developing countries including India. Sundarbans is the largest contiguous mangrove forest of the world; it alone constitutes 3% of the global mangroves forest area (Chanda et al., 2016). Sundarbans protect millions of coastal people and their resources from storms, cyclones, and coastal soil erosion. Moreover, the carbon sequestration rate of mangrove forests is four times higher than other tropical forests (Donato et al., 2011). Sundarbans mangroves are decreasing at an alarming rate due to natural and anthropogenic causes. Mangroves are often considered low value ecosystems (by those who are not dependent on them) because there are very few directly marketed goods that come from these ecosystems. As a result, conversion to other land uses has been an attractive option for many governments, communities and individuals. Some natural factors like increasing salinity of water and soil as well as the daily duration of submersion cause mortality of mangrove plants and excessive silting suffocate the trees. Due to tidal actions, a large part of the organic matter produced by the trees is washed away which can also result in the depletion of nutrients in this fragile ecosystem. The global loss of mangroves can be attributed largely to human population growth and development in the coastal zone. Specific reasons are urban development, aquaculture, conversion to agriculture such as rice farming, and overexploitation of timber. Land cover and land-use change information impart practical uses in various applications, including deforestation, damage assessment, disaster monitoring, urban expansion, planning, and land management. As the area is protected and inaccessible, it is difficult to assess the biodiversity loss and disturbance by conventional means. Periodic and reliable estimation of disturbance regime to this fragile ecosystem is must for a better forest management plan. Satellite remote sensing helps in tracking changes in the mangrove ecosystem and can assess performance through changes in land use, primary productivity and phenology (Kerr and Ostrovsky 2003).

STUDY AREA

Indian Sundarban mangroves (21◦31′N 88◦10′E–22◦30′N 89◦ 51′E) situated on the world's largest delta, are created by the three major rivers, Ganges, Brahmaputra and Meghna that converge in the Bengal basin. The Indian Sundarbans Delta (ISD) is bounded by the Ichamati–Raimangal river in the east, by the Hoogli river in the west, by the Bay of Bengal in the south, and the Dampier and Hodges line drawn in 1829–1830 in the north. In most of the time, the weather remains humid. Seasonal mean minimum and maximum temperatures vary from 12°C to 24°C and 25°C to 35°C, respectively. The total annual amount of precipitation is between 1500 mm to 2000 mm. During the monsoon period, tropical cyclones always hit the Sundarbans, causing severe flooding and wind damage (Ghosh et al., 2015).

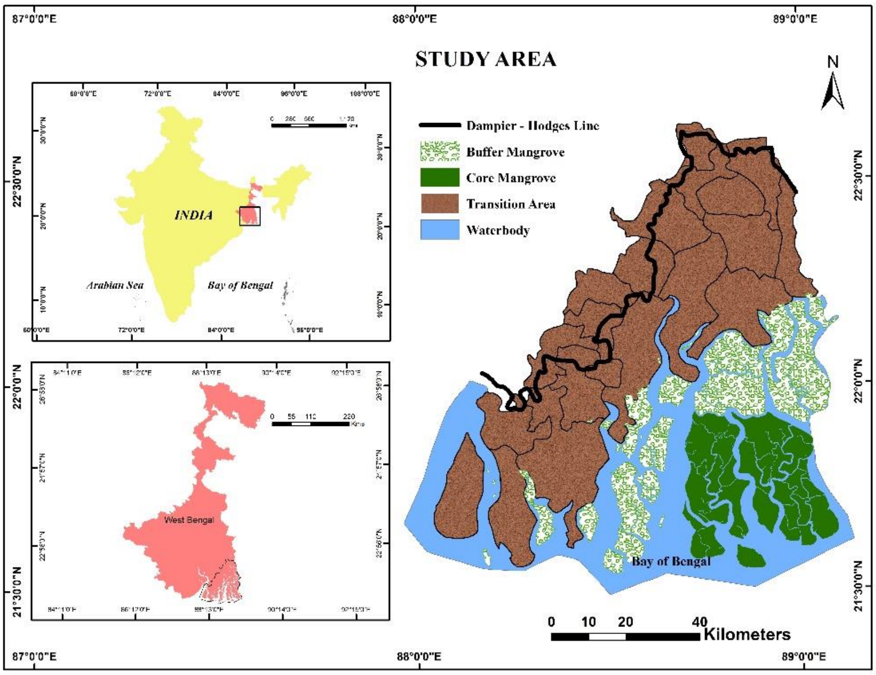

Figure 1. Study area map

OBJECTIVES

To investigate the ecosystem changes of Indian Sundarbans over decades

REVIEW LITERATURE

A mangrove ecosystem represents a transition zone between fresh and saline water that links the terrestrial and marine ecosystems. Mangrove forests are confined to the tropical and subtropical regions of the world, and they are among the earth's most diverse and dynamic ecosystems (Hogarth, 2007). Sundarbans offer numerous ecosystem goods and services to coastal populations and are considered as a biological supermarket and hotspot for biodiversity conservation (Payo et al., 2016). Sundarbans provide a habitat for many threatened and endangered species like the Royal Bengal tiger (Ortolano et al., 2016). Global climate change is expected to alter the precipitation patterns, and temperature variability and increase sea level rise (IPCC, 2014), with potentially severe impacts on mangroves worldwide (Di Nitto et al., 2014). However, apart from a few places mangrove forests have been rapidly disappearing at an alarming rate across the globe—at least 23% of mangrove forests have been lost in the past two decades (Friess and Webb, 2014). The land use land cover change of an area is an outcome of natural and socio-economic aspects and their operation by humans in time and space. Inventory and monitoring of land-use/land-cover changes are indispensable aspects for further understanding of change mechanisms and modelling the impact of change on the environment and associated ecosystems at different scales (Turner et al, 1995). Growing population and increasing socioeconomic needs put pressure on land use land cover, resulting in unplanned and uncontrolled changes in land use land cover and eventually leading to the degradation of the Earth's ecosystem. Due to anthropogenic activities and climate change-related factors mangroves in Sundarbans were gradually decreasing and are considered as one of the most vulnerable tropical ecosystems on the planet. The dense forest of Bangladesh and Indian Sundarbans decreased by an annual rate of 1.20% and 1.60%, respectively, from 1975 to 2020 while water bodies increased by giving an annual rate of 0.48% and 0.71%, respectively, from 1975 to 2020. The decreasing rate of dense forest was higher for Indian Sundarbans (Kanan and Pirotti, 2022). Thakur et al., 2018 reported that the most prominent changes were observed in the waterlogged area class mostly strewn along the northern fraction of the biosphere reserve which has increased from 9.4 to 14.36% of the total area. It was also observed that the settlement area increased from 5.1% of the total area in 2000 to 5.21% in 2017 (an increase of 2.1%) indicating a shift in the LULC dynamics. Saltwater intrusions and increasing the salinity of the cropland and forcing the farmers to shift elsewhere reduce the agricultural area after cyclonic events and storms (Misra et al., 2015). Satellite-based Remote Sensing, by its ability to provide synoptic information on land use and land cover at a particular time and location, has revolutionized the study of land use and land cover change (Attri et al., 2015). Remote sensing data has become a major source for change detection studies because of its high temporal frequency, a digital format suitable for computation, synoptic view, and a wider selection of spatial and spectral resolutions (Chen et al, 2012; Lunetta et al, 2004).

METHODOLOGY

Landsat satellite "collection-1 level-1" cloud-free images (path/ row: 138/44 and 138/45) were used to explore the LULC of Sundarbans from 1978 to 2021. All the images were geometrically corrected and supervised maximum likelihood classification was performed. The classification was assigned to six classes: agriculture, healthy mangrove, aquaculture, plantation with built-up, unhealthy mangrove and water body. A total of 200 random points were generated for accuracy assessment. High-resolution Google Earth images were used as a reference point to identify the actual LULC classes. Figure 2 represents the framework of the methodology adopted for the study.

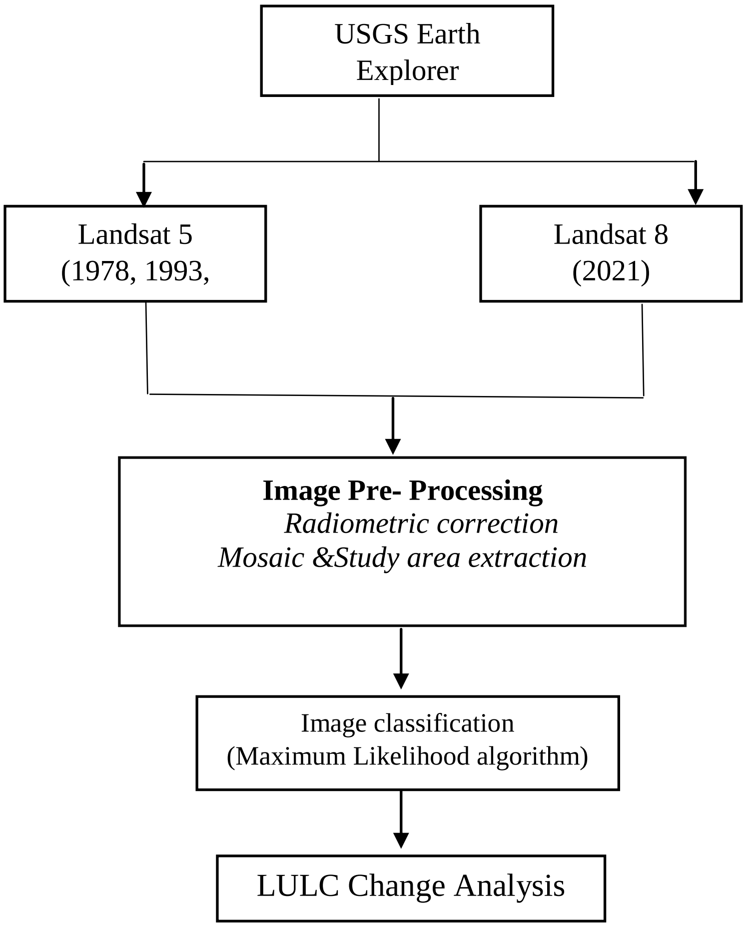

Figure 2. The methodology adopted for the study

RESULTS AND DISCUSSIONS

The accuracy assessment results of the classified images show that the overall accuracy ranges were between 78.8% and 86% from 1978 to 2021. LULC maps revealed that in 1978 and 1993 agriculture cover the maximum area followed by water bodies. In 2007 and 2021 waterbody is the dominant lulc class followed by agriculture. Aquaculture is the least dominant area in all years except in 2007. A slow and steady decline in the agriculture area was recorded during the 40-year study period (1978-2021) (Table 1). The area occupied by agriculture was 3807.69 km^2 in 1978 which decreased to 2483.28 km^2 in 2021, showing a 1324.41 km^2 reduction. The study showed approximately 34% loss of agricultural land occurred between 1978 and 2021 making it the most dynamic land-loss category. Climate change makes the situation more challenging for farmers to sustain their livelihood through agriculture. The frequent occurrence of climatic extremes over the Bay of Bengal has, directly and indirectly, affected the agricultural system of the delta (Ghosh & Mistri, 2021). 27.6 % of mangrove vegetation area increased from 1993 to 2007, after that there was a decrease of 322 km^2 in 2021. The change records demonstrated that the healthy vegetation area constituted 19, 17, 21 and 18 per cent in 1978, 1993, 2007, and 2021, respectively of the total study area. The causes of the increase and decrease of mangrove vegetation in different decadal periods might be due to the damaging and subsequent regeneration of mangrove forests facing various degrees of cyclones (Uzzaman et al., 2020). The trend of changing unhealthy mangrove vegetation is similar to the mangrove class which was inconsistent during the recording periods (Table 1). Unhealthy mangroves covers an area of 302 km^2 in 1978 and considerably increased by about 94 % in 1993, covering 587 km^2 followed by a 79% decrease in 2007. A notable increase of 290 km^2 happened in 2021 mainly due to the impacts of multiple cyclones. The Unhealthy vegetation area increased in different periods because of damage caused by cyclones like Sidr (November 15, 2007), Aila (May 25, 2009), and Amphan (May 20, 2020) (Uzzaman et al., 2020). A slow and steady increase in plantation with built-up areas was observed from 333 km^2 (1978) to 1202 km^2 (2021), showing 869 km^2 of drastic increment. During the 1978-1993 period, 34.19% of the agriculture was retained in 1993, and the remaining was converted into other land use categories. The majority of the converted area was plantation with built up having an area of 443 km^2 (4.93%), followed by water bodies (1.49%). During this period, 15.41 % of mangrove vegetation was retained, but a remarkable conversion took place from mangroves to unhealthy mangrove vegetation in about an area of 302 km^2 (3.36%) and with water bodies (0.54%). In contrast, 100 km^2 of unhealthy mangroves converted to mangroves and most of the water bodies were unchanged. A total of 373 km^2 (4.15%) of unhealthy mangroves converted to mangroves during the 1993-2007 period which is a direct consequence of better management regimes being developed under the “Biosphere Reserve” and “Project Tiger” initiatives, the remaining mangrove covered islands started to be protected and guarded against any outside interference by the FD (Datta and Shovik,2012). As a result of super cyclones like Sidr (November 15, 2007), Aila (May 25, 2009), and Amphan (May 20, 2020) (Uzzaman et al., 2020) 248 km^2 of mangroves converted to unhealthy mangroves during the period from 2007 to 2021 (Table 2).

Table 1. LULC pattern of the study area during the years 1978 to 2021

Sl. No	LULC Name	1978		1993		2007		2021	
		Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
1	Agriculture	3807.69	42.33	3182.13	35.37	2555.79	28.41	2483.28	27.60
2	Healthy Mangrove	1765.78	19.63	1545.12	17.17	1971.96	21.92	1643.74	18.27
3	Aquaculture	25.373	0.28	155.01	1.72	276.75	3.077	292.05	3.24
4	Plantation with Built-up	333.727	3.71	706.34	7.85	1141.07	12.68	1202.90	13.37
5	Unhealthy Mangrove	302.256	3.360	587.07	6.527	122.49	1.36	412.63	4.58
6	Waterbody	2759.35	30.67	2818.49	31.33	2926.10	32.53	2959.57	32.90

Table 2. Comparative area changes of the study area during the years 1978 to 2021

Sl. No	LULC Name	Area change(km^2)			
		1978-1993	1993-2007	2007-2021	1978-2021
1	Agriculture	-625.56	-626.34	-72.51	-1324.41
2	Healthy Mangrove	-220.66	426.83	-328.22	-122.05
3	Aquaculture	129.64	121.74	15.30	266.68
4	Plantation with Built-up	372.61	434.73	61.83	869.18
5	Unhealthy Mangrove	284.82	-464.59	290.14	110.38
6	Waterbody	59.14	107.61	33.46	200.22

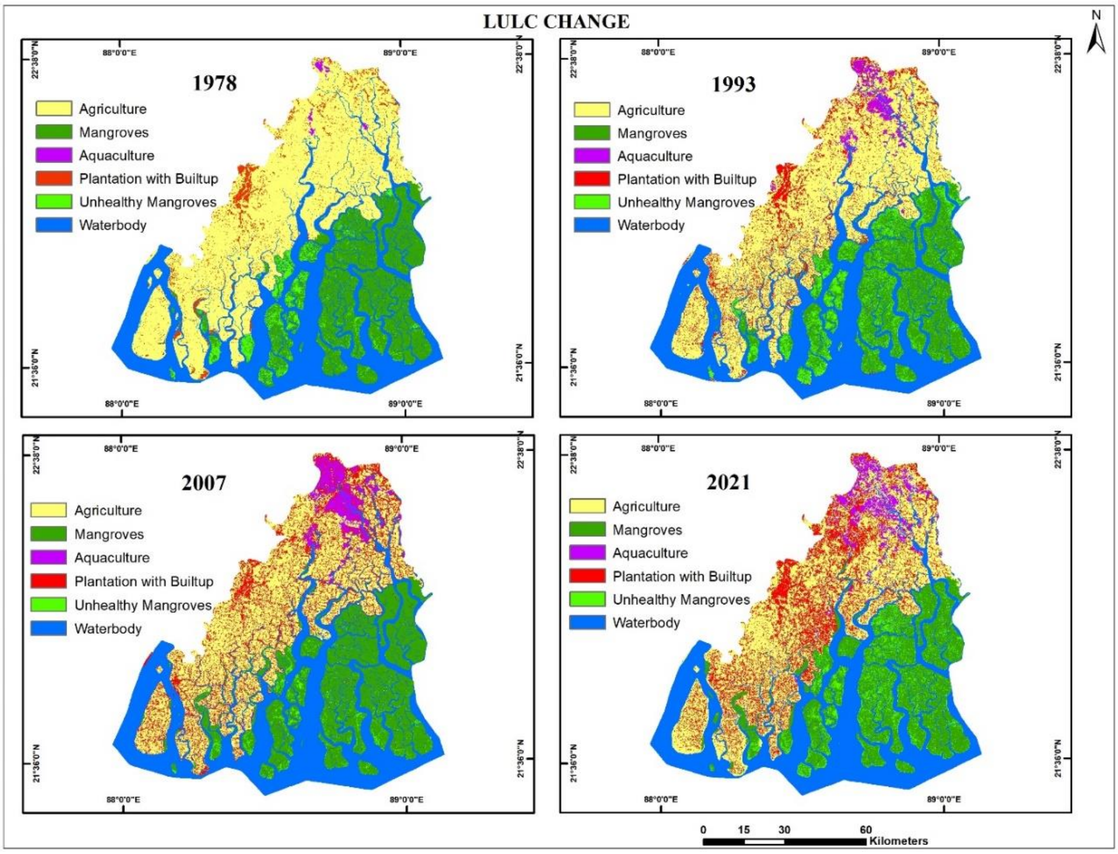

Figure 3. Land use land cover change of the study area during the years 1978 to 2021

CONCLUSION

The study revealed that vegetation growth and mangrove forest of Indian Sundarbans gradually decreased from 1978 to 1993 but increased in 2007 due to better management regimes (Datta and Shovik, 2012). But in contrast, there is a drastic decline in vegetation and an increase in water intrusion in 2021 were recorded. This is probably due to the changes in global warnings, rising sea levels, floods, and due to the damage caused by cyclones (Uzzaman et al., 2020). A consistent increase in plantation with built-up and water bodies, but an inconsistent increase or decrease in healthy or unhealthy vegetation is observed in different decadal periods. Monitoring, maintaining and controlling the mangrove areas are urgently needed to survive the natural coastal ecosystem in Sundarbans.

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AUTHORS' CONTRIBUTIONS

Jose Augustine: Investigation, Visualization, Methodology, formal analysis
Sreelakshmi Prakash: Methodology, Writing -original draft
Abin Varghese: Conceptualization, supervision, reviewing and editing,
Baiju K R: Expert consultant

CONFLICT OF INTEREST

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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SPATIO-TEMPORAL DISTRIBUTION OF AEROSOLS OVER KERALA: A SATELLITE-BASED ASSESSMENT IN POLLUTING CLIMATE

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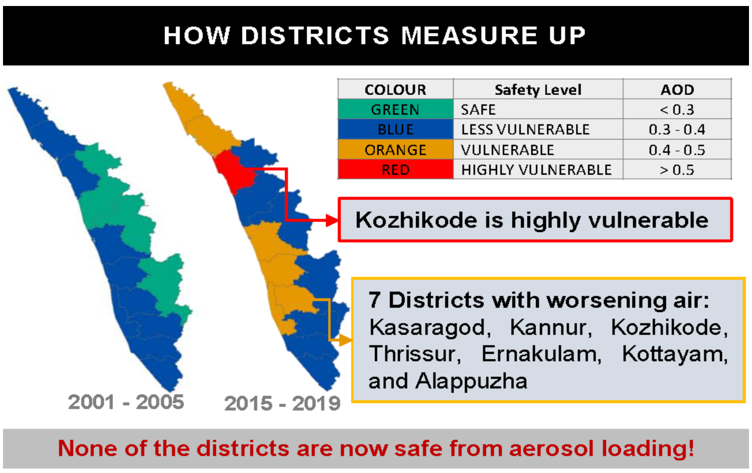
Abstract:

India has seen an increase in extreme rainfall events (EREs) over the years, which is likely to continue due to global warming. The rising frequency of EREs is often linked to increasing atmospheric pollution, particularly atmospheric aerosols, which are one of the key components of the climate system. The recent increase in EREs over Kerala leading to extensive flooding and landslide has demonstrated the consequences of the combined impact of global warming and atmospheric pollution. Studies reveal that the recent EREs are particularly characterized by highly polluted (aerosol-rich) scenarios, supporting cloud invigoration with moisture convergence leading to EREs. In the current era of global warming, where the atmospheric water holding capacity is expected to increase, the prime question is whether there will be sufficient aerosols (as cloud condensation nuclei) to support precipitation? In this context, the present study is dedicated to understanding the spatial and temporal distribution of aerosols over the state of Kerala. Monthly average Aerosol Optical Depth (AOD, 550 nm) from Collection 6.1, level 3 AOD products (1° × 1°) derived from Terra's MODIS measurements for 21 years (2001 – 2021) is used in this study. Spatio-temporal analysis of the district-wise AOD data is carried out along with a trajectory analysis to ascertain probable aerosol sources. Time series analysis indicates a significant increasing trend in AOD over Kerala. A higher rate of increase in AOD is observed among the northern districts, with Kasaragod recording the fastest growth. AOD is particularly heavier during certain months, and the wind trajectory analysis performed reveals the possible sources of observed monthly aerosol variations. Further, the frequency analysis shows an alarming situation, where the frequency of aerosol-pollution-episodes (AOD > 0.4) has increased from 13.3 % (2001-2005) to 38.3% (2017-2021). Further, a classification of the districts of Kerala based on AOD reveals that seven districts (Kasaragod, Kannur, Kozhikode, Thrissur, Ernakulam, Kottayam, and Alappuzha) are now (2015-2019) more vulnerable to aerosol loading than before (2001-2005).

Keywords:

Aerosols; Climate Change; Trend Analysis; Trajectory Analysis; Vulnerability.

Graphical Abstract



INTRODUCTION

Climate Change is likely to have an impact on all natural ecosystems and socioeconomic systems of India, as indicated in the National Communications Report of India to the United Nations Framework Convention on Climate Change (Indian Ministry of Environment and Forest, 2004). During the industrial era, emissions of greenhouse gases (GHGs), aerosols, and changes in land use and land cover affected the composition of the atmosphere and the planetary energy balance and are primarily responsible for climate change (IPCC 2018; Krishnan et al. 2020). Over the past few decades, India has seen an increase in extreme precipitation events, which are likely to continue due to the warming climate (Goswami et al., 2006; Mukherjee et al., 2018; Roxy et al., 2017). The rising frequency of extreme precipitation events is often linked to increasing greenhouse gas emissions and aerosols (Cherian et al. 2013; Lau et al. 2016; Krishnan et al. 2016; Cho et al. 2016; Priya et al. 2017; Hazra et al. 2017). Aerosols are solid or liquid particles suspended in the atmosphere, and are one of the key components of the climate system and the hydrological cycle (Ramanathan et al., 2001). Atmospheric aerosol from both natural and anthropogenic activities has long been acknowledged as one of the important factors influencing regional and global climate change (Ramanathan et al., 2005; Wang, Z., et al 2022). Analyzing the trends and patterns of these atmospheric particles is of utmost importance in the current polluting climate.

For monitoring aerosol, space-born sensors have become the primary tool (Xiaoli et al., 2020). The measurable quantity from space is the AOD which is derived from the solar radiation reflected to space. The optical depth is a valuable aerosol characteristic, which is a key parameter for various aerosol-related studies, such as aerosol radiative forcing, atmospheric corrections of the aerosol effect on remote sensing, etc. (Kaufman et al., 1997). Higher aerosol loading changes cloud properties in terms of size and microphysics, which results in more rainfall but delays the onset of rainfall. The aerosol-cloud microphysical feedback suggests that higher aerosol loading can enhance the strength of convective rainfall and increase the frequency and intensity of extreme rainfall during the Indian summer monsoon (K.K.Shukla, ChandanSarangi, et al 2022). Extreme rainfall events may directly result from an increase in aerosol loading (Lau and Kim, et al., 2006). Kerala State experienced a severe extreme rainfall event during 8-10 August 2019. Aerosols amplified the cloud cover and precipitation over Kerala during 2018 as the moisture over the region was excessive enough to bury the commonly observed semi-direct effect caused by aerosols. This led to intensified precipitation with the combined effect of heavy dust loading near the west coast of India, conductive meteorological conditions, and orography of the region (M.K. Jasmine, Marina Aloysius, et al 2022).

Kerala region is most affected by Vehicular Emission (VE) which is constantly increasing followed by Solid Fuel Burning (SFB) and Open Biomass Burning (OBB). VE contribution has been increasing at a slow rate from 35% (2005-2009) to 38% (2010-2014) to 39% (2015-2019). OBB contribution was from 11-15% with a major contribution in the 2010-2014 period. SFB had a contribution of 25% which hasn’t shown any changes over years. The future projection shows that southern India would become highly vulnerable in 2023 if these sources continue to dominate (Monami Dutta, Abhijit Chatterjee, et al 2022). In the current era of global warming, where the atmospheric water holding capacity is expected to increase, the prime question is whether there will be sufficient aerosols (as cloud condensation nuclei) to support precipitation? In this context, the present study is dedicated to understanding the spatial and temporal distribution of aerosols over the state of Kerala. Monthly average Aerosol Optical Depth (AOD, 550 nm) from Collection 6.1, level 3 AOD products (1° × 1°) derived from Terra's MODIS measurements for 21 years (2001 – 2021) is used in this study. Spatio-temporal analysis of the district-wise AOD data is carried out along with a trajectory analysis to ascertain probable aerosol sources.

STUDY AREA

Kerala is a state in southern India that lies in the tropical region. Its area is 38,863 km^2, and its latitude and longitude are 8^0 18' N and $12^0$48'N, 74^0 52'E, and 77^0 22'E respectively. Kerala's elevation ranges from 48 meters below sea level to 2692 meters above mean sea level, with 35% of its land between 0 and 50 meters, 39.82% between 50 and 500 meters, and 24% over 500 meters. A district-wise analysis of AOD over Kerala is presented in the study.

AIM AND OBJECTIVE

The major objectives of the study are:

- To understand the Spatio-Temporal distribution of aerosols over Kerala.
- To map the aerosol-vulnerable districts of Kerala, and
- To quantify the probable sources from wind trajectory analysis.
- To project the expected aerosol loading in the near future.

DATA AND METHODOLOGY

AOD data

As a decent tool to understand the spatiotemporal properties of aerosols and their effects from global to local scales, satellites are used (Misra et al. 2015). In this study, satellite-based Moderate Resolution Imaging Spectroradiometer (MODIS) data is used. AOD is retrieved from MODIS, a space-born sensor onboard Terra and Aqua polar-orbiting satellites, launched in the years 1999 and 2002 respectively (Remer et al., 2005, 2008). Here, AOD has been obtained from Level-3 MODIS monthly average global product 'MOD08_M3' (ESDT Long Name: MODIS/Terra Aerosol Cloud Water Vapor Ozone Monthly L3 Global 1 Deg CMG), at 550nm with a spatial resolution of 1 degree by 1 degree derived from Terra's MODIS measurements (Platnick et al. 2017). MOD08_M3 product files are available in Hierarchical Data Format (HDF). The AOD at 550 nm is utilized in this study as this product has better consistency (Lyapustin & Wang, 2018).

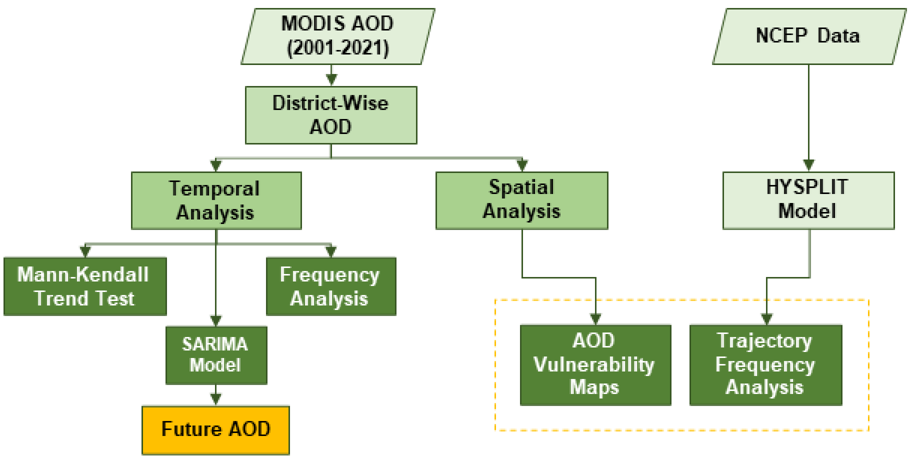


Figure 1: Flow chart of the methodology

Mann-Kendall Test

Trend analysis of AOD has been investigated using the Mann-Kendall test. Mann (1945) initially used this test, and Kendall (1975) subsequently derived the test statistics distribution. Its benefit is that it is distribution-free and does not accept any unique structure for the distribution capacity of the information and has been suggested generally by the World Meteorological Organization for public application. Subsequently, different researchers discovered the MK test to be a fantastic instrument for pattern identification in comparative applications. For the time series $X_{1,}$ ..Xn, the MK Test uses the following statistic.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(Xj + Xi)$$

Where n is the number of observations, x_j is the $_j$th observation, and sgn () is the sign function which can be computed as:

$$sgn(x_j - x_i) = \begin{cases} 1\ if\ (x_j - x_i) > 0 \\ 0\ if\ (x_j - x_i) = 0 \\ -1\ if\ (x_j - x_i) < 0 \end{cases}$$

Under the assumption that the data are independent and identically distributed, the mean and variance of the S statistic in Equation (2) are given by Kendall (1975) as

E(S) = 0

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i\text{-}1)(2t_i + 5)}{18}$$

Where, m is the number of groups of tied ranks, each with t_i tied observations. The original MK statistic, designated by Z, was computed as

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}}\ S > 0 \\ 0\ S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}}\ S < 0 \end{cases}$$

If - $Z_{1\text{-}a/2} \leq Z \leq Z_{1\text{-}a/2}$, then the null hypothesis of no trend was accepted at the significance level of α. Otherwise, the null hypothesis was rejected, and the alternative hypothesis was accepted at the significance level of α

Sen's Slope Estimator

Sen (1968) derived a method for estimating the Kendall Tau. This method has its application in the estimation of the slope of a linear trend, which arises from a linear equation as

$$\mathrm{f(t) = Qt + B}$$

Here, f(t) is a function of time representing the time series, t is the time, B is constant, and Q is the slope. Q can be contracted by the equation

$$Q_i = \frac{x_j - x_k}{j - k}$$

Here at time j and k, j > k and i= 1, 2 …, N, the values of the data pairs are represented by x_j and x_k. We can determine the median of the N values of Q_i by Rahman and Dawood (2017).

$$Q = \begin{cases} Q_{\left[\frac{N+1}{2}\right]} & ; if Nis\ odd \\ \frac{1}{2} Q_{\left[\frac{N}{2}\right]} + Q_{\left[\frac{N+2}{2}\right]} & ; if\ Nis\ even \end{cases}$$

When the value of Qi is positive, one can discern that there is an increasing trend, and similarly, a decreasing trend shows that the value of Qi is negative. A zero value indicates no trend (Salmi et al. 2002; Rahman and Dawood 2017).

Seasonality Test

In the present study, the Seasonality Index (SI), which is proposed by Walsh & Lawler (1981) was applied to identify AOD regimes. In order to find out whether a seasonal variation is present or not for the long-term data of MODIS-derived AOD, SI is used, which is the function of mean monthly and annual AOD is computed using the formula,

$$SI = \frac{1}{12 * \bar{\tau}} \sum_{i=1}^{12} |\tau_i - \bar{\tau}|$$

Where $\bar{\tau}$ is the mean annual AOD and$\tau_i$is mean AOD of the month i.

In the present study, SI was estimated using MODIS for 21 years (2001-2021) of AOD data. Here in the study $\bar{\tau}$&$\tau_i$were mean annual AOD & mean monthly AOD data averaged over 21 years. According to NASA Earth Observation 2021, an AOD of 0.1 indicates a clear sky with maximum visibility, and an AOD value of 1 indicates hazy conditions, so our mean monthly AOD was adjusted (the base value of 0.1 is subtracted from mean monthly AOD values). The classification of the AOD regime based on SI values is shown in the table follows.

Table 1: Classification of AOD regimes based on SI values (Walsh & Lawler, 1981)

AOD regime	Seasonality Index (SI)
Very equable	≤0.19
Equable with a definite pollution episode	0.20-0.39
Rather seasonal with short clear condition	0.40-0.59
Seasonal	0.60-0.79
Markedly seasonal with a long clear condition	0.80-0.99
Most aerosols in 3 months or less	1.00-1.19
Extreme, almost all aerosols in 1-2 months	≥1.20

Trajectory Frequency Analysis

The HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) model is one of the popularly used models which is useful to calculate trajectories of air parcels, dispersion, transport, transformation, and deposition of pollutants using previously gridded meteorological data. It consists of a modular library structure with main programs for each primary application: trajectories and air concentrations (Draxler et al. 2014). Here the trajectory frequency analysis was done in the HYSPLIT model using the NCEP data. The aerosol loading over the State is particularly heavier during certain months. Hence, the model is used to analyze the January-February-March (JFM) period and April-May-June (AMJ) period of Kasaragod and Thiruvananthapuram at an altitude of 100 meters and 1500 meters. Two- day trajectory analysis is done to estimate the trajectory frequency over the two districts and the direction of air mass that mainly causes aerosol loading over the region.

Autoregressive integrated moving average (ARIMA).

The ARIMA method is an iterative and exploratory process intended to best fit long-term observations by using three steps—identification, estimation, and diagnostic checking—to build an adequate model for a time series. The Seasonal-ARIMA (SARIMA) model extends the ARIMA model by taking seasonality into account. Such models are expressed as $(p, d, q) \times (P, D, Q)_m$. where (p, d, q) are as for an ARIMA model, while $(P, D, Q)_m$ express the seasonal autoregressive, integration and moving average components where the seasonality period is m. Here SARIMA model is used. The model aims to simulate the AOD variation and predict future trends over the study area. The AOD data until 2019 is considered due to COVID-19 lockdowns during 2020 and 2021 which caused an overall variation in the trend of AOD.

RESULTS AND DISCUSSION

Spatio-temporal distribution of AOD

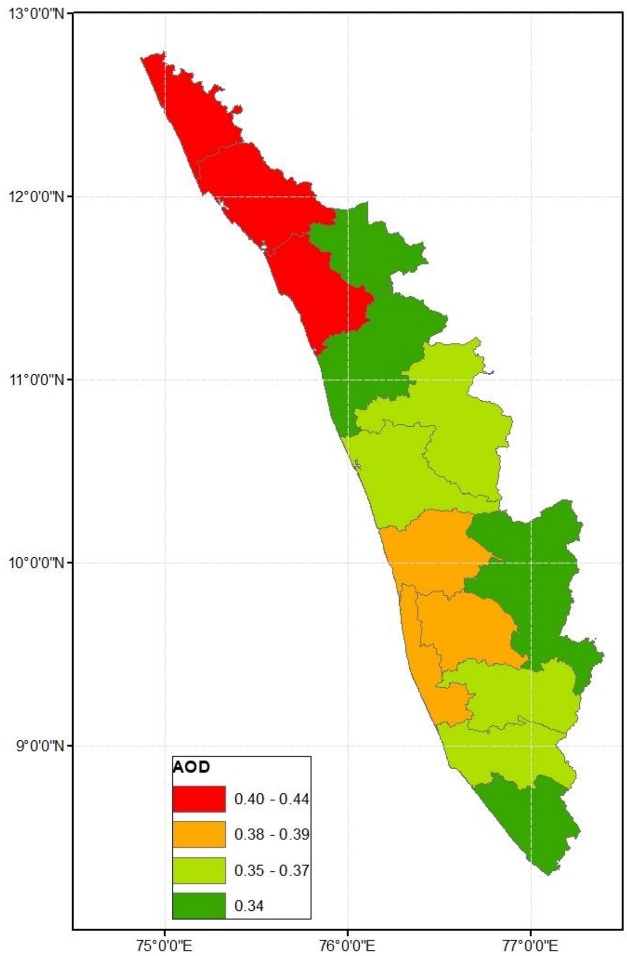


Figure 2: Spatial Distribution of mean AOD over Kerala during 2001-2021

The district-wise long-term mean of AOD during the study period (2001-2021) over Kerala is illustrated in Fig (2). The results show that among the districts Kasaragod, Kannur, and Kozhikode districts had greater AOD in the range of 0.40 – 0.44, followed by Alappuzha, Kottayam, and Ernakulam between the range of 0.38 – 0.39. Districts including Kollam, Pathanamthitta, Thrissur, and Malappuram had AOD between 0.35 - 0.37. The districts with the least AOD in the range of 0.34 – 0.35 were Thiruvananthapuram, Idukki, Malappuram, and Wayanad. All districts had a long-term mean AOD greater than 0.3, indicating a considerable amount of aerosol loading throughout Kerala from 2001 to 2021.

Monthly Aerosol Distribution

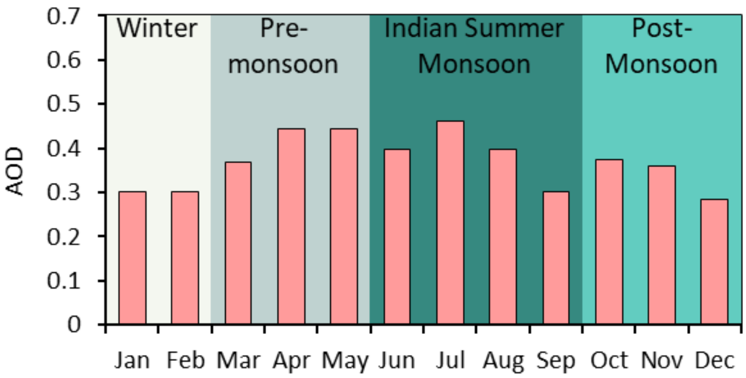


Figure 3: Monthly distribution of AOD over Kerala (2001-2019).

The monthly distribution of AOD over Kerala is shown in figure 3. The state is affected by aerosol loading throughout the year with monthly AOD value of 0.3 or greater. SI is used to find out whether the long-term MODIS-derived data used in the study has a seasonal variation or not. The calculated value of SI based on the long-term period 2001-2021 is 0.13 which belongs to "very equable" AOD regime based on Table (1).

Classification of Kerala Districts in terms of Aerosol Pollution Vulnerability

Monami et al., (2022) defined zones for determining highly vulnerable states in India in terms of air pollution. It was done based on the long-term mean value percentile. Based on these percentiles, four different zones were defined: green or safe zone (AOD value of less than 25th percentile; < 0.3), blue or less vulnerable zone (AOD value between 25th and 50th percentile; 0.3–0.4), orange or vulnerable zone (AOD value between 50th and 75th percentile; 0.4–0.5) and red or highly vulnerable zone (AOD value greater than 75th percentile; > 0.5). In consistent to the greater Indian region, in the present study, similar zones are used to identify the AOD vulnerability of Kerala districts. These zones are shown in Table (2)

Table 2: Vulnerability zones defined by (Monami et al., 2022)

Colour	Safety Level	AOD
Green	SAFE	< 0.3
Blue	Less Vulnerable	0.3 - 0.4
Orange	Vulnerable	0.4 - 0.5
Red	Highly Vulnerable	>0.5

AOD vulnerability maps of Kerala for each year from 2001-2021 are shown in Fig (4), based on the above-defined zones according to each district's annual mean AOD value. It is evident that Kozhikode is the most aerosol-affected district in Kerala. In the case of air quality, Kozhikode was the first district in Kerala to turn into a vulnerable zone in 2003 and was never in a safe zone. From 2007 onwards, Kozhikode didn't fall short of the vulnerable zone until the district turned into a highly vulnerable zone from 2016 to 2018. Kozhikode even attained a less vulnerable level in 2020 but became vulnerable just the year after. Kozhikode is followed by Kannur and Kasargode for its high aerosol concentrations. In 2008, both districts turned into vulnerable zones. In 2016, Kozhikode and Kannur attained a highly vulnerable zone. In 2018 Kasaragod, Kannur, and Kozhikode together turned into a highly vulnerable zone along with all other districts that turned into Vulnerable zones. This was the most aerosol-affected year of Kerala which was right before when COVID hits the next year. Other districts that had worsened air conditions were Thrissur, Ernakulam, Kottayam, Alappuzha, and Kollam which started becoming vulnerable in 2011. Thiruvananthapuram, Idukki, Wayanad, Malappuram, and Palakkad are seen to be the districts with the least AOD value.

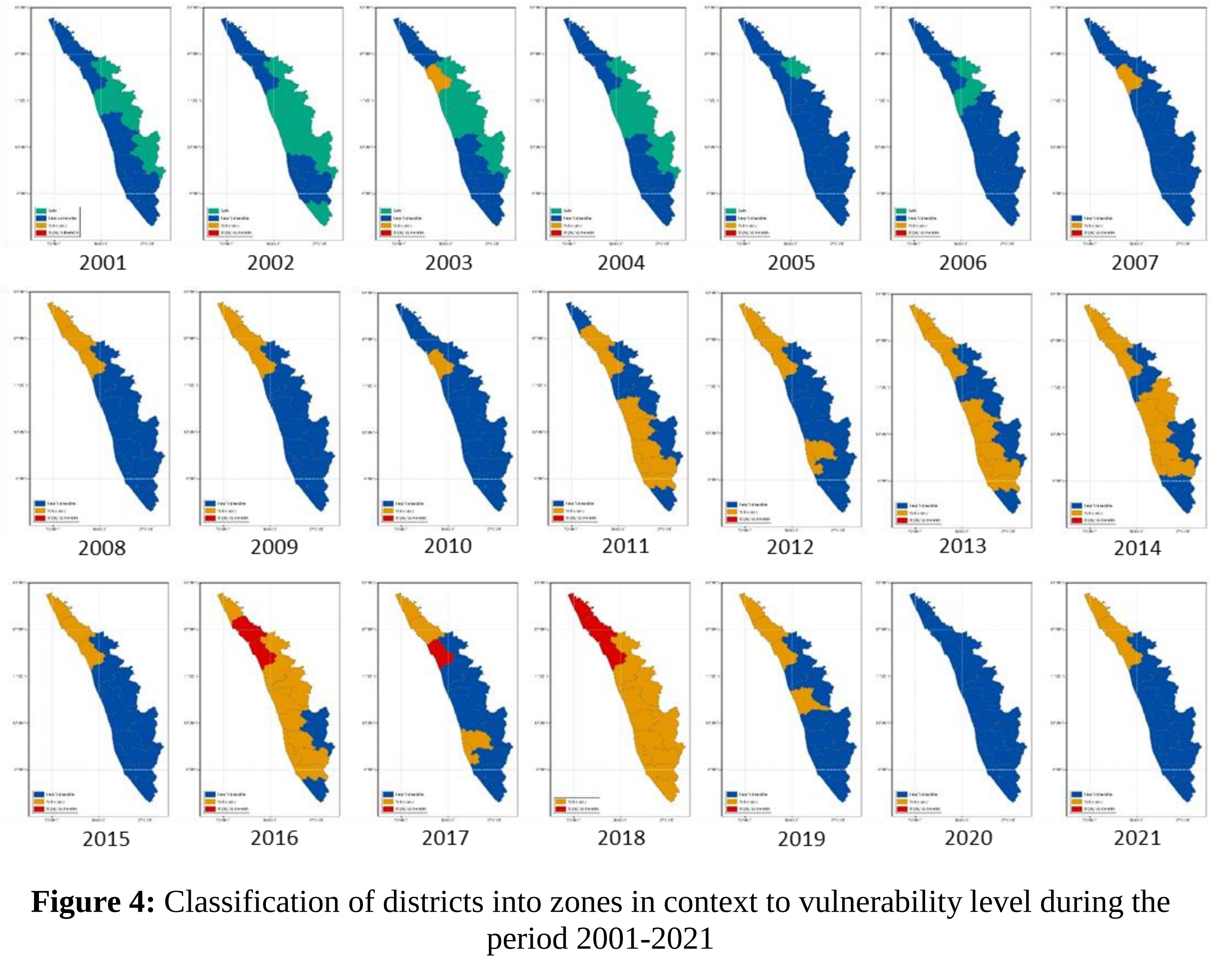


Figure 4: Classification of districts into zones in context to vulnerability level during the period 2001-2021

We have further divided our study period into two sections: 2001-2005 and 2015-2019 to compare the aerosol loading over Kerala during the past and recent periods. Fig (5) depicts district-wise vulnerability from average AOD during the past (2001-2005) and during recent years (2015-2019) periods.

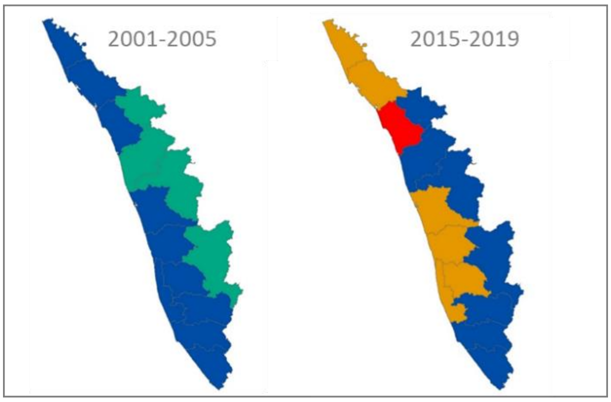
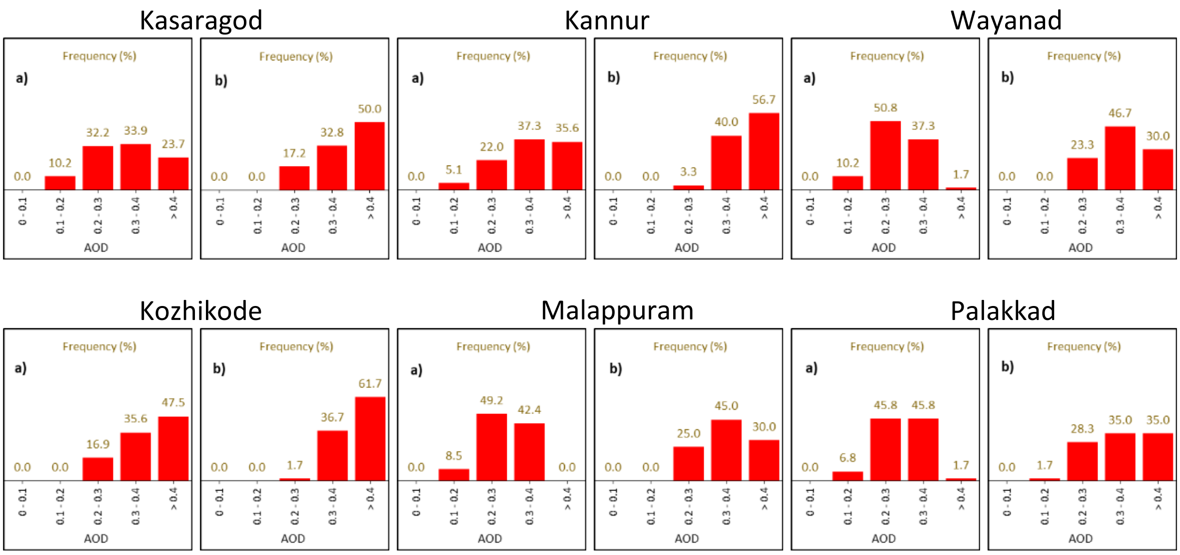


Figure 5: Variation in Vulnerability level (AOD>0.4) in recent decades.

The results suggest that Kozhikode has become highly vulnerable than other districts, and six districts including Kasaragod, Kannur, Thrissur, Ernakulam, Kottayam, and Alappuzha are exposed to a worsening condition i.e., vulnerable. Districts in the less vulnerable zone are Wayanad, Malappuram, Palakkad, Idukki, Pathanamthitta, Kollam, and Thiruvananthapuram. We can also state that no district in Kerala is in safe condition now from aerosol loading.

Frequency distribution analysis is also done to compare the variation in AOD frequency for each district shown in Fig (6) for the past years 2001-2005 period and recent years 2017-2021. The AOD range above 0.4 is seen increasing for all districts during the 2017-2021 period. District-wise AOD in the range of 0.1-0.2 is seen to diminish in 2017-2021. It points out that every district has a significant rise in the frequency of AOD>0.4 indicating the rise in vulnerability during recent years. It is seen that Kozhikode followed by Kannur and Kasaragod peaks in vulnerability level. Malappuram district which never went above the 0.4 AOD range in 2001-2005 can be seen with a rise in 2017-2021 and districts including Wayanad, and Palakkad having less AOD value during past years have shown a rise in vulnerability range in recent years.



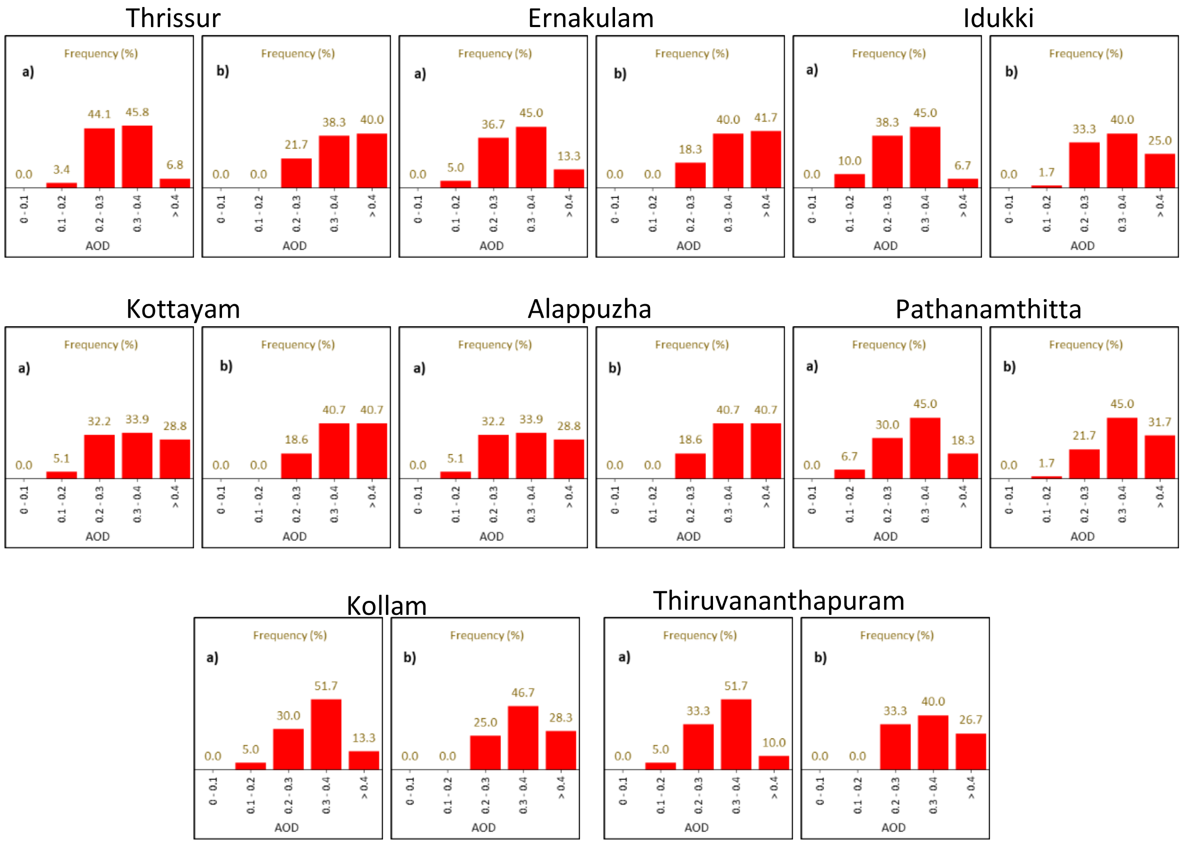


Figure 6 (Continued): Variation in Frequency Distribution (%) of AOD over each district during: **(a)** 2001-2005, and **(b)** 2017-2021.

Analysing the frequency distribution of Kerala, we can tell that there was a 31.7% safe zone (<0.3) frequency distribution in Kerala during 2001-2005 which got diminished to 21.7% in the 2017-2021 period, and less vulnerable (0.3-0.4) frequency got reduced from 50% to 40% whereas, there was an increase in the vulnerability (>0.4) which was 13.3 % in 2001-2005 which eventually stood at a steady increase of 38.3% frequency during 2017-2021 period. Thus, the current scenario of Kerala and its districts are experiencing a steady increase in AOD value above 0.4 reaching the vulnerable condition.

Trends in AOD

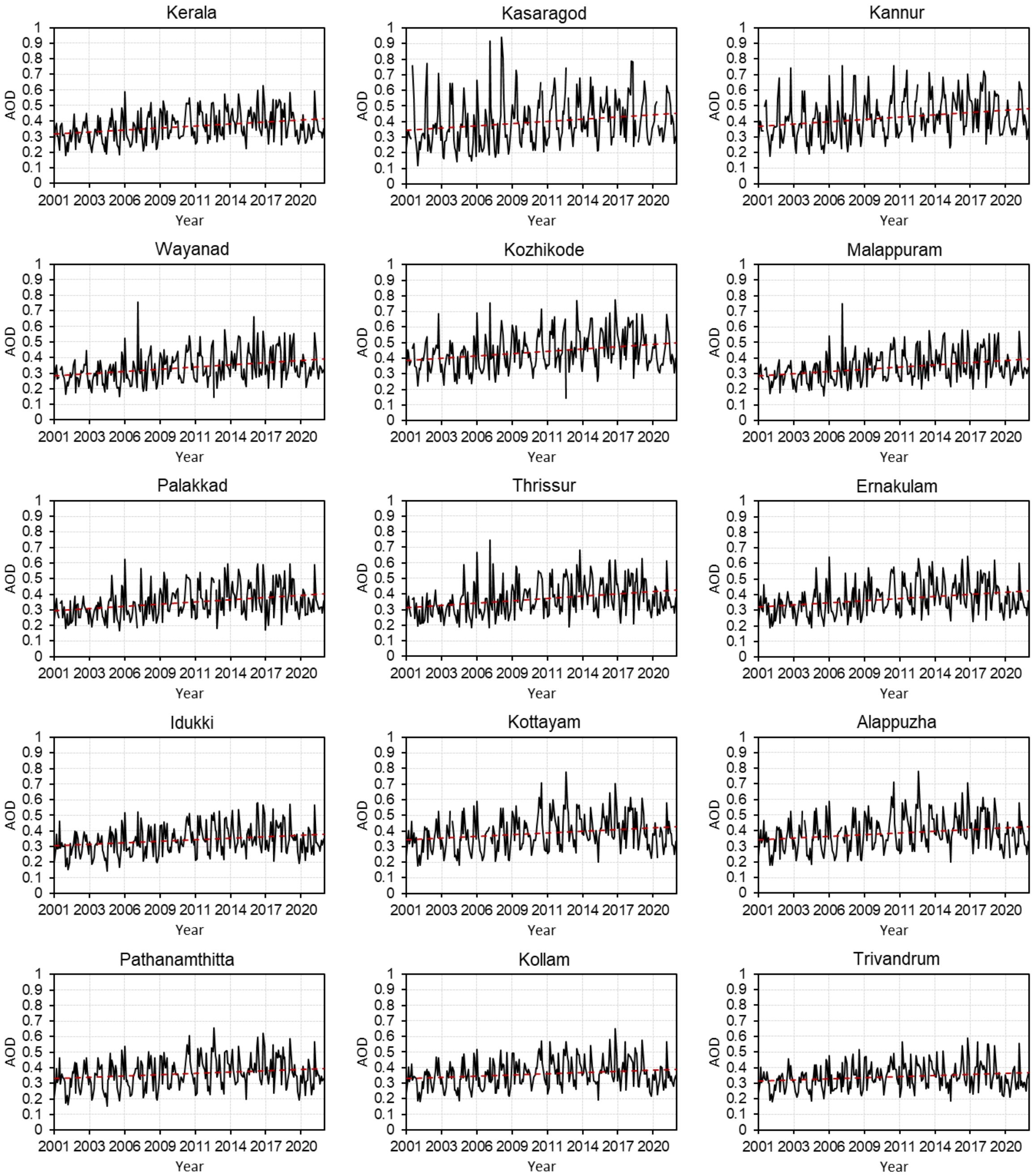


Figure 7: Time Series of AOD over Kerala districts.

Spatial AOD averages were calculated for each month, which enables to study temporal changes over the region. Time series graphs are plotted for Kerala and each district using each district's monthly AOD and Kerala's calculated mean AOD during the time period of 2001-2021. Time series graphs are shown in Fig (7) for Kerala and every district. Time series analysis helps in understanding the temporal distribution of AOD over the region. Here, each district's long-term temporal distribution is closely observed, and to ensure the trend, trend analysis is done.

According to the trend analysis done using Mann-Kendall and Sen's Slope estimator, it is observed that all districts in Kerala are having an increasing trend with *99% significance except

Trivandrum showing **95% significance. The slope per year is also given in the table above. Kasaragod has the highest slope of 0.000529 followed by Kannur with a slope of 0.000496 and Thrissur with 0.000453 whereas the lowest slope is for Thiruvananthapuram with 0.000173. Considering Kerala, the state shows an increasing trend with a significance of 99% and a slope of 0.000346. The trend of the time series and its magnitude are assessed using Mann-Kendall Test and Sen's slope. The result of the trend analysis is shown in Table (3).

Table 3: Mann-Kendall and Sen's Slope Result

Sl. no.	District	Trend	Slope/Year
1	Kasaragod	Increasing*	0.000529
2	Kannur	Increasing*	0.000496
3	Wayanad	Increasing*	0.000403
4	Kozhikode	Increasing*	0.00044
5	Malappuram	Increasing*	0.000404
6	Palakkad	Increasing*	0.000427
7	Thrissur	Increasing*	0.000453
8	Ernakulam	Increasing*	0.000392
9	Idukki	Increasing*	0.000264
10	Kottayam	Increasing*	0.000312
11	Alappuzha	Increasing*	0.000312
12	Pathanamthitta	Increasing*	0.000242
13	Kollam	Increasing*	0.000211
14	Thiruvananthapuram	Increasing**	0.000173
	Kerala	**Increasing***	**0.000346**

SARIMA Forecast

The AOD data required for the forecast is given in a quarterly manner, and with that data, the SARIMA model forecast is illustrated in Fig (8) which shows the observed AOD until 2019 and the forecasted AOD until 2023. An increase in AOD is expected in the future according to SARIMA forecast which is consistent with the current trend in AOD. An increase in AOD in the future indicates an increase in vulnerability level. During 2019, the mean AOD was around 0.38 which is expected to increase to 0.44 in 2023, which is above the vulnerability limit of 0.4

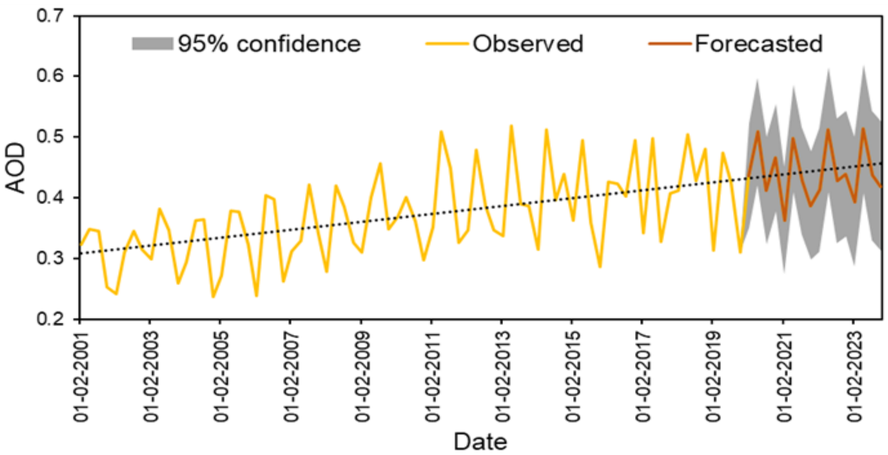


Figure 8: SARIMA forecast until 2023.

K. R. Baiju, Karunakaran Akhildev, Joice K. Joseph, Naveen Babu, Anithomas Idiculla, Asha Rose, Shibu K. Mani, Mahesh Mohan, and A. P. Pradeepkumar. (2023). Proceedings Volume of the 5th International Disaster, Risk and Vulnerability Conference (DRVC) January 19th – 21st, 2023. School of Environmental Sciences, Mahatma Gandhi University, Kottayam, Kerala, India – 686560. p- 1 to 447

Trajectory Frequency Analysis

The aerosol loading over the State is relatively heavier during certain months, and the wind trajectory analysis reveals the possible sources of observed monthly aerosol variations. Thus, based on Sen's slope Kasaragod having the largest slope/year and Thiruvananthapuram with the least slope/year is considered for the trajectory frequency analysis. Air parcel flow patterns from the HYSPLIT model are used to identify aerosols' origin. From the 2-day back–trajectory frequency plot by the HYSPLIT model, the air parcel flow patterns are illustrated for two periods JFM and AMJ at 100m and 1500 m altitude. It is noticed that AOD concentration over both districts is higher during the AMJ period. Kasaragod trajectory frequency at 100m and 1500m is shown in Fig 9(a, c) for JFM and, for AMJ period at 100m and 1500m are shown in Fig 9(b, d) and likewise for Thiruvananthapuram Fig 10(a, c) for JFM period at 100m and 1500m while Fig 10(b, d) for AMJ period at 100 and 1500m respectively.

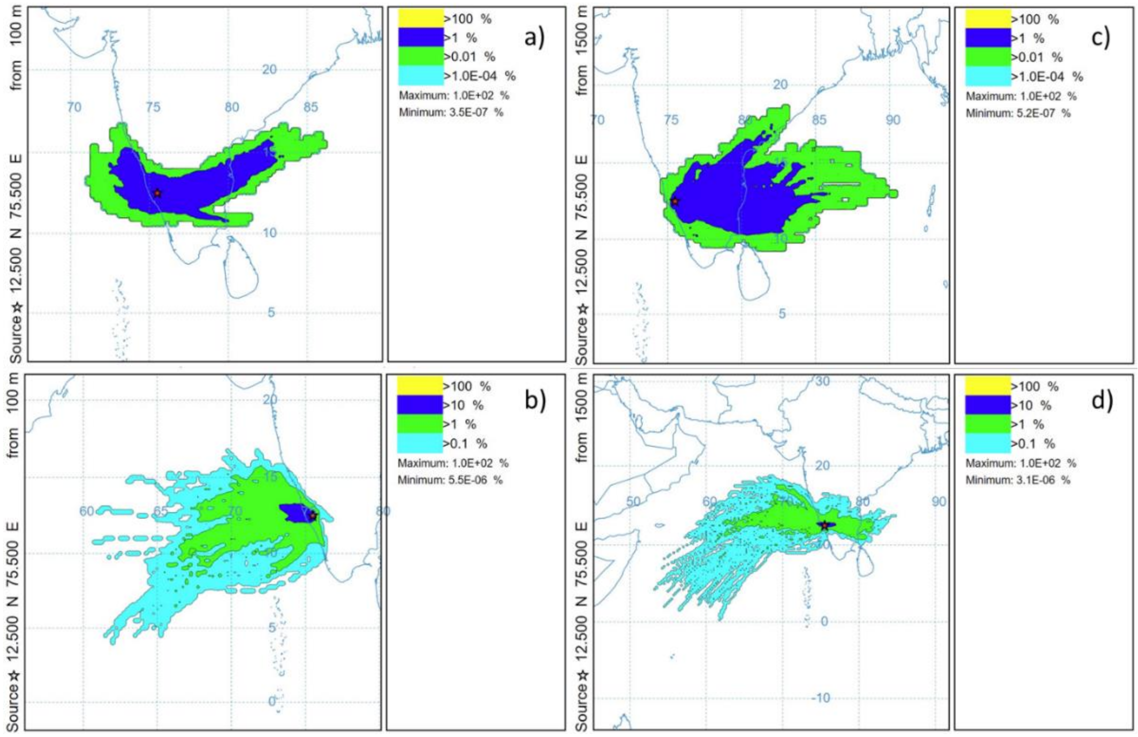


Figure 9: Trajectory Frequency of Kasaragod at 100m and 1500m altitude during JFM (a, c) and at AMJ (b, d) respectively.

In Kasaragod during the JFM period, on both altitudes, the wind trajectories are drawn from the east towards the district while during the AMJ period when AOD is high, air masses are drawn from the west at both altitudes. Air masses from the east are found to dominate during the JFM period likewise air masses from the west during the AMJ period.

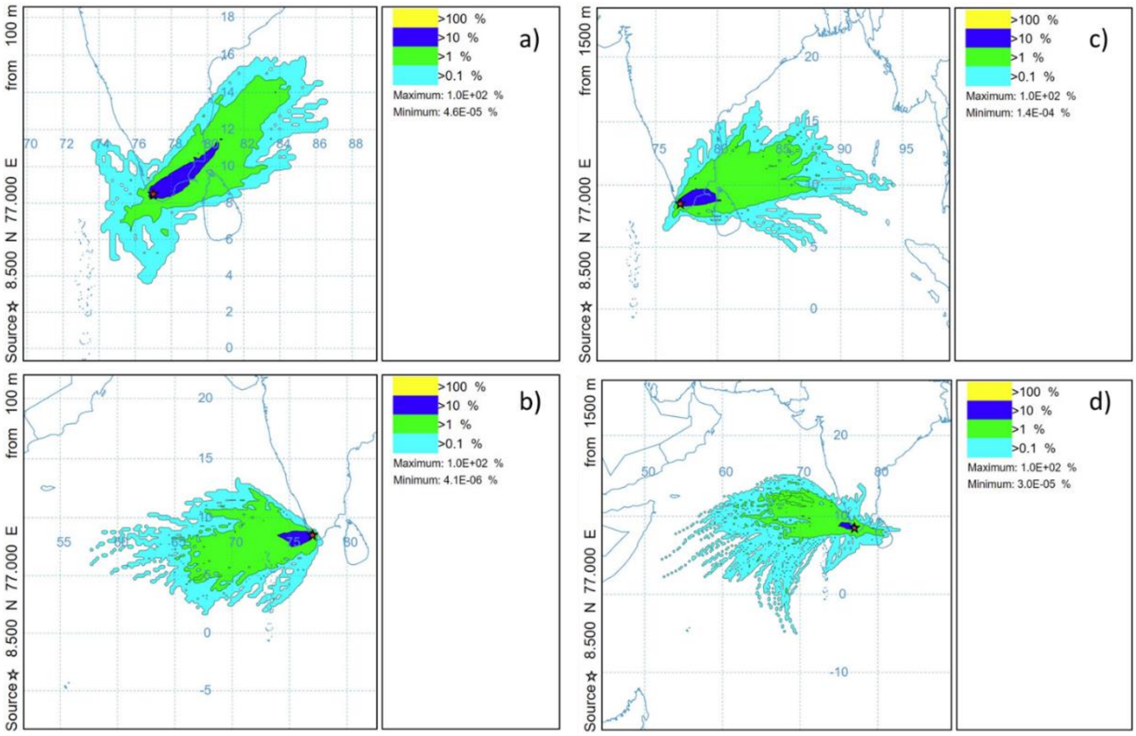


Figure 10: Trajectory Frequency of Thiruvananthapuram at 100m and 1500m altitude during JFM (a, c), and at AMJ (b, d) respectively.

In Thiruvananthapuram, during the JFM period at 100 and 1500 meters, the wind trajectories indicate air masses that are drawn from the east direction to the district whereas, during the AMJ period when AOD is at the highest the air masses are seen drawn from the west at both 100 and 1500 meters. Thus, our output from the HYSPLIT model enables us to understand the two-day trajectory frequency and spot the direction of the probable sources of aerosols influencing the respective district. Further studies are required to find the exact source of the aerosol loading which is out of scope in this study.

CONCLUSION

The 21 years (2001-2021) long-term study reveals the status of aerosol loading over the districts of Kerala. The spatial analysis indicates that Kasaragod, Kannur, and Kozhikode districts in Northern Kerala have greater AOD, followed by Alappuzha, Kottayam, and Ernakulam districts in central Kerala with lesser AOD. The districts with the least AOD are Thiruvananthapuram, Idukki, Malappuram, and Wayanad. After the classification of Kerala districts in terms of aerosol pollution vulnerability for each year from 2001-2021, it is observed that Kozhikode is the most vulnerable district followed by Kannur and, Kasaragod. Districts including Thrissur, Ernakulam, Kottayam, Alappuzha, Kollam, and Pathanamthitta are exposed to worsening air. Thiruvananthapuram, Idukki, Wayanad, Malappuram, and Palakkad are seen to be the districts with less AOD value. The trend analysis confirms that AOD over every district is expected to increase in the future. The SARIMA model also confirms the observed trend leading to an increase in the AOD (>0.4) by 2023 to further strengthen the view on vulnerability in the future. Moreover, the frequency analysis shows an alarming situation, where the frequency of aerosol-pollution-episodes (AOD > 0.4) has increased from 13.3 % (2001-2005) to 38.3% (2017-2021). The most aerosol-affected year was 2018 when Kozhikode, Kannur, and, Kasaragod districts became highly vulnerable (>0.5) and, all other districts in the vulnerable zone (0.4-0.5). The AOD concentration in 2018 must have been a major factor in that year's flood occurrence in Kerala. It was earlier stated that aerosols influenced the ERE occurrence in Kerala in 2018 through intensified precipitation with the combined effect of heavy dust loading from west coast (Jasmine, M. K, et al., 2022). Trajectory frequency analysis shows that air mass from the east is seen drawn during the JFM period and air mass from the west during the AMJ period towards both Kasaragod and Thiruvananthapuram. It also indicates that it is the air masses from the west that influence the AMJ period when AOD is higher at Thiruvananthapuram and Kasaragod. From the study, we can conclude that the current scenario of Kerala having vulnerable districts could expect more vulnerability in the future if the sources continue to dominate.

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AUTHOR'S CONTRIBUTION

S. Vijay: Conceptualization, Methodology, Data curation, Visualization, Writing – review and editing, **S. Nizar**: Conceptualization, Methodology, Data curation, Visualization, Supervision Writing – review, and editing. **A.B.Babu**: Writing – review, and editing. **Aswathy K:** Writing – review, and editing. **D.S.Pai**: Funding Acquisition, Supervision Writing – review, and editing.

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COMPETING INTERESTS

The authors have no competing interests to declare that are relevant to the content of this article.

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THE ECOLOGICAL PARADIGM SHIFT IN THE AFTERMATH OF KERALA FLOOD

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Abstract:

Conservation of nature, disaster prevention activities, preservation of resources, awareness programmes, management activities etc have been planned and implemented at every level of society and continuing. What if the attitude and concept hold by the common people setback these global strategies and policies. It is significant to know the people's world view when framing the new action plans. The new Ecological paradigm by Dunlap measures the respondents stand on environmentalism. It examines the responsibility feeling, environmental knowledge and environmental values of an individual. The current study is designed to measure the dominant social paradigm and the new environmental paradigm of primary and secondary survivors of flood affected in Malappuram district of Kerala. For this study, data collected using Dunlap's New Ecological Paradigm Scale (NEP) from 210 randomly selected samples belonging to primary (N=105) and secondary survivors(N=105).

By analysis found that there is a significant difference between primary and secondary survivors of flood regarding the environmental concern. Findings show that primary survivors rely on ecological paradigm than the secondary survivors. And secondary survivors' attitude is more a dominant social paradigm. Hence, the less affected category of people required more attention and enhance their participation to mitigate the adversities of disaster.

Keywords:

New Environmental/ecological Paradigm, Dominant Social Paradigm, Primary survivor, Secondary survivor.

INTRODUCTION

The environment is made up of all living things, including humans, animals, natural flora, trees, and plants, as well as weather and climate. Our physical surroundings and the features of the neighbourhood where we reside make up our environment. The environment not only helps to keep the climate in balance, but it also offers everything needed for human life. Any resource from the environment that is beneficial to society is an environmental resource. Anything that people find useful in their immediate environment or surroundings is included in this. Environmental degradation is the deterioration of the environment. It is defined as any change or disturbance to the environment perceived to be deleterious or undesirable. Such as decreasing the quality of air, water and soil, destruction of eco system, habitat destruction, the extinction of wildlife and pollution. Human activities have also led to the destruction of nature. When humans interfere with nature it often produces disastrous. Disaster's include Earthquake, Landslide, Flood, Tsunami etc.

Ecological behaviour is the actions which contribute towards environmental preservation and/or conservation (Axelrod & Lehman, 1993, p. 153). A paradigm in ecology is a set of concepts, standards, or ideas that guide the advancement of scientific knowledge at any of a variety of spatial and temporal scales. Metapopulation dynamics, island biogeography, and population regulation are a few examples of conceptual frameworks that are paradigmatic in the way that they are socially constrained theories about how organisms interact with nature.

William Catton and Riley Dunlap gave birth to the New Environmental Paradigm (NEP) with a concern for green thinking that begins with concerns about the high anthropocentric (human oriented) opposition of eccentricism (humans are not just a species inhabiting the earth). According to Dunlap, there are three values orientations that back NEP namely: altruistic value (consisting of equality, peace, social justice, mutual help); egoistic values (social power, prosperity, authority, influence and ambition); and biosphere value (respecting the earth, preventing pollution, integrating with nature and protecting the environment). The conceptualization called New Environmental Paradigm focuses on the belief of human ability to disrupt the natural balance, the limited ability of society and the human right to govern nature. In contrast, dominant social paradigm is the view that humans are superior to other all species, the earth provides unlimited resources for humans, and that progress is an inherent part of human history. As one's belief in the dominant social paradigm increases, their expressed concern for the environment decreases. Further, as their concern for the environment increases, their perception of necessary changes and willingness to change to achieve environmental balance will also increase. Dominant Social Paradigm convinced that technology is a picture of modern man and technology is able to overcome everything. Meanwhile, according to New Ecological Paradigm, technology is not able to solve the problem because humans are just one species on earth and the human and natural interconnections are very complicated that technology cannot match nature.

Environmental attitude is intended to measure public attention to environmental quality or environmental concerns. Not only significant environmental issues such as pollution, waste, and environmental issues related to geography, but also address issues such as ozone depletion, deforestation, biodiversity extinction and climate change. So, then came the effort to examine environmental issues and attitude on the environment (Stern, 2000; Dunlap *et al.*, 2000). The NEP scale is aimed at measuring the support of fundamental paradigms or perspectives on environmental attitude, beliefs and values.

After a disaster people attitude may change by the impact of that disaster. Either positive or negative. Natural disasters are the impact from nature, it mainly affected the humans. So, after these people have changes in their attitude towards nature. Someone may have lost their responsibility feeling towards nature. Also, people attitudes have variation. Sometimes flood affected people attitude may increase than the people not affected by disasters. Correlating these types of people attitudes towards nature helps to understand themselves and the other selves how they are treating nature.

The study was conducted to examine the ecological paradigm in primary and secondary survivors of flood in the South Indian state Kerala in 2018. Primary and secondary were classified in the data, followed by the water flowing condition in the flood affected areas. Primary survivors are the persons whose lives in riverside. The secondary persons are the ones who's not affected by flood, lives in the high land area.

Need and Significance

In the development of human being, ecological system also plays a crucial rule. The ecology not only helps to keep the climate in balance, but it also offers everything needed for human life. After a disaster people attitude may change by the impact of that disaster. Either positive or negative. Natural disasters are the impact from nature, it mainly affected the humans. So, after these people have changes in their attitude towards nature. Someone may have lost their responsibility feeling towards nature. Also, people attitudes have variation. Sometimes flood affected people attitude may increase than the people not affected by disasters. Correlating these types of people attitudes towards nature helps to understand themselves and the other selves how they are treating nature. The important need of the study is to find out the significance of environmental concern in survivors.

Statement of The Problem:

'Ecological behaviour among the Primary and Secondary Survivors of Flood'.

Key Word Definition:

- New Environmental/ecological Paradigm: It is more environmentally conscious world view focuses on the belief of human ability to disrupt the natural balance, the limited ability of society and the human right to govern nature.
- Dominant Social Paradigm: It the view that humans are superior to other all species, the earth provides unlimited resources for humans, and that progress is an inherent part of human history.
- Primary survivors: Primary survivors are the persons whose lives in riverside.
- Secondary survivors: The secondary persons are the ones who's not affected by flood, lives in the high land area.

Objectives

- To compare the ecological paradigm among the primary and secondary survivors of flood.
- To compare the dominant social paradigm among the primary and secondary survivors of flood.
- To compare the ecological paradigm and dominant social paradigm among the primary survivors of flood.

- To compare the ecological paradigm and dominant social paradigm among the secondary survivors of flood.

Hypotheses

- H_{o1}: There is no significant difference between primary and secondary survivors in ecological paradigm.
- H_{o2}: There is no significant difference between the dominant social paradigm among the primary and secondary survivors of flood.
- H_{o3}: There is no significant difference between the ecological paradigm and dominant social paradigm among the primary survivors of flood.
- H_{o4}: There is no significant difference between the ecological paradigm and dominant social paradigm among the secondary survivors of flood.

Method

- ***Tool***

The New Ecological Paradigm (NEP) scale constructed by Riley Dunlap and colleagues. The New Environmental Paradigm is a battery of questions designed to establish where survey respondents stand on environmentalism.

- ***Sample***

The sample of study consist of 210 peoples of Malappuram district. Primary data collected from flood affected area, included the river side area. Such as Irimbiliyam, Karma Road, Illathapadam and Mangalam. Secondary data collected from the high land area, included Kalpakanchery, Athavanad, Trikkandiyur, Tanur. The subjects were randomly taken from these areas. There is no age limit and gender classification used in this study.

Statistical Technique

Independent t test and paired t test are used. It is a statistical technique to compares the means of two independent groups.

REVIEW OF LITERATURE

1. Derdowski, L., Grahn, Å., Hansen, H. and Skeiseid, H. (2020) have conducted a study on the new ecological paradigm, pro-environmental behaviour, and the moderating effects of locus of control and self-construal. The results show a positive and significant association between the endorsement of NEP and a person's pro-environmental traveling behaviour, purchasing behaviour and day to day activities. Moreover, study find that the effects are moderated by a person's locus of control, specifically, it remains positive and significant only for people with an internal locus of control. However, found no moderating effect of a person's self-construal on the association between NEP and pro-environmental behaviour.
2. Christian A. Klöckner (2013) conducted a meta-analysis on comprehensive model of the psychology of environmental behaviour. The model is tested using a meta-analytical structural equation modelling approach based on a pool of 56 different data sets with a variety of target behaviours. The model is supported by the data.

Intentions to act, perceived behavioural control and habits were identified as direct predictors of behaviour. Intentions are predicted by attitudes, personal and social norms, and perceived behavioural control. Personal norms are predicted by social norms, perceived behavioural control, awareness of consequences, ascription of responsibility, an ecological world view and self-transcendence values. Self-enhancement values have a negative impact on personal norms. Based on the model, interventions to change behaviour need not only to include attitude campaigns but also a focus on de-habitualizing behaviour, strengthening the social support and increasing self-efficacy by concrete information about how to act. Value based interventions have only an indirect effect.

3. Jan Krajhanzl (January 2010) establishes environmental and pro-environmental behavior. This study to understand the relationship of an individual to nature. And it also included conservation psychology, it deals with three ranges: relationship to nature factors, personality factors, condition factors. And this study emphasised, the environmental concern, environmental sensitivity and abilities for contact with nature etc.

4. Florian G. Kaiser, Sybille Wölfing and Urs Fuhrer (1999) establishes environmental attitude as a powerful predictor of ecological behaviour. Studies in the past have failed in this endeavour because they neglected to take into account three flaws that limit the predictive power of environmental attitude concepts: [1] the absence of a unified concept of attitude, [2] the absence of measurement correspondence between attitude and behaviour on a general level, and [3] the absence of consideration of behaviour constraints outside of people's control. The current work addresses these issues by using a probabilistic measuring approach and a unified concept of attitude, both of which are based on Ajzen's theory of planned behaviour. Utilized are survey results from two ideologically diverse Swiss transportation groups. By using factor analysis, this study was able to confirm that three measures—environmental knowledge, environmental values, and ecological behaviour intention—are orthogonal dimensions. One such measure, general ecological behaviour, is constructed as a Rasch scale that evaluates behaviour by taking into account the propensity to behave ecologically and the challenges of doing so, which depend on factors outside of the actual control of people's behaviour. The suggested model was validated using a structural equation model, which found that environmental values and knowledge predicted 75% of the variance in overall ecological behaviour and explained 40% of the variance in ecological intention.

5. The study examining ecological behaviour environmental attitude and feeling of responsibility for the environment was conducted by Florian G.Kaiser, Michael Ranney, Terry Hartig, and Peter A. Bowler. The paper established an expanded rational-choice model of environmental attitude that extends into the moral domain by using feelings of personal obligation toward the environment [i.e., Feelings of responsibility] as an additional predictor of intentions to behave ecologically. In study 1 had sample of Swiss adults [N=436] was used to test the proposed model. Study 2 replicated the findings of study 1 with a sample of California college students [N=488]. Environmental knowledge, environmental values, and responsibility feelings together explained 45% [50% in study 2] of the variance of ecological behaviour intention which, in turn, predicted 76% [94%] of the explainable variance of general ecological behaviour the inclusion of responsibility

feelings increased the proportion of explained variance of ecological behaviour intention by 5% [10%]

above and beyond a more basic attitude model, the moral extension of the proposed attitude model is largely supported.

6. Joshua C. Morganstein and Robert J. Ursano have conducted a study of ecological disasters and mental Health: causes, consequences and interventions. These study to understanding natural disasters as they relate to a changing global climate. And disasters are severely impacting resources of a local community. While this article will focus primarily on the human impact of ecological disasters, psychological and behavioural effects, such as stress, anxiety. The conclusion is psychological and behavioural responses create the most significant public health burden following a disaster.
7. Direct experiences from nature, how it will be affect the peoples environmental attitude and environmental behaviours is a study conducted by Claudio D Rosa and Silvia Collado. It tested by 2 sections. Firstly, they measure how and where the experiences occur and second is measuring the relation between environmental attitude and environmental behaviour. Experiences in nature during childhood and adulthood are positively linked to pro-environmentalism. They also suggesting future research to exactly specify the effect of nature experiences on people environmental attitude and environmental behaviour, because they find out several factors that affecting. Such as type of experience of nature, perceived benefits of these experiences and the person's level of specialization in a certain activity.
8. Andra Balunde, Goda Perlaviciute and Linda conducted a correlational study in Lithuania, on the basis of the western Europe and US studies, that revealing relationship between people's biosphere values, environmental self-identity and pro-environmental behaviours. This study points out that there is a positively correlation between general environmental consideration and environmental activism

METHOD

Design of the study:

The purpose of the study was to compare ecological paradigm between primary and secondary survivors of flood in Kerala. So, the quantitative approach was found to be most suitable for the study to collect the relevant data.

Objectives:

- To compare the ecological paradigm among the primary and secondary survivors of flood.
- To compare the dominant social paradigm among the primary and secondary survivors of flood.
- To compare the ecological paradigm and dominant social paradigm among the primary survivors of flood.
- To compare the ecological paradigm and dominant social paradigm among the secondary survivors of flood.

Hypotheses

- H_{o1}: There is no significant difference between primary and secondary survivors in ecological paradigm.
- H_{o2}: There is no significant difference between the dominant social paradigm among the primary and secondary survivors of flood.
- H_{o3}: There is no significant difference between the ecological paradigm and dominant social paradigm among the primary survivors of flood.
- H_{o4}: There is no significant difference between the ecological paradigm and dominant social paradigm among the secondary survivors of flood.

Sample

The sample of study consist of 210 peoples of Malappuram district. Primary data collected from flood affected area, included the river side area. Such as Irimbiliyam, Karma Road, Illathapadam and Mangalam. Secondary data collected from the high land area, included Kalpakanchery, Athavanad, Trikkandiyur, Tanur. The subjects were randomly taken from these areas. There is no age limit and gender classification used in this study.

Tool

The New Ecological Paradigm (NEP) scale:

The New Ecological Paradigm (NEP) scale, which is sometimes referred to as the revised NEP, is a survey-based metric devised by the US environmental sociologist Riley Dunlap and colleagues. It is designed to measure the environmental concern of groups of people using a survey instrument constructed of fifteen statements. respondents are asked to indicate their strength of agreement with each statement (strongly agree, agree, unsure, disagree, strongly disagree). Agreement with the eight odd-numbered items and disagreement with the seven even numbered items indicates pro- NEP responses. Scores on the revised NEP Scale correlate significantly (r =.61) with scores on a 13-item measure of the perceived seriousness of world ecological problems (the higher the NEP score, the more likely the problems are seen as serious); significantly (.57) with a 4-item measure of support for pro environmental policies (the higher the NEP score, the more support for the policies); significantly (.45) with a 4-item measure of the perceived seriousness of state and community air and water pollution (the higher the NEP score, the more likely pollution is viewed as serious); and—most importantly— significantly (.31) with a 10-item measure of (self-reported) pro environmental behaviours (more behaviours are reported by those with high NEP scores). These results, showing that the new NEP Scale is related to a wide range of ecological attitudes and behaviours, suggest that it possesses predictive validity.

Procedure of the study

The current study is designed to measure the dominant social paradigm and the new environmental paradigm of primary and secondary survivors of flood affected in Malappuram district of Kerala. For this, 210 survivors were selected from various villages of Malappuram District as representing Kerala population. The data collected through standardized questionnaire. Primary survivors' data collected directly from them by visiting the flood affected places. Affected location details collected from the disaster management department of Malappuram. On 26/11/2022, we visited Irimbliyam, a highly flood effected area near valanchery. The group of 2 people were collected data on a particular area while others 2 people collected another area. We created a rapport with the subjects in an informal way. They were very supportive to this survey. On, 27/11/2022, we visited karma road near Ponnani. They were not very supportive unlike others. On 4/12/2022, we visited Illathapadam near Tirur. These people also very supportive to this sampling. On 6/12/2022, we visited Perunthiruthi near Mangalam. On 9/12/2022, we visited Kalpakanchery and Athavanad to collect secondary data. Secondary data collected by visiting the high land area and also the google forms were shared to the persons who lives in high land area. Scoring of responses was done after completing data collection.

Statistical techniques

Descriptive statistics such as mean and standard deviation was found. Independent t test is used to find out is there any significant difference between primary and secondary survivors in ecological paradigm. It is a statistical technique to compares the means of two independent groups. Also paired samples t-test is used to compare the means of two samples when each observation in one sample can be paired with an observation in the other sample.

RESULT AND INTERPRETATION

Table - 1: Descriptive statistics

	Survivor Mode	N	Mean	Standard deviation	Std. Error Mean
Ecological paradigm	Primary	105	33.9048	3.651	.4218
	Secondary	105	32.0096	3.281	.32176

Table -1 shows the values of Mean, Standard Deviation standard error mean of ecological paradigm.

The mean score on ecological paradigm for primary survivors is 26.3077(Standard deviation=4.301) and mean score on secondary survivors is 32.0096 (Standard deviation= 3.281).

Table 2

Table - 2 shows the values of Mean, Standard Deviation standard error mean of dominant social paradigm.

	Survivor Mode	N	Mean	Standard deviation	Std. Error Mean
Dominant	Primary	105	23.5810	4.7022	.4588
social paradigm	Secondary	105	26.3429	4.29631	.4192

The mean score on dominant social paradigm for primary survivors is 23.5810 (Standard deviation=4.7022) and mean score on secondary survivors is 26.3429 (Standard deviation= 4.29631).

Table: 3

	t	df	Sig (2-tailed)	Mean difference	Std error Difference
Ecological Paradigm	3.897	208	0.000	1.86667	.47894

The t value of ecological paradigm in survivors was found to be 3.897. Table t value with 208 degrees of freedom is +/-1.9714.

The significant value is found to be 0.001 which is below the significant level 0.05. This indicates that there is significant difference on primary and secondary survivors in ecological paradigm. Thus, the hypothesis which states that "there is no significant difference between primary and secondary survivors in ecological paradigm" is rejected. The mean of ecological paradigm in primary survivors is slightly more than the secondary survivors.

Table 4:

	t	df	Sig (2-tailed)	Mean difference	Std error Difference
Dominant social Paradigm	4.443	208	0.000	-2.76190	.62159

The t value of dominant social paradigm in survivors was found to be -4.443. Table t value with 208 degrees of freedom is +/-1.9714.

The significant value is found to be 0.001which is below the significant level 0.05. This indicates that there is significant difference on primary and secondary survivors in dominant social paradigm. Thus, the hypothesis which states that "there is no significant difference between primary and secondary survivors in dominant social paradigm" is rejected.

Table 5: Mean and Standard Deviation of the primary survivors on two variables.

Variables	**N**	**Mean**	**S D**	**t value**	**sig**
Ecological Paradigm	105	33.9048	3.65199	19.448	0.00
Dominant social paradigm	105	23.2190	4.66571		

Result shows significant difference between the ecological paradigm and dominant social paradigm among the primary survivors of flood.
(0.001<0.005).

Table 6: Mean and Standard Deviation of the secondary survivors on two variables.

Variables	**N**	**Mean**	**SD**	**t value**	**Sig**
Eco. Paradigm	105	32.0381	3.27850	9.944	0.000
Dominant social paradigm	105	26.4000	4.29356		

The result shows there is significant difference between the ecological paradigm and dominant social paradigm among the secondary survivors of flood.

DISCUSSION

The current study is designed to measure the dominant social paradigm and the new environmental paradigm of primary and secondary survivors of flood affected in Malappuram district of Kerala. For this study, data collected using Dunlap's New Ecological Paradigm Scale (NEP) from 210 randomly selected samples belonging to primary (N=105) and secondary survivors(N=105).

Findings:

1. There is a significant difference between primary and secondary survivors in ecological paradigm.
2. There is a significant difference between primary and secondary survivors in dominant ecological paradigm.
3. There is significant difference between the ecological paradigm and dominant social paradigm among the primary survivors of flood.
4. There is significant difference between the ecological paradigm and dominant social paradigm among the secondary survivors of flood.

CONCLUSION

- Ecological paradigm was found to be high in primary survivors than secondary survivors.
- Dominant Social Paradigm was found to be high in secondary survivors.
- Among primary survivors most have concern towards environment than the scientific progress.
- In secondary survivors most view that humans are superior to other all species, the earth provides unlimited resources for humans and science advancement can bring back the nature.
- Ecological disasters change human environmental attitude and values.

Suggestions for Further Research

This study examined ecological behaviour. Based on the current review some recommendations are suggested to future scholars to draw more insights in to these.

- First, more studies can include more sample from different part of the district. The study can be conducted with large sample size to generalize the new ecological paradigm.
- The second recommendation is to apply the mixed method of research, in other words the qualitative or quantitative. And further studies can be done by including more variables.
- Third, include gender differences and comparison studies.

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THE PARADOX OF MANGROVE CONSERVATION AND COMMUNITY VULNERABILITY IN KERALA, INDIA

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Abstract:

Mangroves are a unique ecosystem present in the coastal intertidal zone that provide valuable goods and services to communities, at different spatial and temporal scales. Nonetheless, over-exploitation of these resources can lead to poverty traps, where rural households can no longer use the ecosystem as a source of food security or income. Understanding the perception and the level of vulnerability of the local community to the changes in mangroves stands important for incorporating their benefits, priorities, and preferences into conservation and decision-making processes. The study compared two communities living in mangrove ecosystem in two different locations of Thrissur district, Kerala to analyse the vulnerability and the conservation priority of the community. A conservation index was worked out for understanding the community attitude on mangrove conservation. The vulnerability was analysed as a function of exposure, sensitivity and adaptive capacity using a Community Based Vulnerability Assessment (CBVA) index. Engagement of the communities with the mangroves and the willingness to conserve the mangroves analysed through questionnaire survey was equated with Likert scale. The conservation priority and the willingness to conserve was found to be high for the community that are engaged in the ecosystem for their livelihood needs. The study highlights a paradoxical situation where the community living in close proximity with the mangroves understand the worth of conserving it, even when they are standing backward in their development, livelihood, poverty and conservation indices. Focusing on gender equality with women's participation in conservation and awareness campaigns is also an efficient method for socio-economic upliftment and effective conservation of mangrove ecosystems. The need for interventions like incentivising mangrove conservation and regulation of tenurial aspect from multiple directions like social, ecological, and political approach and its implementation is the need of the hour.

Keywords:

Mangrove, Community Based Vulnerability Assessment, Conservation, Vulnerability, Community perception

INTRODUCTION

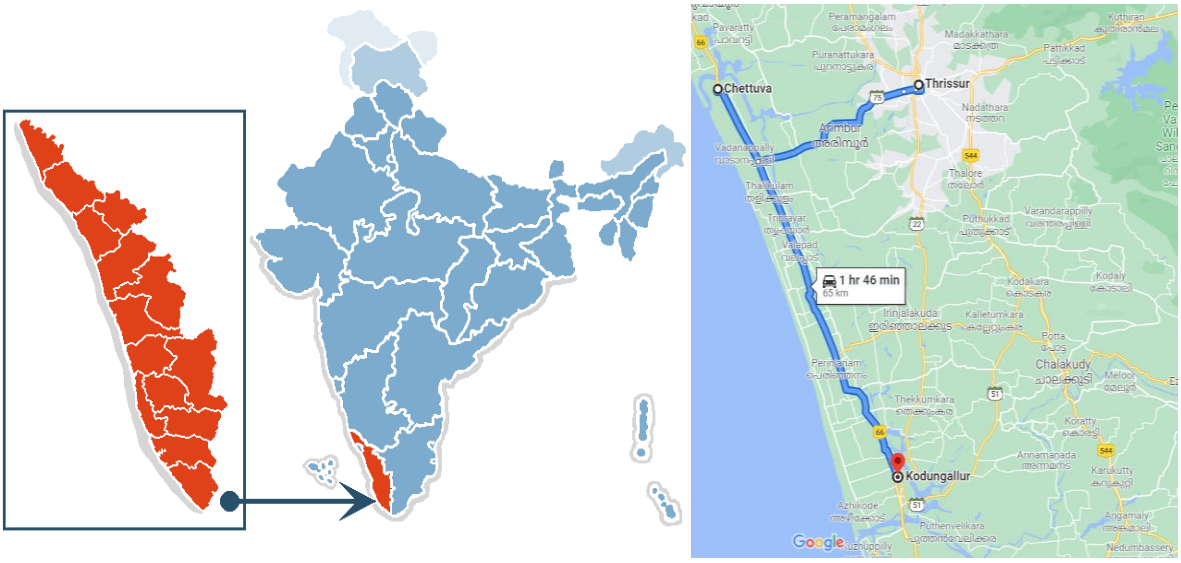
Mangroves are the ecotones of terrestrial and aquatic environments in the earth's tropical and sub-tropical regions. They provide innumerable benefits to the lives and livelihoods of the community and often act as bio-shield against natural disasters like floods and storm events. Nonetheless, over-exploitation of these resources can lead to poverty traps, where rural households can no longer use the ecosystem as a food security or income source. Preventing the loss of just 1 per cent mangroves helps sequester 200 million tons of carbon (State of World's Mangrove, 2022). They are crucial for addressing the climate and biodiversity crises. Mangroves store carbon equivalent to over 21 billion tons of CO_2, thus preventing the worst impacts of climate change by averting the global temperature rises to less than 2°C. Asia has the largest mangrove cover of 5.55 million hectares (Global Forest Resource Assessment, 2020), with India holding a mangrove cover of 4992 km^2. Growing land reclamation for alternate land uses along with the discharge of untreated domestic and industrial waste has affected the existence of mangroves (FSI, 2021). The high returns from aquaculture especially shrimp farming have led to a rather quick transformation of the mangrove lands (Muraleedharan et al, 2009).

The government of India has included mangrove ecosystems under the CRZ-1 category and Kerala Conservation of Paddy land and Wetland act (2008) thereby preventing the destruction of mangroves or conversion of mangrove areas for alternative purposes. Furthermore, the Kerala State Coastal Zone Management Authority is the nodal agency valuing projects involving the destruction of mangrove resources (Hema and Devi, 2015). Government departments (Fisheries, Revenue, local self-governments, Forest and Tourism), quasi-government agencies (Kerala Agricultural University), Central government (Railways) and a major share under private ownership own the mangrove patches in Kerala. The area under private ownership is mostly in a degraded state. The marginalized community dependent on the mangroves tries to protect the ecosystem, while the larger holdings destroy it. Understanding the local community's perception and vulnerability to the mangroves changes is important for incorporating their benefits, priorities, and preferences into conservation and decision-making processes. With this background, the present study analyses the vulnerability and the conservation priority of two different communities residing in the mangrove ecosystem in two different locations in Thrissur district, Kerala.

STUDY AREA

The present study is conducted in Chettuva and Kodungallur panchayats of Thrissur district of Kerala (Map 1). Chettuva harbours the largest mangrove patches in Kerala and falls under Engandiyur Panchayat of Thrissur District. It is an ecotourism spot. Since fisheries was one of the major livelihood options for the people in Chettuva, there is scope for protecting marine ecosystem and building strong institutional frameworks and policies for the changes in the pattern of usage of land.

Kodungallur is a historically significant town situated on the banks of river Periyar on the Malabar Coast in Thrissur district of Kerala. It has better access to markets, schools and hospitals as compared to Chettuva. Here the wards 10,11 and 12 have been chosen considering the closest proximity (From 1 to 2 Km) to the mangroves. The study involved 5 per cent of the households chosen randomly from the wards that are near the mangroves.



Map 1. Map of study area

METHODOLOGY

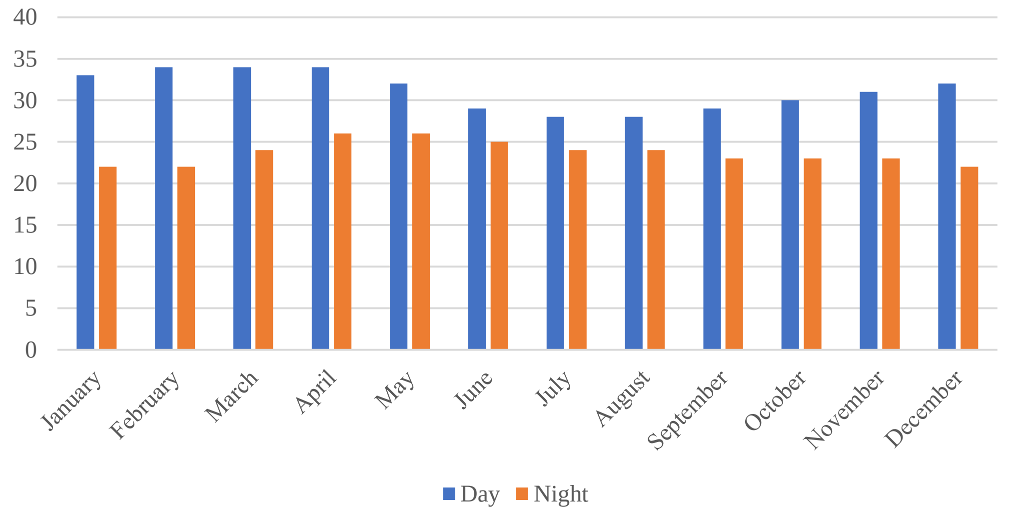
The study uses primary data supplemented by secondary data wherever necessary. A structured questionnaire survey conducted among the resident community revealed their socio-economic status and preferences for the conservation of the highly vulnerable ecosystem. A conceptual framework was developed to assess the vulnerability level of the community based on the IPCC (2001) definition of vulnerability. Accordingly, vulnerability is a function of exposure, sensitivity and adaptive capacity. The analysis was carried out based on a Community Based Vulnerability Assessment (CBVA) index. The parameters selected are observed on the basis of indicators. The major parameters considered include temperature, precipitation, plant changes, natural hazard, livelihood activities, agriculture, fisheries and biodiversity, physical infrastructure, natural resources, wild animal threats, seasonal changes, water scarcity, health aspects, human capital, natural aspects, social aspects, financial aspects, among others.

RESULTS AND DISCUSSION

Temperature and rainfall

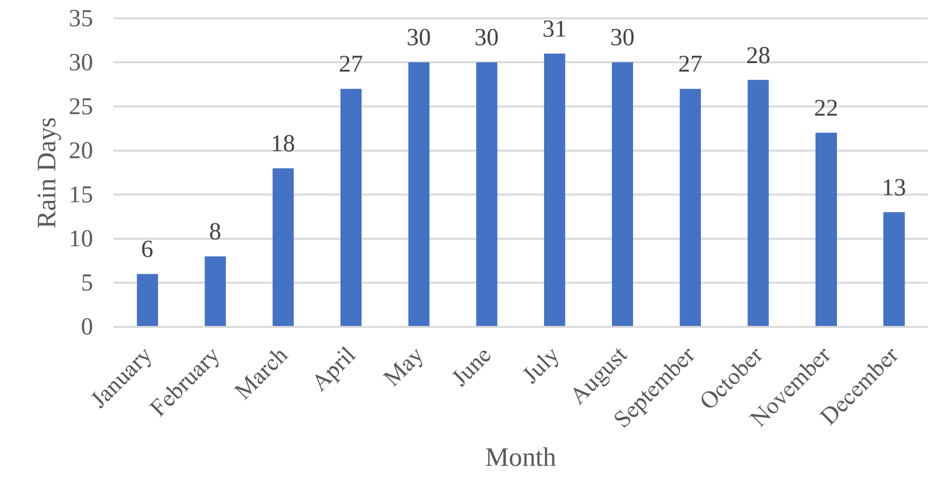
The evaluation of biophysical conditions such as climate, soil and erosion status, and freshwater availability helps in understanding the feasibility of the mangrove restoration programs. The average temperature of Thrissur district considering both the day as well as night temperatures shows a temperature abobe 20 degrees Celsius throughout the year (Figure 1, 2).

Figure 1. Average Temperature of Thrissur - 2021



Rain Days in Thrissur shows maximum rainfall days from May to August. The least number of rainfall days was in the months of January and February.

Figure 2. Rain Days in Thrissur - 2021



The climatic conditions of temperature and rainfall in Kodungallur. The average temperature is above 25 degree celcius and average rainfall in the region is above 250 mm (Figure 3, 4).

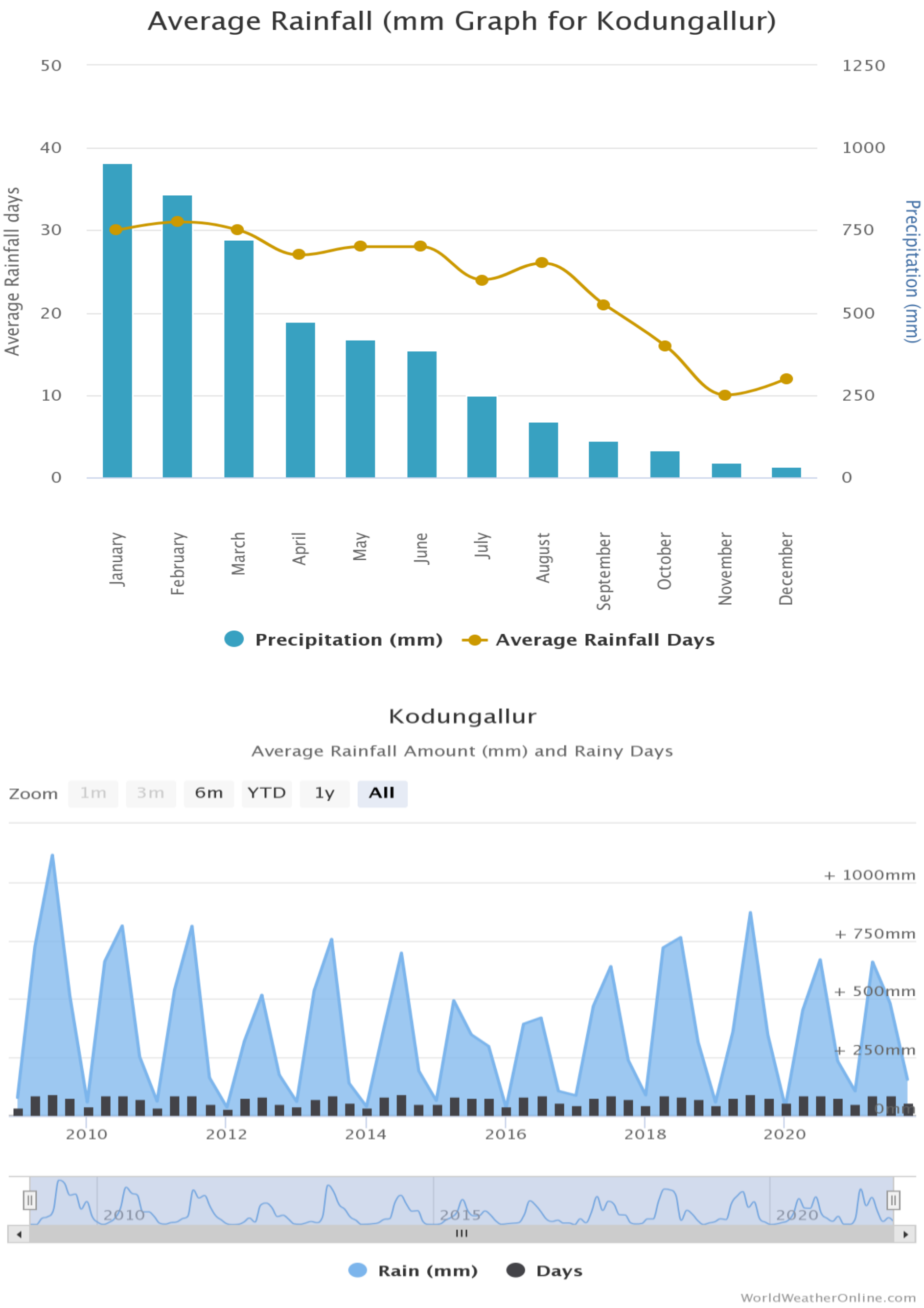


Figure 3. Average rainfall in Kodungallur

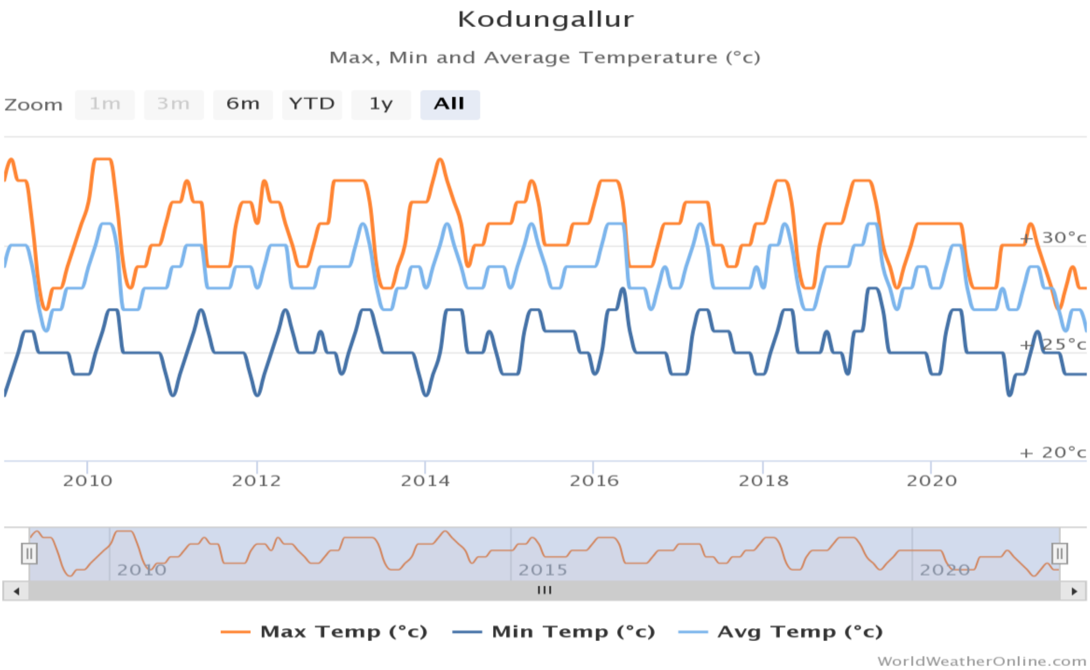


Figure 4. Average temperature in Kodungallur

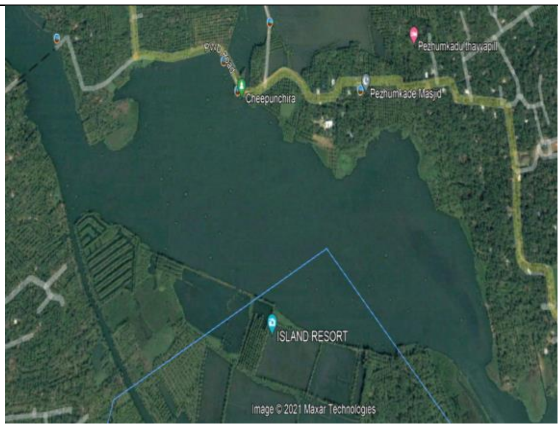
Land use change

The Land cover change has been analysed using Google Earth Pro for selected patches selected for the study. From 2004, there has been continuous changes due to multiple factors. It is important to understand and accept the kind of pressure land is facing due to both natural as well as anthropogenic activities.

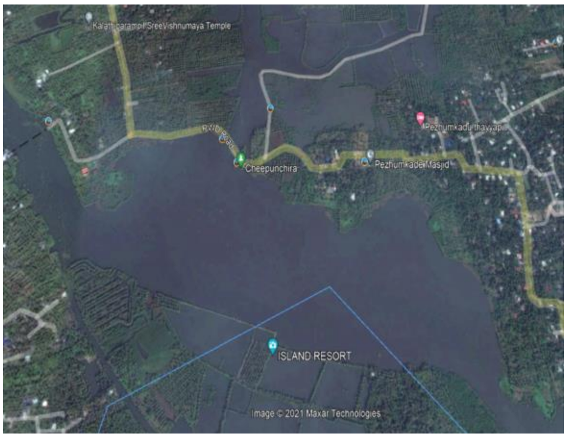
a. Chettuva patch in 2004

b. Chettuva patch in 2012

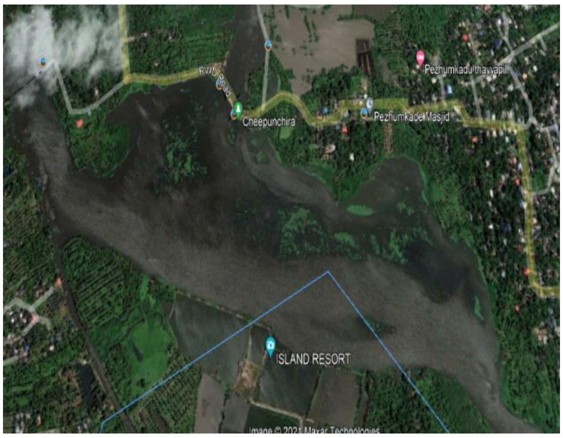
c. Chettuva patch in 2021



d. Kodungallur patch in 2004



e. Kodungallur patch in 2014



f. Kodungallur patch in 2021

Plate a-f. Landuse change in mangrove locations

Both locations have gone through drastic loss of mangroves over the period of time but in Chettuva, higher engagement and awareness of the community has resulted in natural regeneration of mangroves.

Land tenure

The ownership of the land in mangrove area exists in 3 forms here.

1. Government ownership
2. Common Land (Community or Panchayat)
3. Private Land (Private Owner)

Apart from households and the nearby lands, major quantity of the land is with Community or with Private Owner (Figure 5). The awareness and ownership about mangroves in both the sites show that with the increase in ownership of private lands there is a decrease in awareness about mangroves (Table 1,2).

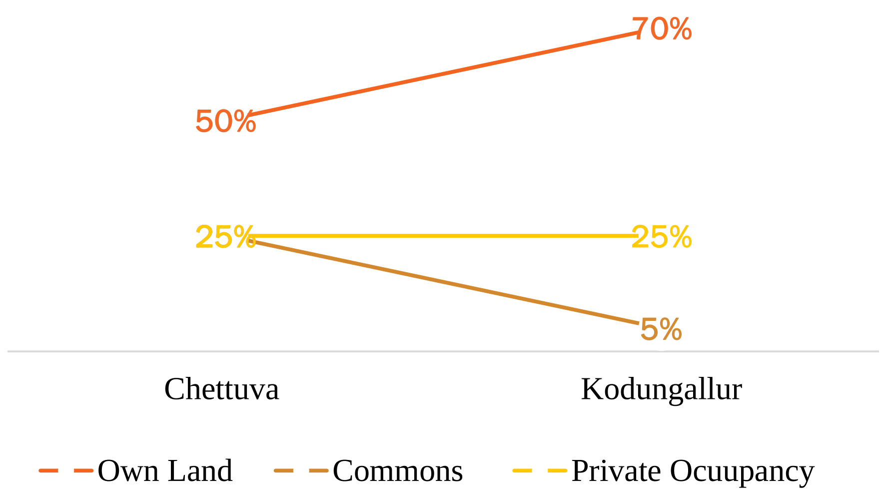
Table 1. Awareness of the community on mangroves	
Chettuva	100%

Kodungallur	74.35%

Table 2. Ownership of mangroves

Location	Private	Commons	Government
Chettuva	50%	25%	25%
Kodungallur	70%	5%	25%

Figure 5. Ownership of Land

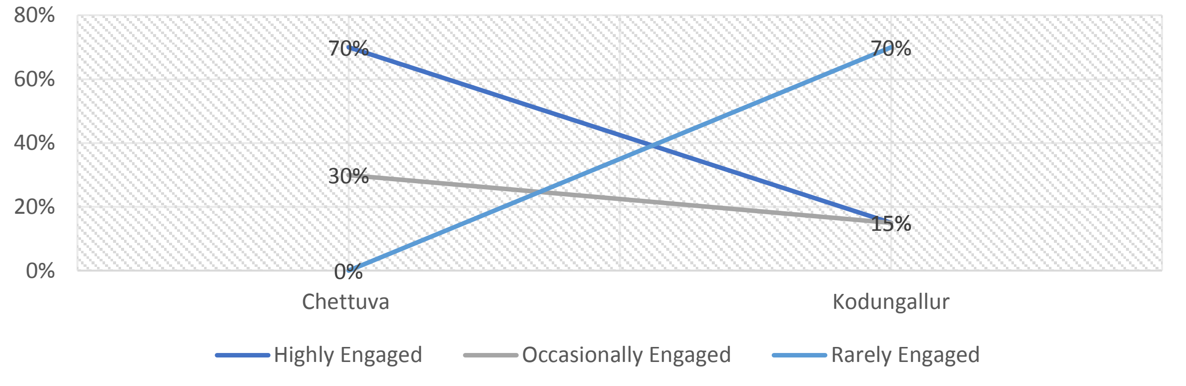


Community involvement with Mangroves

One of the most effective ways to restore the damage on mangrove forest is by involving the local community thereby enabling them to gain their livelihood for a sustainable future. Government as the regulator may involve them, based on ecological mangrove principles, in planning, implementing and monitoring the appropriate or inappropriate of restoration. The policies and regulations regarding private land owners' right to freehold property, which mangroves colonizes are yet to be specified with more clarity.

Engagement with the mangroves and the willingness to conserve the mangroves in both the study areas based on the interaction questionnaire equated with Likert scale.

Figure 6. Comparison of community engagement with mangroves (Thrissur District)

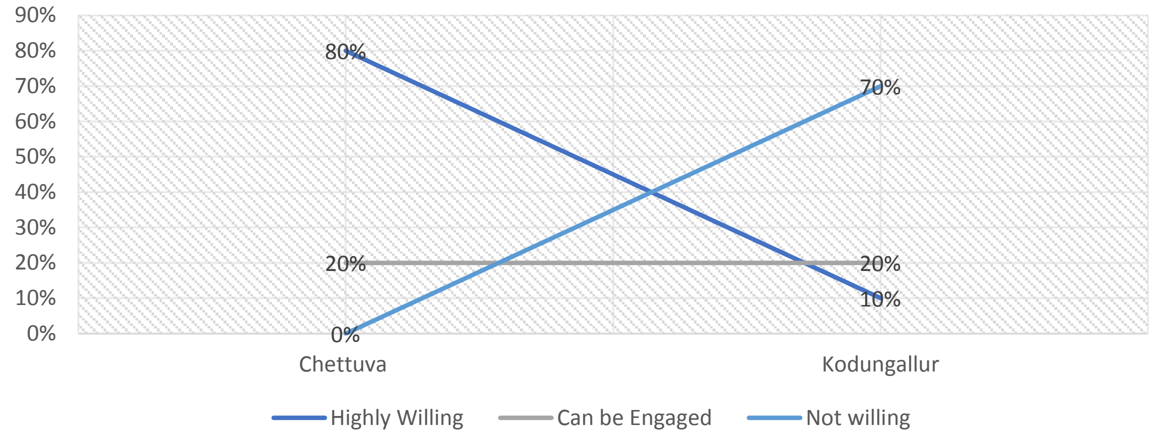


Community engagement with the mangroves is more in Chettuva than in Kodungallur as there is a negligible number in the rarely engaged category. In case of Kodungallur, there are 70 per cent of the community who are not even engaging and 15 per cent are engaging occasionally and in many cases that is through indirect way. This is another clear indication that community should be taking part in the conservation of Mangroves.

Willingness to conserve mangroves

In similar lines with the engagement, Willingness to conserve the Mangroves is also high (80%) in Chettuva where community is taking part. It is exactly the opposite case in Kodungallur where 70 per cent of the people responded that they are least bothered about the Mangroves (Figure 7) and even some were making complaints about the snakes, stray dogs and foxes which is a sign of resistance towards co-existence.

Figure 7. Willingness to conserve (Thrissur district)



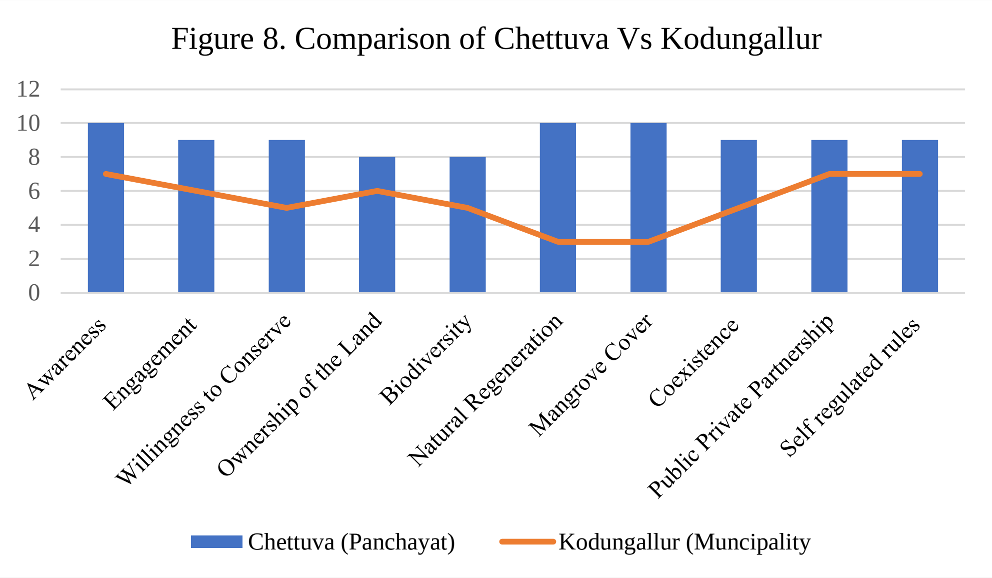
There are multiple stakeholders involved in Mangrove Ecosystem. This includes Coastal communities, Forest Department, Fisheries Department, Private Land Owners, Tourists and Researchers. 10 significant factors considered for comparison based on ground results are as follows (Table 3).

Table 3. Parameters considered for mangrove conservation	
1.	Awareness
2.	Engagement
3.	Willingness to Conserve
4.	Ownership of the Land
5.	Biodiversity
6.	Natural Regeneration
7.	Mangrove Cover
8.	Coexistence
9.	Public Private Partnership
10.	Self-regulated rules

By incorporating both the perceptions analysis and the interaction questionnaires, these parameters have been measured by the Likert scale of 1 to 10 and compared with study areas. Chettuva performed better due to better awareness, engagement with the mangroves, willingness to conserve along with self-regulated rules for managing the commons and there is better management of mangrove cover and the adaptability to co-exist (Table 4).

Table 4. Chettuva Vs Kodungallur (Municipality)

Parameter	Chettuva (Panchayat)	Kodungallur (Muncipality
Awareness	★	⯪
Engagement	★	⯪
Willingness to Conserve	★	☆
Ownership of the Land	★	⯪
Biodiversity	★	☆
Natural Regeneration	★	☆
Mangrove Cover	★	☆
Coexistence	★	☆
Public Private Partnership	★	⯪
Self regulated rules	★	⯪



Comparison of Development, Poverty, Livelihood and Conservation Aspects

Based on the data collection and observations, the following indices were formulated to get a closer look at Chettuva and Kodungallur and to analyse the practices followed by both regions in par with the mangroves. This helps understand the present status and build a better understanding of how to reduce the fundamental issues of the vulnerable community and align them with mangrove restoration.

Development Index: The Development Index (Table 6) aims to understand the availability of the basic amenities present in the location and the basic habits of people living in a region, indicating how aware and equipped they are as a community. The transporation facility in both the area is good. The waste disposal pattern in Chettuva is poor as compared to Kodungallur.

Table 6. Development Index (DI)

Sl. No	Indicator	Chettuva	Kodungallur
1	Transport Facilities	1	1
2	Waste Disposal	0.3214	0.7692
3	Vote in the last election	1	0.9744
4	Electricity	1	1
5	Years of education	0.4167	0.5590
6	Access to smartphones	1	1
	Development Index	**0.7153**	**0.8650**

Source: Primary data estimates

The DI of Kodungallur is more than that of Chettuva, which aligns with our observation as well. Kodungallur is more developed than Chettuva. The major difference comes when looking at years of education and waste disposal methods. People in Kodungallur have more years of education than people in Chettuva and also in Kodungallur, waste is mainly collected either by Panchayat or Municipality. Chettuva needs a better approach to waste disposal as disposing of the waste properly is of utmost importance because it directly affects the health of people and Mangroves.

Poverty Index: The Poverty Index (Table 7) is calculated based LPG connection, toilet facilities, own vehicles, Above Poverty Line, Ration Card, and possession of own land.

Table 7. Poverty Index (PI)

Indicator	Chettuva	Kodungallur
LPG Connection	1	1
Toilet Facilities	1	1
Own Vehicles	0.7857	0.8462
Above Poverty Line (APL) Ration card	0.5179	0.8333
Own land	0.9286	0.9231
Poverty Index	**0.8231**	**0.9177**

Source: Primary data estimates

The comparative analysis between the two regions indicated the Kodungallur being better of than Chettuva with higher PI. Most of the respondents in Kodungallur hold an APL ration card as compared to Chettuva, where more people are below the poverty line. Scarcity of drinking water was yet another problem in Chettuva, which is mentioned later, and most people are not wealthy enough to buy drinking water from elsewhere. Water nearby is saline primarily, and for their daily needs they rely on it. Lack of basic amenities and lack of proper funds allocation for necessary facilities also comes in between socio-economic upliftment of community and conservation.

Livelihood index: The livelihood Index (Table 8) aims to understand and compare the financial stability of the study area.

Table 8. Livelihood Index

Indicator	Chettuva	Kodungallur
Dependent on loan	0.8214	0.9487
Bank account	1	1
Wage	0.2700	0.2394
Livelihood Index	**0.6053**	**0.6101**

Source: Primary data estimates

Based on the indicators the Livelihood Index of Kodungallur is more than that of Chettuva. The wages data of the Chettuva region includes the wages received when the conditions were ideal, but that is not the actual case most of the time; professions in Chettuva have high variability include fishery, business, etc. The livelihood of community in Chettuva is dependent on aquaculture and tourism. Frequent floods and high tides were observed, with accelerating climate change than before. This hinders fishermen from going to sea or to water bodies to catch fish, and also market prices keep on fluctuating, which again adds to the variability for them and other businesses. The wages in Chettuva show a considerable amount of variance compared to Kodungallur wages data. Another factor that adds to the variability of Chettuva is the frequent floods which damage the structure of the houses, adding to the maintenance costs. As per the survey, floods are a frequent occurrence in that region and make the communities more vulnerable.

Conservation Index: The CI is based on the community's sensitivity to conservation (Table.9)

Table 9. Conservation Index			
Sl. No.	**Indicator**	**Chettuva**	**Kodungallur**
1	Rainwater harvesting	0.0357	0.1538
2	Scarcity of drinking water	1	0.9487
3	Dependency on timber	0.8214	0.8205
4	Waste disposal	0.3214	0.7692
CI		**0.3116**	**0.5509**

Source: Primary data

The Conservation Index depicts the CI of Kodungallur to be higher than Chettuva. Kodungallur is more developed and well off than Chettuva. More people in Kodungallur are aware of methods like rainwater harvesting. They know the importance of disposing of their waste hygienically. Chettuva has more mangrove cover, and people there are more dependent on it for their livelihoods, and hence they are more sensitive towards it. However, the variability in climate and lower socioeconomic conditions do not allow them to go beyond a certain extent to protect their nearby forests. The close proximity to mangrove forests here becomes even more critical for the people as well as governing authorities to take well-planned steps to dispose of the waste sustainably because most people in Chettuva were found to be burning their waste, which is not a sustainable practice.

Comparative Analysis of Chettuva and Kodungallur

It is thus concluded that Kodungallur is more developed in terms of basic facilities and awareness (Table 10). In terms of job stability, people in Kodungallur have more stable jobs than in Chettuva. Proximity-wise to mangroves Kodungallur is lesser vulnerable to floods and cyclones and are more financially stable. Chettuva needs better government interventions, for the socio-economic upliftment of the community and needs to run training and awareness programs for the local community.

Table10. Comparative Analysis of Chettuva and Kodungallur			
Sl. No.	**Indices**	**Chettuva**	**Kodungallur**
1.	Development Index	**0.7153**	**0.8650**
2.	Livelihood Index	**0.6053**	**0.6101**
3.	Poverty Index	**0.8231**	**0.9177**
4.	Conservation Index	**0.3116**	**0.5509**

Source: Primary data

As Chettuva is closer to mangroves, local communities understand the importance and significance of mangroves to a great extent. This could be of help when running training and awareness programs. The scarcity of drinking water needs to be addressed urgently. This scarcity not only affects people's health but also with time makes them ignorant towards mangroves and the Government if no active measures are taken. Women's participation in conservation and awareness campaigns is also an efficient method for socio-economic upliftment and effective conservation as well.

Majority of the households that are dependent on mangroves directly, were more vulnerable. In Chettuva, fishing, dairy and shrimp farming are the major means of occupation. There is a lack of other means of income for certain households living closer to the mangroves. In such households, higher number of drop outs due to financial issues were observed. However, those households that did not depend on mangroves for livelihood needs, were generally less vulnerable. While the indices were showing a lower value for Chettuva, but their conservation priority was found to be better than Kodungallur. Thus, the study highlights a paradoxical situation where the community living in close proximity with the mangroves understand the worth of conserving it, even when they are standing backward in their development, livelihood, poverty and conservation indices.

CONCLUSION

The present study had focused on the mangrove cover and the linkages of the community residing in the close proximity towards conservation of the fragile ecosystem. The perceptions of mangrove ecosystem are context-specific and influenced by multiple factors, including proximity of communities to mangrove forests, social factors, and local communities' contact with management committees. A deeper understanding of the preference of the local stakeholders for mangrove ecosystem can help to strengthen the links between local communities and conservation actors for sustainable management of mangrove forests. Focusing on gender equality with women's participation in conservation and awareness campaigns is also an efficient method for socio-economic upliftment and effective conservation of mangrove ecosystems. The need for interventions like incentivising mangrove conservation and regulation of tenurial aspect from multiple directions like social, ecological, and political approach and its implementation is the need of the hour.

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TUNNELLING IN SQUEEZING GROUND – A REVIEW ON PREDICTION AND MEASUREMENT OF BOUNDARY DEFORMATION AND AVAILABLE MITIGATION METHODS

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Abstract:

Tunnelling in squeezing ground is a serious concern in rock engineering as it is difficult to predict the ground movement around the opening because such large deformation in tunnels is due to plastification of rocks (often under high stress) following the excavation. This paper presents a critical and comprehensive review of the squeezing phenomenon during tunnelling and the approaches adopted to mitigate this problem throughout the world are also summarised based on the published literature. The focus is given to the prediction and classification of squeezing ground conditions through empirical and semi-empirical approaches, and to various methods utilized in measuring the boundary convergence and in examining the failure mechanisms. Subsequently, an attempt is made to discuss all the major contributions of previous researchers concerning their innovative design of flexible support systems in mitigating squeezing failure. Finally, a summary of the various support systems with their inherent advantages and unique support characteristics is presented. Studies shows all available modern support techniques are generally used to deal with large deformation problems in squeezing ground. The over-excavation technique, flexible support, compressible layer between the excavation boundary and the stiff lining, longitudinal gaps in the shotcrete lining, and yielding rock bolt are commonly applied in combination. Since only a limited number of parameters is considered in predicting SGC, it is expected that numerical analysis programs based on detailed rock mass characteristics would help rock engineers estimate and mitigate tunnel squeezing problems more accurately to restrain deformations and reduce the cost of tunnelling.

Keywords:

Squeezing ground; Tunnels; Deformable elements; Support optimizations; Flexible support.

INTRODUCTION

Tunneling in squeezing ground is characterized by large time-dependent complex ground movement around the opening. The main reason for such large deformation is the plastification of intact rocks (often under high stress) following the excavation. This slow creep deformation (squeezing) may terminate during construction or can continue over several days or weeks (Agan, 2016; Barla, 2001).

Tunnelling through weak and tectonically disturbed rocks of many mountainous regions poses serious problems to tunnel engineers (Bian et al., 2019; Chen et al., 2019). During underground construction, calamities like rock-burst, collapse and squeezing occur frequently, which bring great challenges during tunnel construction. This is mainly because of the complex geological conditions in those regions. In some locations, due to low strength, the rocks are susceptible to overstressing under high overburden load. This overstressing is believed to be responsible for the failure of the rocks in the vicinity of excavation, which ultimately leads to squeezing ground conditions (SGC) and anisotropic deformations (Dube et al., 1986; Mahdevari et al., 2012).

The squeezing behavior is commonly encountered during excavation through weathered rock masses, fault/shear zones (Barla et al., 2011; Dusseault & Fordham, 1993; Fabre & Pellet, 2006; Goel et al., 1995; Rostami, 2016). To make reliable guesses of squeezing at the design stage is very difficult during tunnel construction as SGC may vary over short distances due to rock heterogeneity and fluctuations in rock mass properties (Barla et al., 2010, 2012). The squeezing phenomenon can be mechanically treated as an elasto-viscoplastic behavior of the medium under the existing state of stress (Ö. Aydan et al., 1996). This implies that SGC may only occur when the rock is yielded by the redistributed state of stress following the excavation (Akagi et al., 1984; O. Aydan et al., 1993; Ö. Aydan et al., 1996; Gioda, 1982).

The rate of deformation, the magnitude of tunnel convergence and the extent of the yielding zone around the tunnel depend on various factors, such as the geological and geotechnical conditions; depth of the opening; the groundwater flow and pore water pressure; deformation modulus of the rock mass; the in situ state of stress relative to rock mass strength, etc. (Barla et al., 2010; Dube et al., 1986; B. Singh & Goel, 1999; M. Singh et al., 2007). The squeezing conditions may also arise for rocks at shallow depth if horizontal stresses are too high. The squeezing rate and the rock loads, to some extent, depend also on tunnel advance rate and tunnel span (Mahdevari et al., 2012).

For large deformation in weak rock, traditional support systems with large stiffness, such as grid steel frame, I-shape steel arch, concrete-filled steel tube arch, may not play a significant role in controlling the deformation effectively (Xu et al., 2017). Hence, SGC requires specific attention of engineers so that they can strategize the best possible construction measure. This may lead to huge adaptation of the excavation method and support system. Fundamentally, for squeezing rocks, there are two main support principles i.e. a) the resistance principle and b) the yielding principle (Dalgiç, 2002; Kovari, 1998; Mezger et al., 2018). The resistance principle is signified by the rigid/stiff concrete tunnel lining support system. Whereas the yielding principle allows the rock mass deformations to occur by adjusting the thickness of the lining. But in general, a situation arises somewhere between these two extreme cases. Several recent innovations regarding yield-control support systems helped increase the tunnel advancing rate in highly stressed squeezing rock mass at great depth.

This paper presents a critical and comprehensive review of the squeezing phenomenon of tunnels and the methods adopted to mitigate this problem throughout the world, based on the published literature. Based on theoretical, physical, and mechanical backgrounds, the focus is given on various methods utilized in measuring the boundary convergence and failure mechanisms induced by tunnel squeezing. The use of numerical simulation with regard to squeezing problems is not discussed in this paper because it is a vast topic that requires a specific separate attention. Finally, a summary of the various flexible support systems with their inherent advantages and unique support characteristics is presented.

PREDICTION AND CLASSIFICATION OF SGC

Squeezing ground conditions were first experienced in tunnelling through Alpine mountain ranges during the early 1900s. Fernner (1938) first proposed an elastoplastic approach to describe the squeezing behavior for an underground opening. He introduced the term "*ground reaction curve*", which depicts the relationship of the rock pressures with the corresponding tunnel wall displacement.

Squeezing ground conditions are often encountered in deep mountainous tunnels, where geological data may be limited. Hence, there is always a risk for a Tunnel Boring Machine (TBM) to be stuck in such squeezing rock mass conditions (Gong et al., 2016; Hasanpour et al., 2018; Rostami, 2016). For example, with regard to hydroelectric tunnelling projects, attempts to use TBMs in weak rocks occurring at great depths within the Himalayan region were often unsuccessful because of SGCs (Panthi & Nilsen, 2007; Swannell et al., 2016). Therefore, the identification, quantification, and classification of SGC are very important before any excavation. Unfortunately, in the majority of the cases, there is a significant mismatch between the extrapolated/predicted geology based on limited available geological information and the actual geology encountered during tunnelling as the excavation progresses (Home, 2016). In other words, the reality often brings about more geological complexities for tunnelling than anticipated initially.

The tunnel response under SGC requires a full understanding of the creep mechanism of the rock mass surrounding the tunnel (Kabwe et al., 2020). Considering ground response as elastoplastic or viscoelastic behavior, a few approaches have been suggested by researchers to identify SGC. They provide some basic equations based on their practical field experiences and reported case histories. These approaches are mainly empirical or semi-empirical in nature and are discussed in the following sections.

Empirical approaches

The empirical relations are intended to identify the potential squeezing zones in tunnels. There is a significant amount of research and empirical modelling which strongly argues that the tunnel squeezing mechanism is a function of the tunnel depth, tunnel width or radius, rock mass quality (*Q*) and rock mass number *(N*). Some of these cases are briefly reviewed below.

Based on a total of 39 case histories in the Himalayas, Singh et al. (1992) identified the squeezing problems in tunnels. According to these observations and data from Barton et al. (1974), they suggested an empirical correlation between rock mass quality (Q) and overburden (H) to identify the occurrence of SGC (**Fig. 1**) and concluded that SGC would take place if

$$H \gg 350\, Q^{1/3} meters \qquad (1)$$

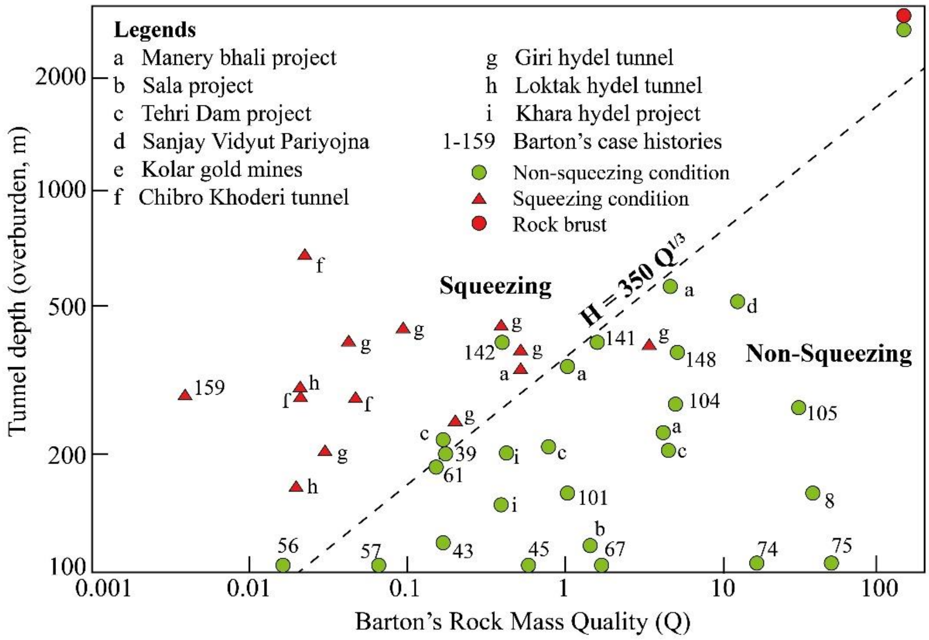

Fig. 1. Criteria for predicting squeezing ground conditions (modified after (B. Singh et al., 1992))

The study by Goel et al. (1995), however, indicated that the Q-system is unsafe for large tunnels under SGC. Hence, they proposed a new correlation considering tunnel depth/overburden (H), tunnel span/diameter (B), and Rock Mass Number (N) data from a total of 72 case histories to obtain a reliable estimation of tunnel support pressures. In **Fig. 2**, the line AB separates the squeezing and non-squeezing cases. The equation of this line AB is given below:

$$H = \left(275\, N^{0.33}\right) . B^{-0.1} \; meters$$
$$\frac{J_r}{J_a} \leq 0.5 \qquad (2)$$

i.e. for the occurrence of squeezing ground conditions

$$H >> \left(275\, N^{0.33}\right) . B^{-0.1} \; meters \qquad (3)$$

where, J_r = joint roughness number for the critically oriented joint sets, and J_a = joint alteration number for critically oriented joint sets.

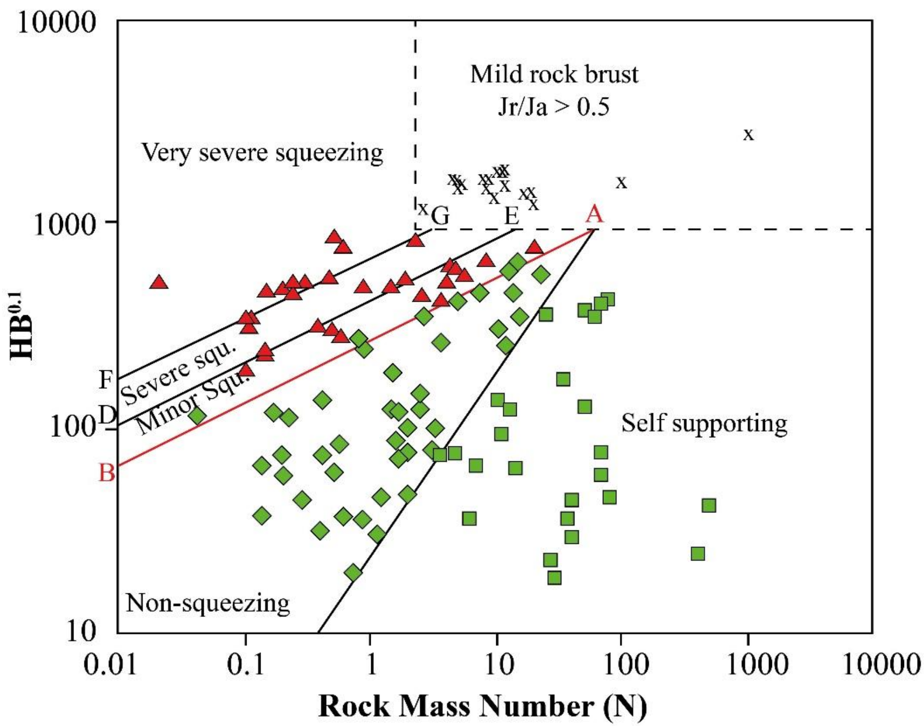

Fig. 2. $HB^{0.1}$ plotted against rock mass number (N) for predicting ground conditions (modified after (Goel et al., 1995; B. Singh & Goel, 2011))

Jimenez and Recio (2011) proposed a novel empirical method for the prediction of squeezing conditions in rock tunnels based on an extensive database of 62 well-documented squeezing case histories from tunnels in the Himalayan region. They observed that the probability of squeezing increases with the increase in tunnel depth and decrease in rock mass quality. They concluded that SGC would occur if

$$H \gg 424.4\, Q^{0.32} meters \quad (4)$$

The above equation is very much similar but slightly less conservative in comparison to the equation proposed by Singh et al. (1992). This can be attributed to the tunnel case histories and database they used to develop the equation in which the maximum depth of tunnels was 800 m. Beyond this depth, however, this equation may not be valid for predicting tunnel squeezing. Therefore, more case histories are required to develop a new correlation.

Dwivedi et al. (2013) also developed three empirical correlations to predict tunnel squeezing. This data was mainly from hydroelectric projects in the Himalayan region. Their empirical relation between the predicted tunnel strain and the observed tunnel strain yielded a correlation coefficient of 0.94. The governing parameters involved in the developed empirical equation are Joint factor (J_f), Barton's rock mass quality (Q), vertical stress (σ_v), tunnel radius (a) in meters and support stiffness (K) in MPa, rock mass number (N) and tunnel depth (H). The equations are given below:

Using J_f and K

$$\frac{u_p}{a} = \frac{5\times10^{-10}\sigma_v J_f^3}{K+0.5} + 0.0052 \quad (5)$$

Using Q, σ_v, and K

$$\frac{u_p}{a} = \frac{0.0191\sigma_v Q^{-0.2}}{K+1} + 0.0025 \quad (6)$$

Using H, N, and K

$$\frac{u_p}{a} = \frac{a^{0.12} H^{0.81}}{10.5 N^{0.27} K^{0.62}} \quad (7)$$

where, u_p is the predicted radial deformation of the tunnel (m), and $N = (Q)_{SRF\,=\,1}$. The J_f is defined by the following relation:

$$J_f = \frac{J_n}{n \times r} \quad (8)$$

Here, J_n = joint frequency, i.e. no. of joints/m towards loading direction, n = inclination parameter, subjected to the orientation of the joint plane w.r.t loading direction, and r = joint strength parameter dependent upon the joint thickness, joint alterations due to weathering and joint condition (whether cleaned, rough or filled joints, etc.).

It should be noted that the developed correlations (5) and (6) are valid only for tunnels excavated by drilling and blasting in SGC, where tunnel strain is > 1%. In other words, these equations do not take the other conventional methods like "New Austrian Tunneling Methodology (NATM)", "Drainage, Reinforcement, Excavation, Support Solution (DRESS) method" and Mechanized Method such as tunnelling with road headers, TBMs, etc. into account.

Dwivedi et al. (2019) proposed another empirical relation to predict squeezing and non-squeezing ground conditions and validated the same with regard to recently excavated Himalayan tunnels. In **Fig. 3**, the joint factor (J_f) is plotted along the *x-axis* and the product of tunnel depth (H) and tunnel diameter (D) is plotted along the *y-axis* (on a logarithmic scale). According to the plot, the squeezing condition will only occur if

$$H.D > 170234e^{-0.017 J_f} \quad (9)$$

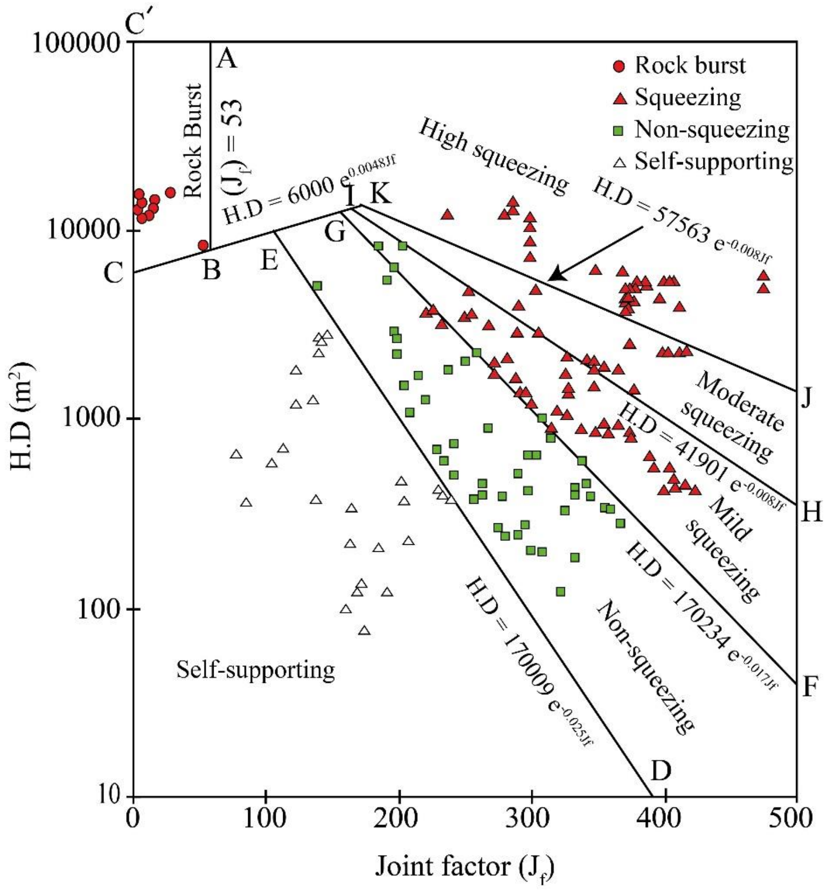

Fig. 3. Demarcating different squeezing zones based on the product of tunnel depth and diameter (H.D) vs. joint factor (J_f) (modified after (Dwivedi et al., 2019))

The effect of potential discontinuities and horizontal in-situ stress conditions on ground behavior was not taken into consideration in this approach. This becomes more important especially for tunnels constructed in regions like the Himalayas where horizontal stress can be extremely high. Although for a depth more than 400 m in the Himalayas, the ratio of averaged horizontal stress to vertical stress (k) can be assumed as unity, this requires further research.

Semi-empirical approaches

Semi-empirical methods not only identify the SGC but also estimate the deformation around the tunnel and the required support pressure to tolerate the radial pressure exerted by the surrounding rock mass.

Jethwa et al. (1984) defined the degree of squeezing based on the ratio of $\sigma_{rm}/2P$, where σ_{rm} is the uniaxial compressive strength (UCS) of the rock mass and P is the hydrostatic primitive stress equal to cover pressure. They plotted the SGC curves between the peak angle of internal friction of rock mass (φ_p in degrees) in the elastic zone (along the x-axis) and P_{ult}/P along the y-axis, where P_{ult} is the ultimate rock pressure on tunnel supports under squeezing rock conditions (**Fig. 4**).

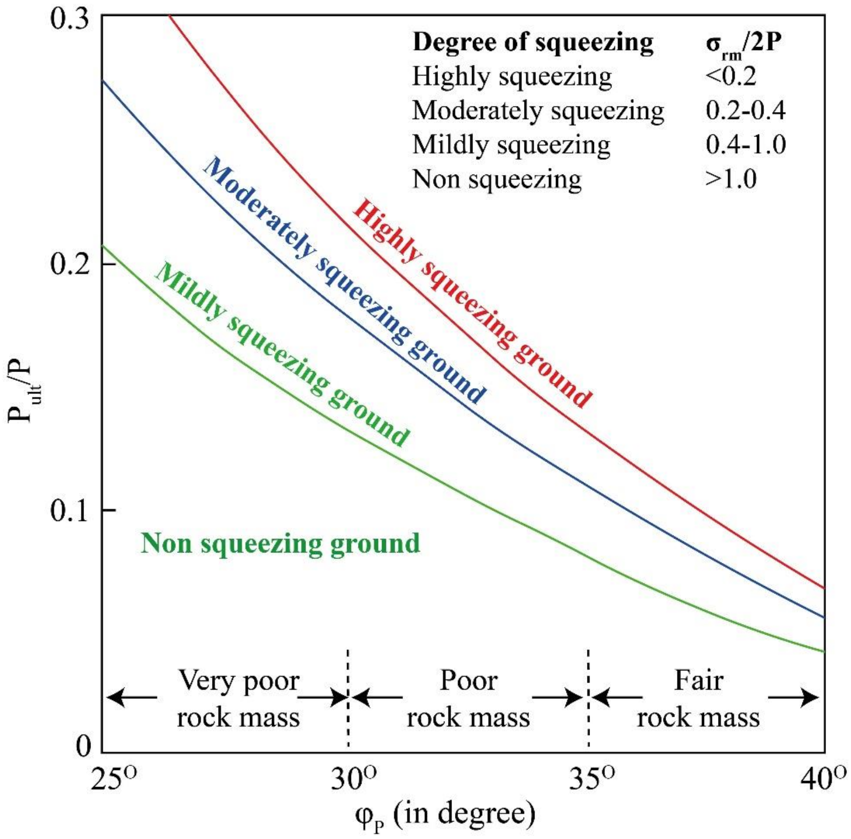

Fig. 4. Charts for ultimate rock pressure on tunnels under squeezing rock conditions (modified after (Jethwa et al., 1984))

Aydan et al. (1993) compared the strains to define squeezing potential by considering tunnel case studies from Japan (**Fig. 5**). Their approach is based on the analogy between the stress-strain response of rock in the laboratory and the tangential stress-strain response around tunnels (**Fig. 6**). As shown in **Fig. 6**, five distinct states of the specimen during loading are experienced at low confining stress σ_3 (i.e. $\sigma_3 \leq 0.1\ \sigma_{ci}$). The following relations provide the normalized strain levels η_p, η_s, η_f, and the levels of normalized deformation are expressed as a function of uniaxial compressive strength (σ_{ci}) of the rock material:

$$\eta_p = \frac{\varepsilon_p}{\varepsilon_e} = 2\sigma_{ci}^{-0.17}, \eta_s = \frac{\varepsilon_s}{\varepsilon_e} = 3\sigma_{ci}^{-0.25}, \eta_f = \frac{\varepsilon_f}{\varepsilon_e} = 5\sigma_{ci}^{-0.32} \tag{10}$$

where, ε_e is the elastic strain limit, ε_p is the strain level at the peak of the stress-strain curve, ε_s and ε_f are the post-peak strain levels as described in **Fig. 6**. They described the following necessary conditions for SGC:

The uniaxial compressive strength of the intact rock (σ_{ci}) to the overburden pressure (γH) should be less than 2.

The tangential strain of the tunnel wall should be greater than 1%.

The porosity of rocks is an important factor than their water content regarding the squeezing potential of rocks. This is because an increase in porosity weakens the rock's mechanical resistances. Although the water content is not directly involved, it had been observed that the water content of the squeezing rocks was more than 25% in this particular study.

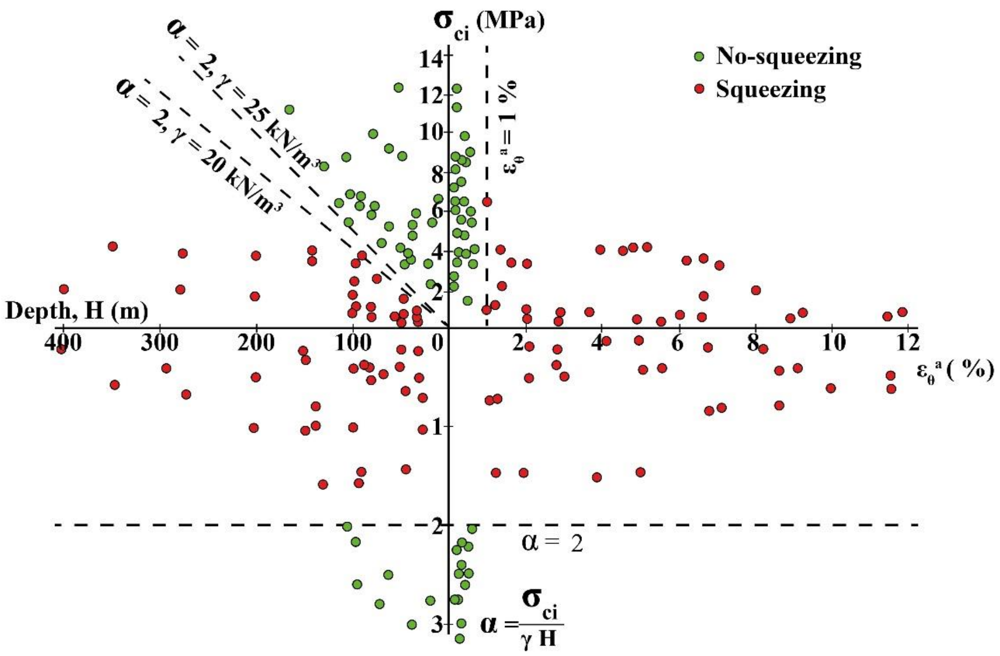

Fig. 5. Approach for predicting squeezing conditions (modified after Aydan et al., 1993). The dots represent data of surveyed tunnels.

There is a similarity between the axial stress-strain curve of intact rock samples and the tangential stress-strain response of rock adjacent to the tunnel boundary. Aydan et al. (1993) concluded from their experimental study that there are five distinct states of rock samples during a compression test which can be associated with squeezing rocks (Fig. 6).

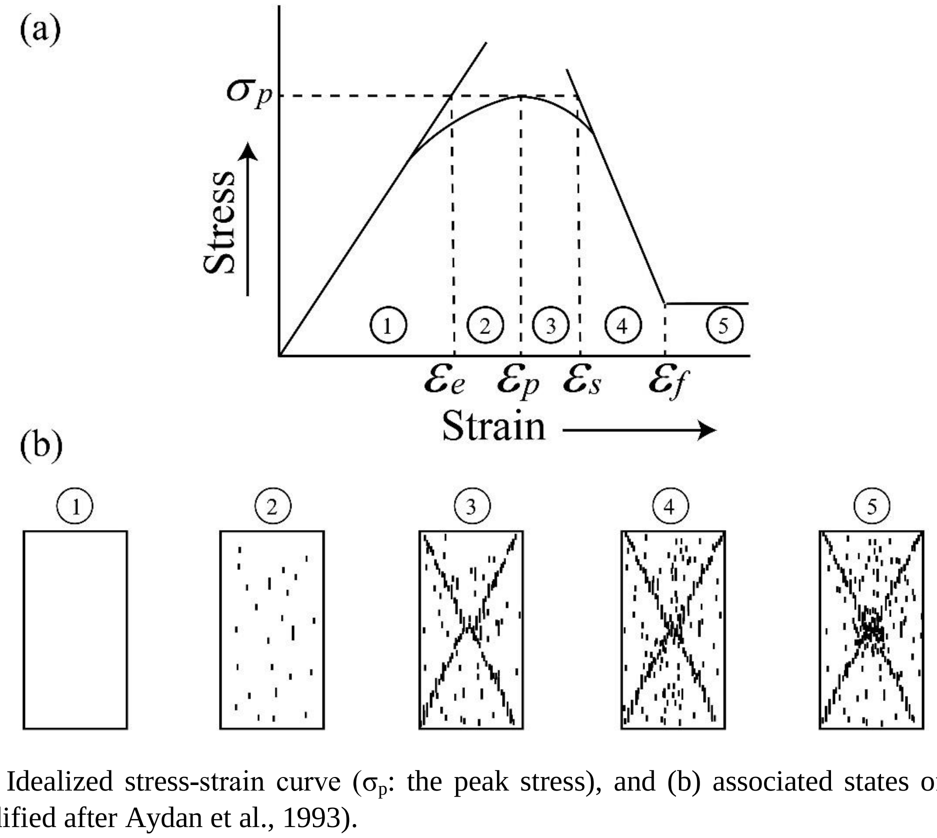

Fig. 6. (a) Idealized stress-strain curve (σ_p: the peak stress), and (b) associated states of squeezing rocks (modified after Aydan et al., 1993).

These five conditions are described as follows: 1. Elastic state: no-cracking is visible and the rock behaves almost linearly. 2. Hardening state: non-linear behavior, microcracking starts to occur and the orientations of microcracks generally coincide with the σ_1 direction. 3. Yielding state: post-peak stress-strain curve, micro-cracks tend to superimpose to initiate macro-cracks. 4. Weakening state: initiated macro-cracks grow and align in the most critical orientations. 5. Flowing state: micro-cracks along the most critical orientations completely coalesce and constitute sliding planes, and fractured material flows along these planes. The first three states may be referred to as microscopic stages followed by the remaining two macroscopic states.

Barla (1995b) presented a semi-empirical correlation to predict SGC using parameters like UCS of the rock mass (σ_{rm}), unit weight of the rock (γ), and H. As proposed by him, squeezing will only occur if

$$\frac{\sigma_{rm}}{\gamma H} \leq 1.0$$

As apparent from the existing literature, researchers attempted to quantify the limiting value of tunnel boundary deformation for squeezing grounds. The degree of squeezing can be represented by tunnel strain as indicated in (Table 5).

Table 5 Classification of squeezing grounds

Reference	**Squeezing level**	**Tunnel strain (%)**
(B. Singh et al., 1995)	Mild or minor squeezing	1–3 %
	Moderate or severe squeezing	3–5 %
	High or very severe squeezing	>5 %
(O. Aydan et al., 1993)#	Non-squeezing (NS)	$\varepsilon_\theta^a / \varepsilon_\theta^e \leq 1$
	Light-squeezing (LS)	$1 < \varepsilon_\theta^a / \varepsilon_\theta^e \leq \eta_p$
	Fair-squeezing (FS)	$\eta_p < \varepsilon_\theta^a / \varepsilon_\theta^e \leq \eta_s$
	Heavy-squeezing (HS)	$\eta_s < \varepsilon_\theta^a / \varepsilon_\theta^e \leq \eta_f$
	Very heavy-squeezing (VHS)	$\eta_f < \varepsilon_\theta^a / \varepsilon_\theta^e$
Hoek (2001, 1999) (Fig. 8)	Few support problems	<1 %
	Minor squeezing problems	1 - 2.5 %
	Severe squeezing problems	2.5 -5 %
	Severe squeezing problems	5 -10 %
	Extreme squeezing problems	>10 %

The tangential strain at the tunnel wall (ε_θ^a), and elastic strain limit for the rock mass (ε_θ^e) can be obtained by the following expressions:

$$\varepsilon_\theta^a = \frac{1+v}{E_i}(P_o - P_i) \tag{11}$$

$$\varepsilon_{\theta}^{e} = \frac{1+v}{E_i}\left(\frac{\sigma_{ci}}{2}\right) \tag{12}$$

where, E_i and v are elastic modulus and Poisson's ratio of the intact rock, respectively, P_i is the internal support pressure, and P_o is the *in situ* stress.

Hoek (1999) reported that the ratio of the uniaxial compressive strength of the rock mass (σ_{rm}) to the in situ stress (P_o) can be used as an indicator of tunnel convergence. They proposed an empirical relation for predicting tunnel squeezing based on these two parameters:

$$tunnel\ strain\,(\varepsilon) = \frac{\delta_i}{d_0} = \left(0.002 - 0.0025\frac{P_i}{P_0}\right)\left(\frac{\sigma_{rm}}{P_0}\right)^{\left(2.4\frac{P_i}{P_0}-2\right)} \tag{13}$$

where δ_i is the tunnel sidewall deformation, d_o is the original tunnel diameter in m. The parameter σ_{rm} can be expressed by the following expression

$$\sigma_{rm} = \left(0.0034 m_i^{0.8}\right)\sigma_{ci}\left\{1.029 + 0.025 e^{(0.1 m_i)}\right\}^{GSI} \tag{14}$$

Here, *GSI* is the Geological Strength Index and m_i is the material constant. The parameter P_i can be determined from the Q and RMR value of the rock mass. Barton et al. (1974) suggested that the relationship between Q and the permanent roof support pressure can be estimated from the following expression (when the no. of joint set > 3):

$$P_i = \left(\frac{0.2}{J_r}\right) Q^{-1/3} \tag{15}$$

Simillarly, Goel et al. (1995) suggested an empirical expression for predicting SGC in tunnels with a depth of >50 (m) using RMR:

$$P_i = (7.5 B^{0.1} \times H^{0.5} - RMR) / 20 RMR \tag{16}$$

If there is no support system provided to the tunnel after excavation (i.e. $P_i = 0$), equation (13 changes to equation 17 (Hoek & Marinos, 2000) (**Fig. 7**) as given below:

$$\varepsilon = 100 \times \left(0.002\right)\left(\frac{\sigma_{rm}}{P_0}\right)^{-2} \tag{17}$$

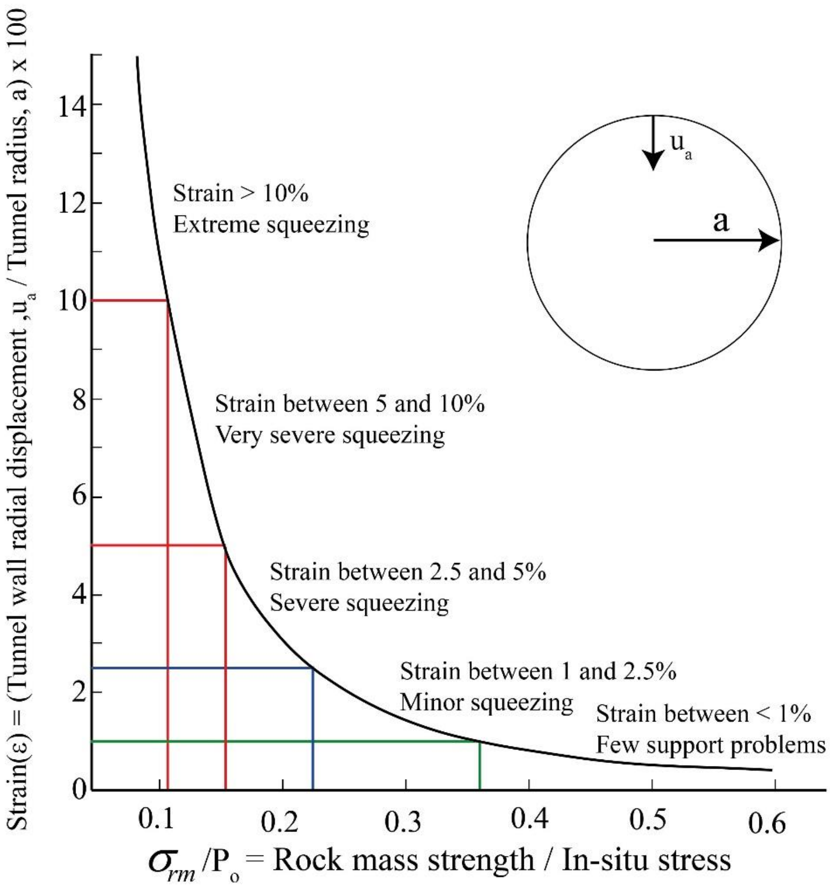

Fig. 7. Tunnel strain against ratio of rock mass strength to in situ stress (modified after Hoek, 2001).

Although these methods give a useful indication of tunnel convergence, they should not be considered adequate for final design purposes. Because these are simple closed-form solution for a circular tunnel in a uniform hydrostatic stress field (Hoek & Marinos, 2000). In this regard, the assumptions like homogenous and isotropic rock material, 2D plane strain condition with no displacement along the tunnel axis, uniform radial support pressure for the support system etc. seem to be far from the reality.

MEASUREMENT OF BOUNDARY DEFORMATION

The tunnel closure gives a good indication of probable damage to the rock mass and associated construction problems. So, it is very useful as well as important to determine the final converged displacement and the range of the final loosening zone in the planning and designing of a tunnel. Labasse (1949) introduced the idea of "*zone of broken rock mass*", where the broken rock around the tunnel opening is under a constant volumetric expansion due to the creation and propagation of new fractures (**Fig. 8**).

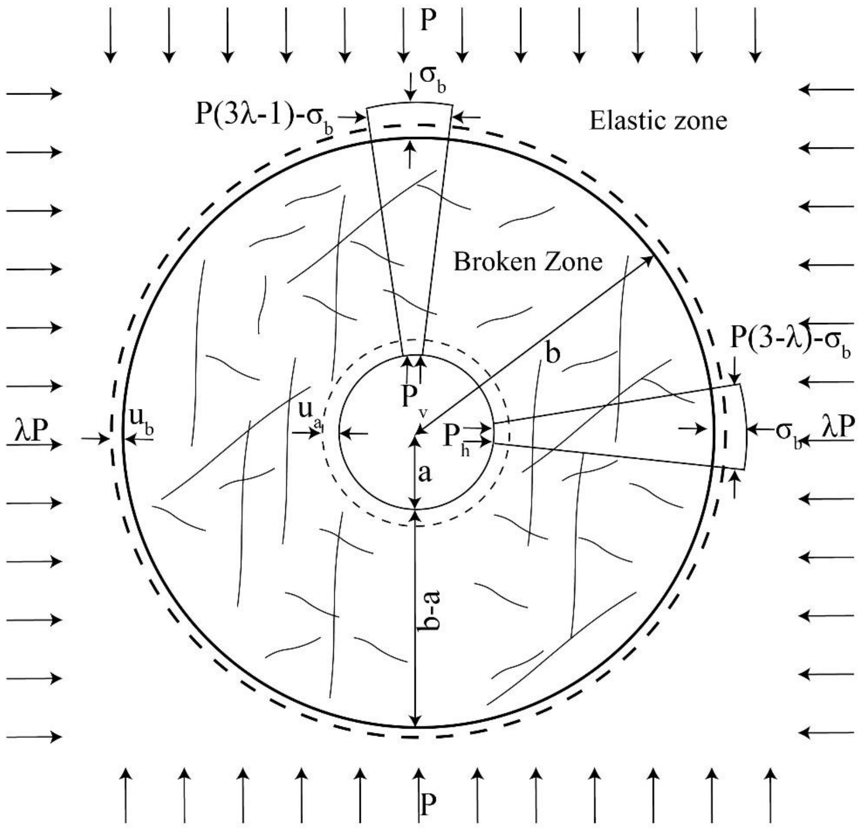

Fig. 8. Schematic diagram of the broken zone around a tunnel opening (modified after Dube et al., 1986). Here, λ is the ratio of the average horizontal (primitive) stress and vertical primitive stress, P is the maximum primitive stress, P_v is the vertical rock pressure, P_h is the horizontal rock pressure, σ_b is the stress on the tunnel due to the broken zone of radius b.

The coefficient of volumetric expansion (*k*) within the broken zone was expressed by the following equation:

$$k = \frac{2\left(au_a - bu_b\right)}{\left(b^2 - a^2\right)} \tag{18}$$

where, *a* & *b* = radius of tunnel opening and broken zone, respectively, u_a = tunnel wall displacement at the periphery of the opening, u_b = tunnel wall displacement at the boundary of the broken zone. For the calculation of local variations of *k* in the broken zone, the equation (18) can be generalized as:

$$k_{1,2} = \frac{2\left(r_1 u_{r1} - r_2 u_{r2}\right)}{\left(r_2^2 - r_1^1\right)} \tag{19}$$

where, $k_{1,2}$ = co-efficient of volumetric expansion within the annular zone between r_l and r_2, r_l & r_2 = smaller and larger radius of annular zone, respectively, and u_{r1} & u_{r2} = radial displacement at r_l and r_2, respectively,

Daemen and Fairhust (1972) proposed the analytical solution for outer boundary displacements (u_b) at the broken zone for the hydrostatic stress field by the following expression:

$$u_b = \frac{1-\upsilon}{E}\left(P\sin\varphi_p + c_p\cos\varphi_p\right) \quad (20)$$

where, E = Young's modulus of rock mass and υ = Poisson's ratio of the rock mass, P = maximum primitive stress, c_p = peak cohesion of intact rock, φ_p = angle of internal friction of intact rock.

Dube et al. (1986) presented the following expression for tunnel wall displacement from his elastoplastic stress analysis:

$$u_a = \frac{k\left(b^2 - a^2\right) + 2bu_b}{2a} \quad (21)$$

Kitagawa et al. (1991) also presented the conventional constitutive equation to predict tunnel displacement in elastic condition, using Young's modulus and Poisson's ratio of the rock:

$$u_a = \frac{1+v}{E_i}(P_o - P_i)a \quad (22)$$

Singh et al. (2007) provided a rational classification of squeezing potential in tunnels based on the "*Squeezing Index (SI)*". The SI (ratio of actual strain to the critical strain) defines the likelihood of squeezing or the occurrence of probable problems during construction. The SI may be defined as:

$$SI = \frac{Observed\ or\ expected\ strain}{Critical\ strain} = \frac{u_a / a}{\varepsilon_{cr}} \quad (23)$$

where, u_a is the radial closure and a is the radius of the opening. Also, the critical strain (ε_{cr}) may be obtained as:

Singh et al. (1997)

$$\varepsilon_{cr} = 31.1\frac{\sigma_{ci}^{1.6}}{E_i\rho^{0.6}Q^{0.2}}(\%) \quad (24)$$

Barton (2002)

$$\varepsilon_{cr} = 5.84\frac{\sigma_{ci}^{0.88}}{Q^{0.12}E_i^{0.63}}(\%) \quad (25)$$

where, E_i is the tangent modulus of the intact rock (MPa) and ρ is the density of rock mass in gm/cc.

It should be noted, the equations presented above, where deformation modulus is used as a parameter to predict squeezing, an important factor like the increase of modulus with depth is not considered by many researchers. In other words, although the deformation modulus is used to determine the tunnel strain, the adjustment factor for depth while calculating the modulus does not seem to have been considered.

MITIGATION MEASURES OF SQUEEZING FAILURE

In this section, an attempt is made to discuss all the major contributions of previous researchers regarding their innovative design of the flexible support systems in chronological order. While designing a tunnel, one of the most interesting subjects is to see the effects of interaction between rock mass and their applied support system. Therefore, it becomes extremely important to calculate the tunnel deformation, estimate the extension of the loosening zone around the tunnel, the required support pressure, and support stiffness.

In general, the controlling principle of rock mass deformation should be fixed based on a complete understanding of the geology and the physical and mechanical properties of the intact rock block/rock mass. The highly stressed squeezing rock may cause serious stability problems. Hence, the applied support used under such conditions should be able to carry these high loads and also able to accommodate large deformation without suffering severe damage. While designing the support system, one has to be aware of the fact that the rock squeezing can not be exactly predicted (Sharma et al., 2020). To avoid the squeezing ground condition, the designers may either realign the tunnel to reduce the cover or make it pass through a rock mass having a higher RMR or Q value. For soft rock tunnels, under high in situ stress, the support resistance subjected to stress release may cause the rock mass reach its yield strength quickly and can make the tunnel unstable. Therefore, the rock mass deformation should be controlled by support systems that can accommodate the stress release. If primary support is used, it needs to be strengthened so that large deformations cannot cause failure, cracking, and bending of the primary support.

If deformation of the rock mass surrounding a tunnel is restrained, the squeezing is superimposed on rock failure mechanisms which ultimately leads to long-term increase of load on the tunnel lining. If there is a delay in support installation, the rock mass may move into the tunnel allowing stress redistribution with the development of the plastic zone and load reduction on the impending tunnel lining. Therefore, there is a complex interaction between rock deformation, plastic zone development, creep effects, the time of tunnel support installation, and the capacity of the tunnel support (lining, bolt, shotcrete, etc.) (Swannell et al., 2016).

The support system used to mitigate the highly squeezed rock mass can be broadly classified into two types, i.e. (a) flexible support system and (b) heavy or rigid support system (Dalgiç, 2002). The flexible support can be achieved through a variety of techniques or a combination of two or more support mechanisms. For example, it includes the over-excavation, longitudinal compression slots (or gaps) in the shotcrete lining, yielding rock bolts, flexible support, sliding joints in steel sets, etc. However, the tunnel designer should also consider the strategical usefulness of the individual elements. For example, a shotcrete lining delivers surface support, the steel ribs provide line support and rock bolts are effective in point support to hold the jointed rock blocks (Kovári & Staus, 1996). In some cases, where the deformation is extremely high, the flexible support systems may not be effective. In that scenario, heavy approaches can be adopted to limit the deformation of the rock by using a strong support/lining system. For example, the Bernold method and the abutment drift method are common heavy approach methods.

Schubert (1996) first applied yielding steel elements to reduce the effect of stress concentrations of the stiffer rock portions around the tunnel boundary. The steel pipes (energy absorbing elements) were installed in the gaps between the shotcrete segments to maintain an adequate ductility and to avoid shearing of shotcretes. This further improved the efficiency of the shotcrete lining (**Fig. 9**). The load-deformation curve of 100 mm diameter steel pipe showed that with increasing deformation, the load varied between 100 kN and 250 kN, subjected to the state of buckling. The application of this yield element turned out to be extremely encouraging in the tunnel support design for squeezing rock mass.

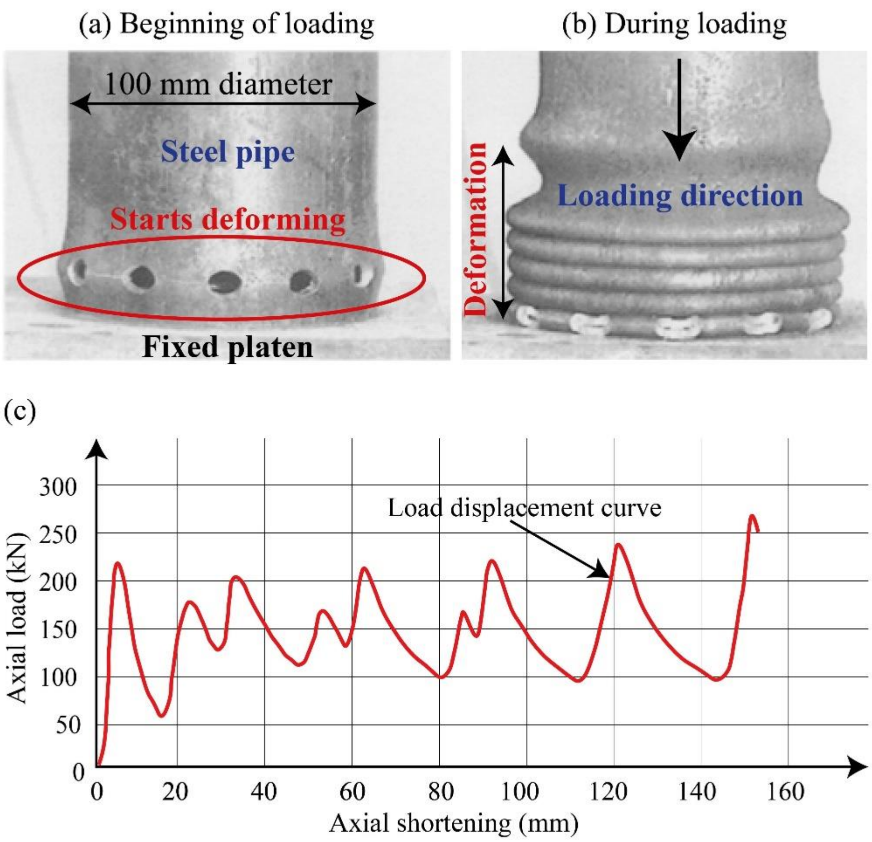

Fig. 9. Yielding steel elements in the laboratory test: (a) beginning of loading, and (b) during loading; and (c) load-displacement curve of the yielding element (modified after Schubert, 1996).

Hoek (1998) suggested the idea of a sliding joint steel rib support system for very heavy squeezing conditions (**Fig. 10**). Two or three of these yielding elements were merged in each steel rib segment and were set to slide a pre-determined distance, depending upon the amount of closure to be permitted, before encountering a positive stop welded onto the rib.

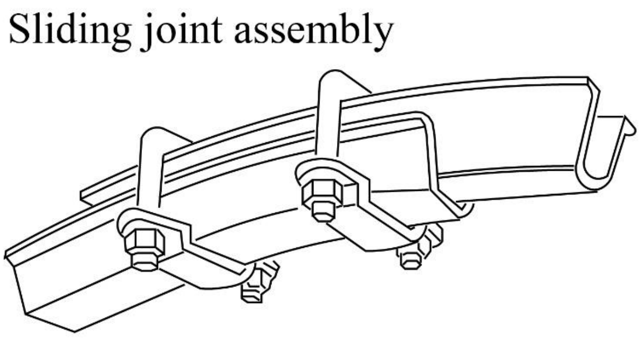

Fig. 10. Assembly of a sliding joint in a Toussaint- Heintzmann or Top Hat section steel rib (modified after Hoek, 1998).

Schubert and Moritz (1998) suggested the application of the lining stress controller (LSC) element, which consists of multiple steel pipes in a concentric assembly to prevent brittle failure in the steel set and sprayed concrete or shotcrete. It can absorb large deformations occur during tunnel driving in weak ground. LSC steel elements are installed into these deformation joints as shown in

Fig. 11. The elements have a defined workload during compression so that the primary lining is not damaged.

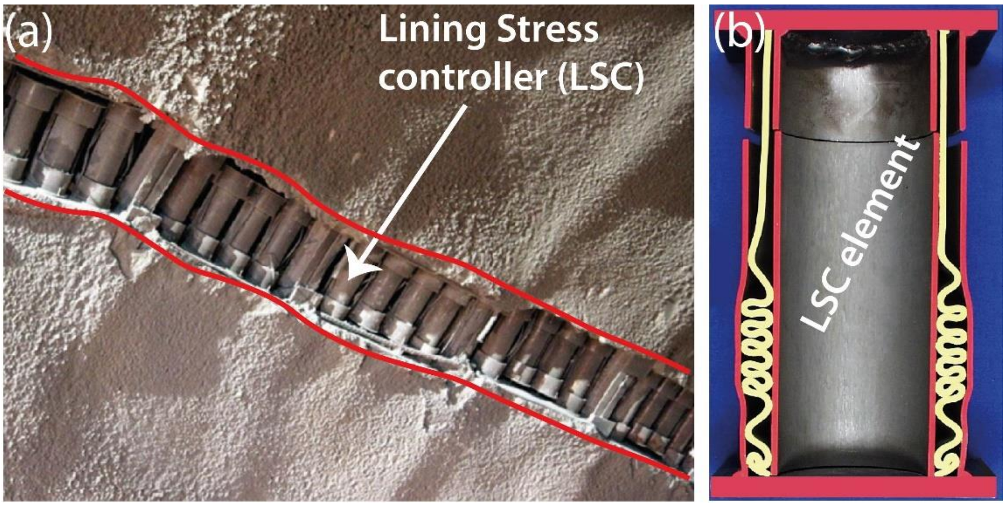

Fig. 11. (a) A row of lining stress controller (LSC) installed in a slot in the shotcrete, and (b) its cross-section details (modified after Yokota et al., 2020).

Cantieni and Anagnostou (2009) recommended two basic yielding support options i.e. a) radially deformable support (which allows radial rock deformations) and b) tangentially deformable lining support (which allows deformations in the circumference) (**Fig. 12**). The sliding joint assembly of Hoek (1998) is an example of tangentially deformable lining support system. This type of deformable support can be installed to withstand the large convergences inside the tunnel opening.

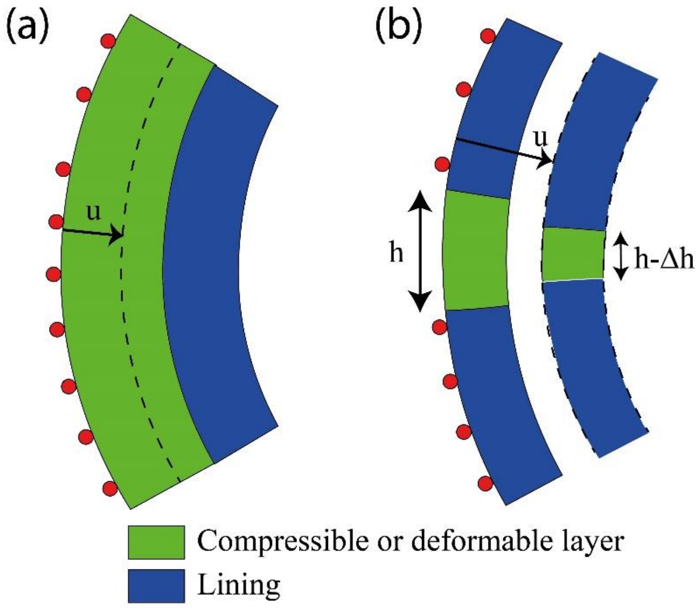

Fig. 12. (a) Radially deformable and (b) tangentially yielding supports (h: initial gap and Δh: deformation value) (modified after Cantieni and Anagnostou, 2009).

The radially deformable element (RDE) comprises a compressible layer between the lining and excavation boundary. On the other hand, the tangentially deformable element (TDE) comprises special yielding supports with steel sets, shotcrete and compressible layers. This could also be implemented in shield tunnelling by arranging compressible elements in the longitudinal joints of the segments (Cantieni & Anagnostou, 2009).

To control large tunnel deformations due to SGC, the rock bolts are also used. In general, rock bolts reinforce the loose rock at the excavation surface by linking them into the stronger host rock (D. Li et al., 2017; Thenevin et al., 2017). In case of jointed rock mass, the pre-tension in the rockbolt increases the shear strength of joints by creating a unifrom zone of compression in the damaged zone around the excavation. However, the rock bolts used for SGC should meet the requirements of both strength capacity and deformability. For that, energy-absorbing rock bolts, such as D bolt (with a very unique and innovative rib profile), are very common as well as successful in the deep underground tunnels to avoid sudden failure (C. C. Li, 2010). The D bolt has large load-bearing and deformation capacities (**Fig. 13**). The static pull tests and dynamic drop tests show that the bolt length elongates by 14–20% at the highest strength of the bolt, thus absorbs a large amount of energy (cumulative dynamic energy absorption = 47 kJ/m). Moreover, the average impact load of a 20 mm (diameter) D bolt is 200–230 kN. The results of the study carried out by Li and Doucet (2012) suggest that the displacement of the D bolt increases linearly with the increase in the impact energy. They noted that the energy absorption of a D bolt section is directly proportional to the volume of the bolt section, ultimate strain, and the tensile strength of the bolt material. Cao et al. (2013) also reported that the rock bolt rib profiles have a significant impact on the performance of the bolt. Though the D bolt has a high absorbing capacity, the fully grouted rock bolts are widely used in case of SGC (Yokota et al., 2020).

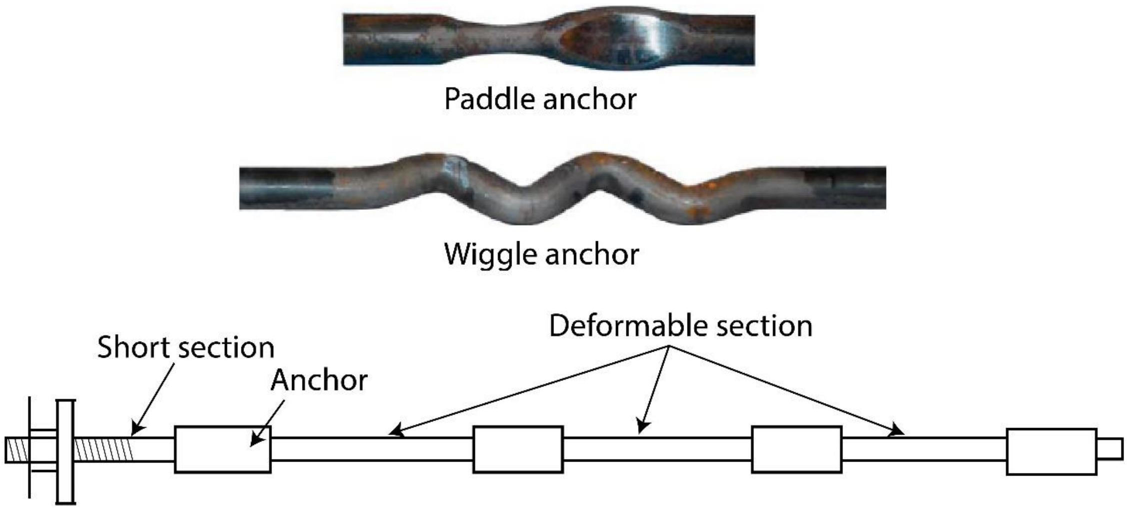

Fig. 13. Layout of the paddle anchor, wiggle anchor, and schematic diagram of D bolt. (modified after Li, 2010).

Barla et al. (2011) successfully adopted highly deformable concrete elements in the tunnel lining for projects using conventional excavation methods. They presented a case study of a tunnel excavated in a Carboniferous Formation for the Lyon-Turin rail line project, excavated between the portals in Italy and France. As shown in **Fig. 14**, the “Highly deformable concrete (HiDCon) elements” have a beam shape and are installed in between the TH steel ribs, firmly incorporated in the mesh reinforced shotcrete lining, while allowing the ribs to slide freely. It was succesfully tested in the Lyon-Turin railway tunnel project. The new HiDCon is composed of a mixture of steel fibers, cement, and hollow glass particles. The glass particles increase the void fraction of the mixture and collapse at predetermined compressive stress (**Fig. 14**). This was a very innovative and effective method to accommodate the rock mass convergence during tunnel construction.

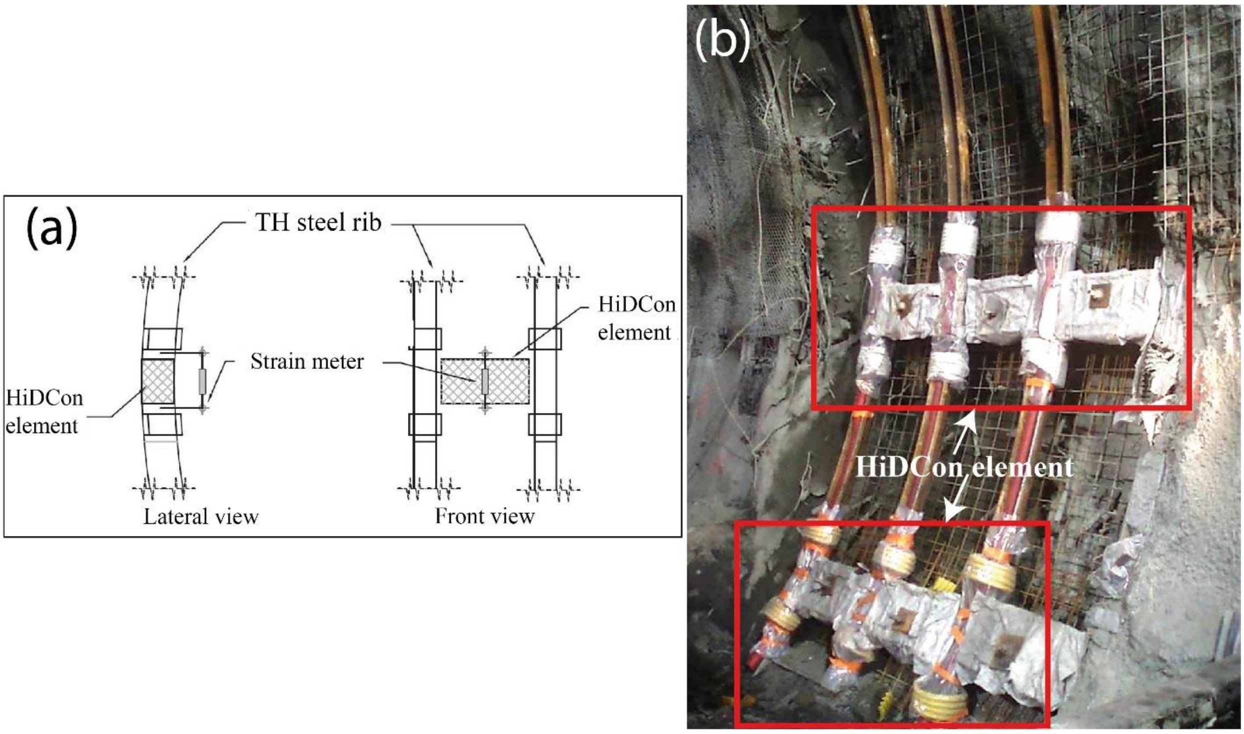

Fig. 14. (a) HiDCon elements installed in lining with special monitoring section, and (b) HiDCon elements during installation in between TH steel ribs (before placement of shotcrete) (modified after Barla et al., 2011).

Wang et al. (2013) introduced a specially designed energy-absorbing rock bolt that can accommodate large squeezing pressure in the rock without any damage. From the design perspective, this bolt is different from D bolts as proposed by Li (2010). The bolt comprises a smooth steel bar with an anchor at the bottom end. The anchor is fixed with grouting within a borehole and the smooth part of the bolt inserted in the anchor can slide in response to rock movement (squeezing) once the load exceeds the pre-set limit (**Fig. 15**). The static pull tests on these bolts show, it can absorb a large amount of energy to maintain the stability of surrounding rock by elongating to any expected length at a high load level. A similar pull-out test performed by Thenevin et al. (2017) also reveals that the dilational slip of rock bolt, the shearing slip between the grout and plain section of rock bolt and the cohesion at the grout to rock bolt interface can be considered as the major resisting contributors to the axial load.

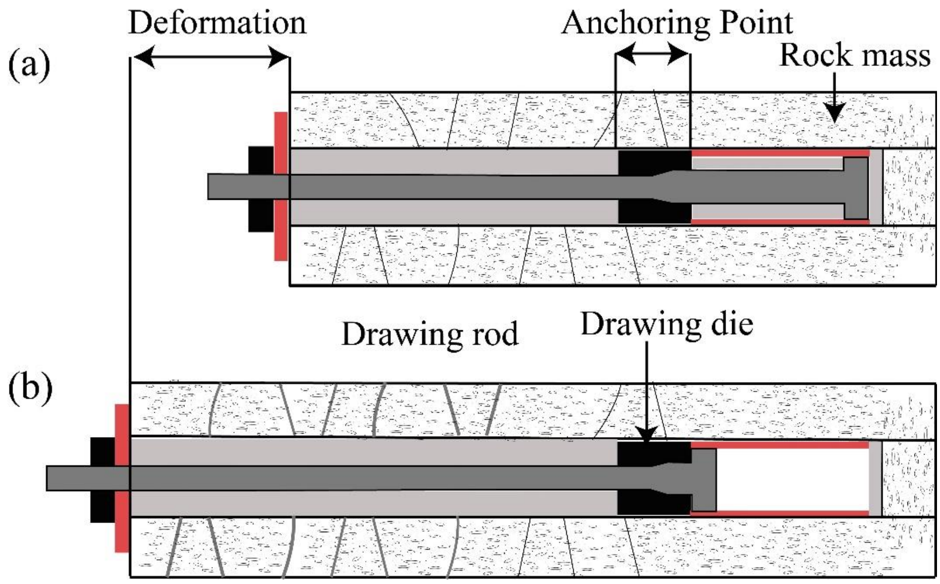

Fig. 15. Illustration of the bolt: (a) after installation, and (b) after rock dilation. (modified after Wang et al., 2013).

Xu et al. (2017) observed the major damage of the Jinpingyan tunnel (Chengdu-Lanzhou, located adjacent to Songpan town of Aba plateaus, Sichuan Province, China). The rock mass primarily composed of weathered phyllite surrounding the tunnel was unstable and underwent large deformation during construction leading to local collapses of the tunnel. In order to mitigate the damage, Xu et al. (2017) designed a new type of support system made up of grid steel frame-core tube. This includes a grid steel frame-core tube support structure, with three A elements, two B elements, two C elements, two D elements, and three E elements (**Fig. 16**). For A, B, and C elements, the outside structure was made up of flexible steel grating, splay structural bar, while steel core tubes were placed at the center. To accommodate the tunnel convergence, the individual elements (A, B, and C) were coupled together with steel sleeves cushioned with a rubber blanket. I-beam was used as D and E elements to increase the lateral strength. Xu et al. (2017) reported that their support system was much more effective than the traditional support system in controlling large deformation of surrounding rocks. One thing to note here is that the shotcrete behaves like a brittle material with high stiffness and less tensile strength. For this reason, the shotcrete may be incompatible with the deformation properties of the steel frame core element. The applied shotcrete lining may fail even for a small eccentricity of the normal force due to the non-uniform distribution of the rock pressure (if present) around the tunnel. This non-uniform stress distribution around the tunnel may occur due to several factors such as anisotropic strength and deformation properties of the rock layers, inhomogeneities in the vicinity of the opening, dissimilar initial vertical and horizontal stresses, etc.

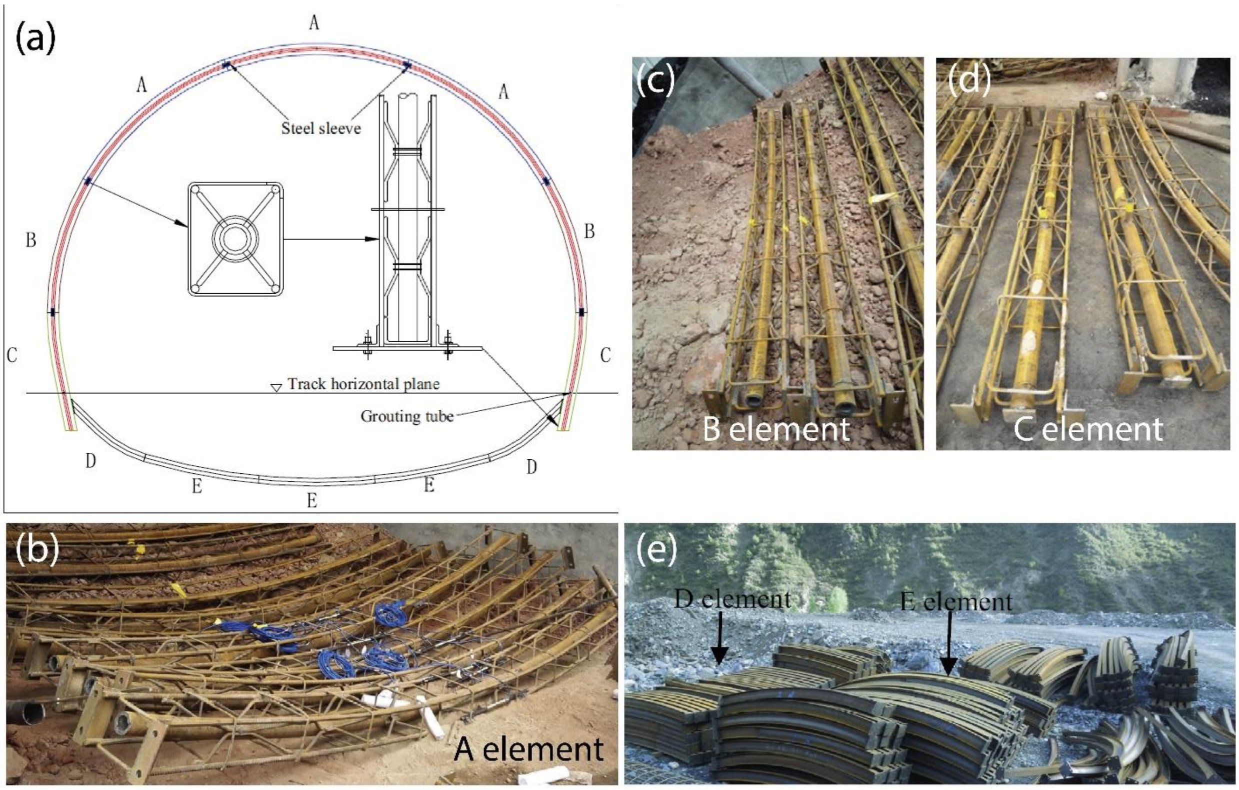

Fig. 16. (a) Schematic diagram of a new type support structure, (b) A element, (c) B element, (d) C element, (e) D and E elements (modified after Xu et al., 2017).

Cao et al. (2018) presented a case of Laodongshan tunnel as a part of Guangtong-Kunming railway in China. They effectively controlled the squeezing failure using L-shaped and U-shaped steel assemblies along with other support measures such as grouting reinforcement, improvement of support stiffness, early closure of the tunnel ring, and timely installation of secondary linings (Fig. 17). The L-shaped and U-shaped steel assembly solved the problem of insufficient welding and improved the effect of the connection between lock-feet bolts and steel frames.

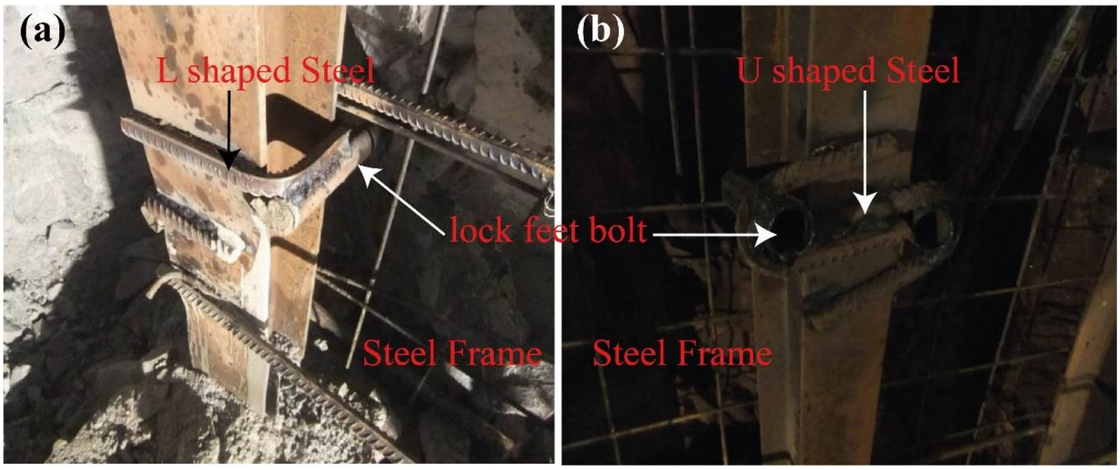

Fig. 17. (a) L-shaped and (b) U-shaped steel assembly (modified after Cao et al., 2018).

Yokota et al. (2020) proposed a new type of energy-absorbing deformation-controlled rock bolt (DC-bolt). This has a high loading and deformation capacity. These bolts are capable of controlling the rock displacement by the specially designed rock bolt anchor. The DC-bolt has four elements, i.e. (1) a smooth bar, (2) a threaded bar, (3) an end anchor (diameter > smooth bar), and (4) a ring which does not attach to the smooth bar as shown in **Fig. 18** (a). The elements help reproduce the tri-linear deformation behavior (**Fig. 18** (b)).

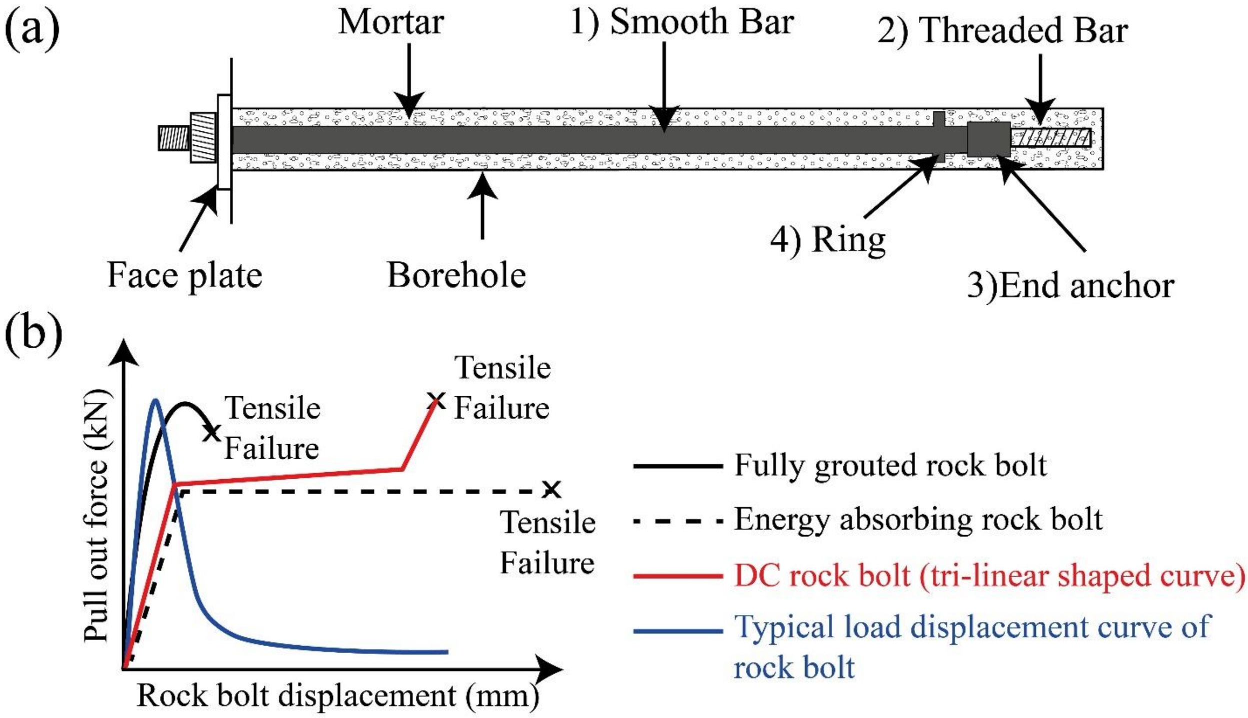

Fig. 18. (a) Illustration of deformation-controlled rock bolt; and (b) comparison of load-displacement curves of different bolts (modified after Yokota et al., 2020).

Similarly, based on the existing energy-absorbing devices, Zhao et al. (2020) recently proposed a new energy-absorbing rock bolt called "compression-expansion-friction bolt (CEF bolt)" having a tube of variable-diameter and a hollow cone attached at the distal end of the bolt. This bolt can provide controllable constant resistance to the rock mass and it is also very effective in dealing with large deformation around the tunnel boundary.

It has been observed that stress redistribution takes place around the tunnel if the support installation is delayed and consequently, the rock mass converges into the tunnel. On the other hand, if the deformation is reserved, squeezing will lead to long-term load accumulation on the support system. In view of this, the authors opine that the first situation can be taken care of by over-excavating the rock mass beyond the designed periphery and the second circumstance can be controlled by using a combination of flexible support systems.

SUMMARY AND CONCLUSIONS

Squeezing is a physical process and involves the dilatant behavior of rocks. Squeezing ground conditions are influenced by several factors like rock-type (lithology), rock mass strength, the attitude of the rock discontinuities, state of stresses, construction procedures, water condition, applied support systems, etc. These factors do not, however, have the same degree of influence (Steiner, 1996). This unique problem is experienced by rock engineers while excavating tunnels through very poor-quality rock masses under high rock overburden. Therefore, to design stable support system, the prediction of SGC is essential.

Several researchers proposed empirical and semi-empirical methods for the prediction and classification of SGC. The tunnel closure measurement provides a good indication of probable damage to the rock mass and associated construction problems. In the literature, the value of critical strain is generally taken as 1%. The equations used to measure this boundary displacement were extracted from the literature and presented in the chronological order in this paper.

To mitigate the squeezing problem, designers proposed several innovative support system solutions (

Table **6**). Different support systems respond differently. Sometimes, a minimal support pressure is effective to stabilize the rock mass in non-squeezing ground conditions while in case of squeezing ground, a combination of deformable/ductile steel sets with shotcrete may deliver much higher support pressure than a dense pattern of rock bolts. In literature as well as in practice, the support system approach used to mitigate the highly squeezed rock mass can be broadly classified into two types: (i) flexible support system and (ii) heavy or rigid support system. The ‘flexible support system’, based on the estimates of the amount of deformation is required to reduce the rock load. There are two conceptual options for applying the flexible support system: (a) a yielding lining in contact with the excavation boundary or (b) a compressible layer between the extrados of a relatively stiff lining and the excavation boundary. On the other hand, the ‘rigid support system’, is a rigid lining designed to sustain the expected rock load.

The flexible support system includes over-excavation, longitudinal compression slots (or gaps) in the shotcrete lining, yielding rock bolts, flexible support, sliding joints in steel sets, etc. During over-excavation, the tunnel is excavated to a size, which accommodates the convergence and support installation, including the inner lining. The flexible lining may provide both (a) radially deformable support (which allows radial rock deformations) and b) tangentially deformable lining support (which allows deformations with regard to the circumference). The radially deformable support may include a compressible layer between the excavation boundary and the extrados of a stiff lining that will allow a reduction in its circumference (Cantieni & Anagnostou, 2009). The yielding steel element of Schubert (1996), sliding joint assembly of Hoek (1998), HiDCon elements between the TH steel ribs of Barla et al. (2011), new support system of grid steel frame-core tube of Xu et al. (2017) and L-shaped and U-shaped steel assembly of Cao et al. (2018) are some successful examples of tangentially deformable lining support.

The increasing interest in the use of rock bolt support systems has an economic significance. In comparison with other support systems, this system is less time and material consuming as well as technically more viable. Various energy-absorbing rock bolts designed by Li (2010), Wang et al. (2013), Zhao et al. (2020) and Yokota et al. (2020) are quite efficient in dealing with squeezing rocks. All of these bolt types have some inherent advantages. The displacement of the D bolt designed by Li (2010) is linearly related to the impact energy when subjected to a dynamic load. Its energy absorption capacity is directly proportional to the volume of the bolt section, bolt tensile strength, and ultimate strain of the bolt material. The bolt with varying diameter designed by Wang et al. (2013) has got a high energy absorption capacity compared to other types of yieldable rock bolts. Similarly, the “compression-expansion-friction bolt” (CEF bolt) of Zhao et al. (2020) is capable of providing controllable constant resistance to the rock mass and it is also very effective in dealing with large deformation around the tunnel boundary. The DC bolt designed by Yokota et al. (2020) can withstand a large deformation without rupturing.

Table 6 A summary of flexible support system design for squeezing rock mass

References	Support characteristics	Advantages
Over-excavation technique		
(Dalgiç, 2002)	Tunnel excavation radius considered larger than original design radius. Accommodating deformations.	Less damage to support systems.
Flexible lining		
(Schubert, 1996)	**Yielding Steel element** 100mm diameter steel pipe. An array of multiple steel pipes installed in gaps between shotcrete segments.	Considerable reduction in deformation within area of excavation. Prevention of shearing of shotcrete
(Hoek, 1998)	**(b) Sliding joint assembly** Two or three of these yielding elements merged in each steel rib segment and set to slide a pre-determined distance.	Useful for very heavy squeezing conditions.
(Schubert & Moritz, 1998)	**(c) Lining stress controller (LSC)** Comprised of multiple steel pipes in a concentric assembly	Prevention of brittle failure in steel set and sprayed concrete
(Cantieni & Anagnostou, 2009)	**(d) Radially deformable element and tangentially deformable lining support** Radially deformable element (RDE) comprising a compressible layer between lining and excavation boundary. Tangentially deformable element (TDE) incorporating special yielding supports with steel sets, shotcrete, and compressible insets.	Withstanding large convergences inside tunnel opening. Implementable in shield tunnelling by arranging compressible elements in longitudinal joints of segments.
(Barla et al., 2011)	**(e) HiDCon elements** Highly deformable concrete (HiDCon) elements. Beam shaped elements and installed between TH steel ribs. Firmly incorporated in mesh reinforced shotcrete lining. Allowance for ribs to slide freely. Mixture of steel fibers, cement, and hollow glass particles.	Void fraction of the mixture increased by glass particles and collapse of particles at predetermined compressive stress. Effective method to accommodate huge rock mass deformation.

(Xu et al., 2017)	**(f) Support system of grid steel frame-core tube** Grid steel frame-core tube support structure. Three A elements, two B elements, two C elements, two D elements, and three E elements. For A, B, and C elements, outside structure made up of flexible steel grating, splay structural bar, while core tubes placed at centre. I-beam used as D and E elements to increase lateral strength. Individual elements (A, B, and C) coupled together with steel sleeves cushioned with rubber blanket to accommodate tunnel convergence.	Substantial control of large deformation as compared to traditional support systems. Less time requirement for assembly or erection of steel ribs No fracture of the shotcrete lining.
Cao et al. (2018)	**(g) L-shaped and U-shaped steel assembly** Lock feet bolts attached in both L- and U-shaped steel assemblies.	Effective in controlling squeezing failure. Efficient in solving problem of insufficient welding. Capable of improving effect of connection between lock-feet bolts and steel frames.
Yielding rock bolts		
Li (2010)	**D bolt** A kind of energy-absorbing rock bolts. Required strength capacity and deformability. Very unique and innovative rib profile. Large load-bearing and deformation capacities. Linear increase in displacement of D bolt with increase in impact energy	Significant impact of rock bolt rib profiles on bolt performance. Energy absorption of a D bolt section directly proportional to volume of bolt section, ultimate strain and tensile strength of bolt material
Wang et al. (2013)	**Specially designed energy-absorbing rock bolt** Bolt comprising smooth steel bar with anchor at bottom end. Anchor fixed with grouting within borehole and slidable smooth part of bolt inserted in anchor in response to rock movement.	Accommodation of large squeezing pressure in rock without any damage. Absorption of large amount of energy by elongation to any expected length at high load.
Yokota et al. (2020)	**DC-bolt** New type of energy-absorbing deformation-controlled rock bolt Bolt comprising of four elements, i.e. (1) smooth bar, (2) threaded bar, (3) end anchor (diameter > smooth bar), and (4) ring (not attached to smooth bar).	Capable of controlling rock displacement by specially designed rock bolt anchor. High loading and deformation capacities

To deal with large deformation problems, nowadays, all available modern support techniques are used. The over-excavation technique, flexible support, compressible layer between the excavation boundary and the stiff lining, longitudinal gaps in the shotcrete lining, and yielding rock bolts are commonly applied in combination. These mitigation methods are experimentally designed based on the squeezing ground conditions. Some of them are specific to site conditions. Therefore, further experimental research is needed to improve the existing practices and to develop new methods. It is also recommended, in case of a suspected occurrence of squeezing, the tunnel condition should be evaluated by numerical analysis using good 2D or 3D FEM/FDM/DEM programs based on detailed rock mass characteristics. This will enable rock engineers to estimate and mitigate tunnel squeezing phenomena more accurately to restrain deformations and minimize the cost of tunnelling.

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COMPETING INTERESTS

The authors declare no competing interests.

AUTHOR CONTRIBUTIONS

Ratan Das: Writing—original draft, conceptualization, methodology, visualization.

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Urban Flood and Mitigation Strategies: An Overview of Operation Anantha Scheme at Thiruvananthapuram City

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Abstract:

Floods are one of the major problems faced by Indian cities, among them urban flooding is most common. This happens due to the increasing trend of urbanization. During the last couple of decades frequent water logging tended to disturb regular activities of people in Thampanoor ward of Thiruvananthapuram district, Kerala. Severe flooding during 2015 drew Government attention and 'Operation Anantha' an inter-departmental urban flood mitigation programme was launched under the Disaster Management Act (2005) by Central Government. This was to improve the drainage system and reduce water accumulation in Thiruvananthapuram city. The first phase of this mitigation programme was undertaken and its short-term goals were accomplished. Therefore, a temporary solution to the water logging in Thampanoor was found. However due to technical issues the second phase of 'Operation Anantha' was unable to carry out. So today people here are experiencing water logging even during low rainfall. This adversely affects the daily life, health and sanitation of people. Thus, the aim of this research is to investigate the problem of water logging in Thampanoor ward and to prepare an overview of 'Operation Anantha' scheme implemented in the city. The primary data has been taken from field survey and secondary data has been collected from government reports and mass media. The study shows that the primary cause of water logging in the ward is urbanization, inadequacy, lack of maintenance of sewage systems and storm water drainage. In addition, restarting 'Operation Anantha ' will give a permanent solution to the water logging in Thampanoor ward.

Keywords:

Urban flood, Mitigation programme, Urbanization, Operation Anantha

INTRODUCTION

Flooding in the urban areas widely reported in most cities of India. It is mainly formed due to the proximity of the coast, location near the river or the influence of the monsoon. Due to urbanization open space and spill area are declining, making it impossible to store excess water due to monsoon. Urban flooding also occurs when rainfall falls on impervious surfaces such as roadways and other paved areas. Conversion of low-lying areas to build area, clogging of storm water drains by dumping of wastes, constructions above the storm water drains, filling up of lakes and ponds cause obstruction to the surface runoff and contribute to flooding. This has led to an increase in the risk of water logging in urban centers. Adequate practical solutions are needed to solve problems such as urban floods to create a sustainable environment in urban areas, which affects urban infrastructure, mobility, overall urban environment, and quality of life of its people.

During last couple of decades frequent flooding tended to disturb regular activities of urban dwellers in Thiruvananthapuram city. Urban flooding in Thiruvananthapuram occurs 3 to 6 times during monsoon with water depth of 0.6 to 1.2 meter, persists 2 to 24 hours in the central part and 3 to 4 days in the southern part of the city. No suitable mitigation measures were implemented successfully till to date. Hence precise assessment of flood prone area becomes a more vital demand in development planning. To reduce urban flooding, it is important first to identify flood prone areas and to construct drainages that are correctly arranged along the natural flow routes.

Severe water logging during 2015 drew Government attention and 'Operation Anantha' an inter-departmental urban flood mitigation programme was launched under the Disaster Management Act (2005), to improve the drainage system and reduce water accumulation. This project is to investigate water logging problem in the Thiruvananthapuram city, discusses the after result of 'Operation Anantha' and the subsequent water logging in the city of Thiruvananthapuram during the 2021 monsoon. In addition, the study also focuses on critical review of the 'Operation Anantha' programme and the disruptions to transportation systems, including railways and environmental pollution.

'OPERATION ANANTHA' AS A PREVENTIVE MEASURE

Thiruvananthapuram city particularly Thampanoor and East Fort areas face the problem of acute water logging since a very long time. There were several interventions, engineering programmes technical studies undertaken on behalf of the government departments, and Thiruvananthapuram Corporation but a sustainable solution to the problem could not be found, although money was spent. Poor people who are living in the low-lying areas of Chenkal Choola, Thampanoor, Karimadom, East Fort and Chalai suffer loss of their lives and property in each rainy season. The flash floods during summer season worsen the situation for which people and the authorities are least prepared. There were demands to find a permanent solution of this problem as thousands of people suffer due to recurring flooding events. Thiruvananthapuram city particularly Thampanoor and East Fort areas face the problem of acute water logging since a very long time. There were several interventions, engineering programmes and technical studies undertaken on behalf of the government departments, and Thiruvananthapuram Corporation but a sustainable solution to the problem could not be found, although money was spent. Poor people who are living in the low-lying areas of Chenkal Choola, Thampanoor, Karimadom, East Fort and Chalai suffer loss of their lives and property in each rainy season. The flash floods during summer season worsen the situation for which people and the authorities are least prepared. There were demands to find a permanent solution of this problem as thousands of people suffer due to recurring flooding events. On April 2015 afternoon, a torrential rain of 161 mm caused by upper cyclonic circulation off the Lakshadweep Sea pours down to the city and it flooded low lying areas unexpectedly. This was the heaviest amount of rain ever received in the city in 24 - hours' time for the month of April. Chenkalchoola, Thampanoor, Edapazhinji, East Fort, Pettah and Karikkakom were completely inundated. Traffic was disrupted in many parts of the city. Trains schedules were delayed for 40 minutes to 1-hour due to flooding of the rail track. This incident forced the government to initiate serious steps to mitigate the water logging problem in the city. On the next day, a team of officials headed by Chief Secretary visited the flood affected areas and identified that encroachments on the banks of Amayizhanjan Thodu caused a big hindrance to smooth flow of water through it and resulted in water logging in Thampanoor. The Cabinet gave the nod to remove all the encroachments in Amayizhanjan Thodu on 30th April 2015. The meeting called by the Chief Secretary on the same day with District Collector, Principal Secretaries of all departments and other officials decided to undertake necessary steps to permanently solve the issue as per the provisions of National Disaster Management Act, 2005.On 30th April 2015, Chief Secretary, District Collector, Sub-Collector and other district officials inspected various parts of the city which were frequently flooded and found out that canals and drains particularly Amayizhanjan Thodu and Thekkanamkara Canal are silted and blocked by waste dumping besides huge encroachments all around. Pipelines for drinking water supply and underground cables were found to be laid at the edges of the canals and drains. In order to remove all the encroachments on the canals and streams, to remove the 29 sludge and silt from the canal/stream beds, and to ensure the smooth flow of water through them to stop water logging and spread of contagious diseases, a rapid warfront action plan was drafted which is called 'Operation Anantha'.

Functioning of Operation Anantha

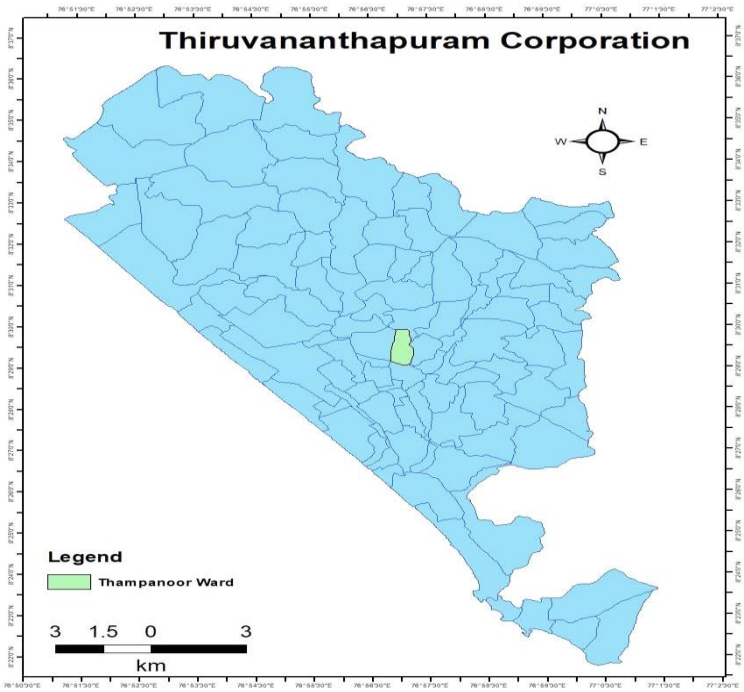
The mission 'Operation Anantha' was officially started on 1st May 2015. The vision and mission of 'Operation Anantha' has widened with the progress of implementation. It has two goals according to the limit of time. They are short-term goal and long-term goal. They mentioned below.

Short- term Goals	**Long- term Goals**
• Cleaning and desilting of drains.	• Restoration of water bodies.
• Shifting of KWA pressure pipes across canals.	• Widening of railway culvert at Thampanoor.
• Completion of box culvert at Thampanoor.	• Strengthening for solid waste management through Suchitwa mission in consultation with experts.

Operation Anantha was led by former chief secretary Jiji Thomson IAS, Thiruvananthapuram district collector Biju Prabhakar IAS, sub collector Karthikeyan IAS etc. The district administration issued notices to the encroachers as per the National Disaster Management (NDM) Act 2005 and started demolition of unauthorized structures from 2nd May onwards. Under the leadership of Tahsildar of Thiruvananthapuram district encroachments were removed from Pazhavangadi, Karimadom Colony, Thampanoor Mosque Line, Chenkal Choola, Chalai Market, Aristo Jn., Aryasala, Marakada Jn., Ruby Nagar, Edapajinji,Elanjimoodu, Kochar Road, and Kariyil Thode upto 26th May 2015. The demolishing of encroachments included portions of residential buildings and hotels, and shops and compound walls. The line of unauthorized shops that had set up over the slabs covering the canals in East Fort and Thampanoor which prevented the cleaning of canals were also demolished. Earth movers were used to clear the encroachments and to dredge the waste dumped on the canals and streams. The slabs constructed illegally over Amayizhanjan Thode to provide easy access to private properties were also removed. The flood mitigation drive received good co-operation from the people. Below is the amount spent by government departments for Operation Anantha.

STUDY AREA

Thiruvananthapuram also known as Trivandrum is the capital of Kerala, the Gods own country. The city is located on the south west coast of India near the extreme south of mainland. The city has latitude of $8^{o}25'26''$ N and longitude of $76^{o}55'25''$ E. Thampanoor is located almost in the south-central part of Thiruvananthapuram city. Thampanoor, is the 81^{st} ward of the Thiruvananthapuram corporation, which has 100 wards. Frequent floods and failure of adequate sewerage systems have been a problem in Thiruvananthapuram district for the last few years. Even though the natural landscape of Slope in Thiruvananthapuram City is sufficient to allow the sudden influx of water due to rainfall, the faulty drainage systems and frequent blockages of primary drains cause local flooding and water logging. Even today, an instantaneous rain of high potency can throw the city in to disarray. These floods are causing huge economic losses to the city and its peoples. Rapid urbanization severely challenges existing flood management infrastructure. This study focuses on Thampanoor and adjoining areas because of the frequent flood during the monsoon and the associated problems in administration, economy, transportation, and environment.



1 Location map

OBJECTIVES OF THE STUDY

- To investigate the problem of urban flooding in Thiruvananthapuram city especially for Thampanoor area.
- To prepare an overview of 'Operation Anantha' scheme implemented in Thiruvananthapuram city.

REVIEW OF LITERATURE

Achmad G. Hozali (2015), "Mitigation and Adaptation on Flood Management between Ayutthaya city (Thailand) and Samarinda city (Indonesia)" - A study regarding the flood management in the cities of two different countries were chosen to study by Urban and Regional planning department, Civil Engineering Department, Kalimantan Institute Of Technology, Balikpapan, Indonesian Urban and Regional Planning Department and Sepulah Institute Of Technology .The Rapid increase in population and Urbanization has contributed to Urban flooding. The climatic change also had significant impact on flood. The paper explores the flood management in Ayuthaaya in Thailand and Samarinda in Indonesia, the cities having same characteristics and the governmental role in flood management. The first objective of the study is to compare the climate change adaptation on flood management between Indonesia and Thailand. The second objective is to have comparative study of Ayuthaaya and Samarinda in climate change adaptation, co benefit adaptation and evaluation between the cities. The study found out that despite the similarities in climate change hazard and heavy rainfall has established community-based participation in flood and built a "disaster resilient community ". Whereas, in Ayothaaya city governmental role in it was less and moreover they were only limited to emergency adaptation despite of the fact that both the cities have same degree of flood damages and has high degrees of recovery.

Fred Mugisha (2015), discussed about the “Severe Flash Flood Problems Faced by Kigali like other Tropical Cities”. This study has been done to perform an assessment of the cause of regular flooding in Mapzi basin. The previous studies suggested that to cope up with flooding the wet land and marshes have to be restored to their original condition. Flood hazard mapping was another option to delineate the hazard areas. This study showed how the requirements were used to prepare flood hazard maps. The flood calibration was done by comparing the observed flood depth obtained from fieldwork through interviewing the citizens prone to flooding.

Ar. K Lavanya (2012) in her study on “Urban Flood Management and A Case Study of Chennai City” focused to perform an assessment of the cause of regular flood in Chennai city and ways for preventing the occurrence of flood to an extent. The major reason for the occurrence of flood was pointed as the lack of proper planning in the development of city, Rapid urbanization, and some topographic factors to an extent. The author mainly tried to emphasis the reasons, at the same time he/she also point out the ways to prevent these re occurring flood through preparation of Master plans for flood mitigation, proper and effective land use, flood preparedness etc. The paper was concluded by emphasizing about the sequence of action to hurls out from the flood hazard both structural and non-structural.

Dr.Jairay Phatak (2015) discussed about the “Urban Flood of Mumbai”. Mumbai is originally a group of 7 islands and many reclaimed areas are just 5 meters above low tide sea level. Mithi River dividing the city in the western& the eastern suburb, rapid urbanization has blocked the water ways, storm water drainage function of MCGM can cause floods in Mumbai. Author Also suggested to step up structural measures such as gates on Vihar and Tulsi lakes holding ponds upstream of airport on Mithi river, augmentation of railway culvert. Contour mapping of city required for better storm-water management Upgrade flood warning and forecasting measures to “nowcasting”, network of Doppler Weather Radars to be put in place etc. are some suggestions which given by the author as remedies for this problem.

Niloy Pramanick and Rituparna Acharyya (2021), discussed about the “Urban Flooding of Kottayam District in Kerala”. Kottayam had ranked second in terms of the area inundated from June to September in 2018. In the district of Kottayam, there are 23 villages. Among these villages, Vadayar, Kaduthuruthy, Naduvile, Muttuchira, and Manjoor are most affected by flooding. Vadya was the most affected village by the floods. The flooded area expanded from 8.71 km2 to 15.95 km2 from June 15 to August 21, followed by a minor decrease of 13.15 km2 on September 7, the flooded area started to decrease from September onwards. On the other hand, Changanassery was the least impacted village by the inundation. Its areal extent varied from 0.41 km2 to 1.22 km2 between June 15 and August 21, followed by a decrease of 0.12 km2 on September 7. The flood inundation has been mapped, which increases between June 15 and August 21, and then steadily decreased from September 7. This region has a significant predominance of water bodies shown deep blue portions in the map (are the permanent water bodies. The adjacent light blue portions are the inundated portions.

DATA SOURCE AND METHODOLOGY

The present study is based on the analysis of primary as well as secondary data. The first objective of the study is to investigate the problem of water logging in Thiruvananthapuram city especially in Thampanoor area. It has been studied mainly based on the primary data obtained through

- Direct personal interviews.
- Indirect personal interviews.
- Collection through questionnaires.
- Collection through enumerators.
- Collection through local sources.

The second objective is to prepare an overview of 'Operation Anantha' scheme implemented in Thiruvananthapuram city. Secondary data such as newspapers, magazines, and information obtained through online platforms are also used.

RESULT

The primary cause of water logging in the city is urbanization, inadequacy, and lack of maintenance of sewage systems and storm water drainage. Proper maintenance and upkeep of the drainage system is the main reason for avoiding water logging in the city. Strong measures should be taken to prevent encroachment on drainage. Innovations like sponge city should be implemented to reduce the intensity of water logging. In addition, if Operation Anantha's second phase is implemented, a permanent solution to the water logging in the city of Thiruvananthapuram can be found completely. This can be evident from the recent floods caused in the monsoon rainfall of 2016 where the intensity of flooding is comparatively lower than the past floods. The cleaning of some canals and drains is the major reason for this. The people responded that after the implementation of the project -Operation Anantha, the condition is some far better than the past incidents. There are so many projects being done as part of Anantha. The people pointed out that after the successful completion of all projects under Operation Anantha, the problem of urban flooding will disappear from the city limits. During the last two decades, even after a slight rain the city became flooded. But in the intense rain of June 2016, there is no prolonged water logging condition in Thampanoor region. Respondents adopt moderate approach to Operation Anantha. Because the first phase was successful but they could not do the second phase Operation Anantha was evaluated by many without realizing that it was a temporary solution.

CONCLUSION

Thiruvananthapuram city is undergoing massive urbanization. With the current rate of urbanization and development, the city and the adjoining urban sprawl is expected to witness a massive growth in its population. Increasing frequency of urban flooding, severe droughts, and windfall of trees in the recent past has proved disastrous to life, property, and livelihood in the city. Thiruvananthapuram city was one of the first cities to be entirely electrified in South India, to possess a full-fledged sewage draining system for its residents, the first city in South India to implement the concept of drinking water through pipelines.

The causes and effects of urban flooding in Thiruvananthapuram Corporation with special reference to Thampanoor is the main concern of the present study. The recurrent floods as a result of insufficient drainage are the perpetual problems faced by Thiruvananthapuram City during the past several years. Thampanoor and East Fort are the major areas which worst affected with considerable water logging. Transitory measures to prevent water logging is tried from time to time to ease the graveness of the situation. However, an abrupt rain of high intensity disrupts the city life considerably. A permanent solution to the problem is not yet found. Regular stagnation of water results in environment and health hazards. The shape, width and depth of the new drainage canals are entirely different from the old drainage system constructed by the royal rulers. Each canal in the city was well connected in olden canal system.

Urban flooding in the city is primarily owing to inadequate maintenance and management of sewerage systems and storm water drains. The reclamation of water bodies and low-lying areas or encroachments for development is the main reason for flooding. Most of the flood moderation zones inside the city have already been converted into concrete dwellings and apartments resulting in excessive runoff. Natural streams in the city flows through constrained channels due to encroachments on the banks of the streams, siltation, crisscrossing of communication cables and utility pipelines and dumping of solid waste, particularly plastic waste. Improper construction of pavements, buildings, roads, other impervious structures, choking of drainage etc. are factors that aggravate the magnitude of urban floods.

Improper maintenance of the already existing drains coupled with excessive runoff is the root cause of flooding inside the city. The rapid urbanization happened world widely contributed to relatively irregular and unreasonable planning patterns. Climatic changes also add yet stress to these causes of flooding. For instance, the houses being built in the flood plain areas in Trivandrum city which makes residents suffered from floods when heavy rains happened.

. From the planning perspective, there should be clear restrictions of land use in urban areas especially in flood prone areas. As per the Disaster Management Act, Government initiated a programme to ensure that the city is free of storm water flooding, named Operation Anantha. After the mitigation plan started by the Operation Anantha, the intensity and vulnerability of flooding in the city is less. The proper management of proposed projects done by the government authorities will reduce the negative impacts of flooding.

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AUTHORS' CONTRIBUTIONS

Bhadra J. Santhosh: A graduate in Geography who is a student of First MSc Geography, Government College chittur, Palakkad came up with the idea, done a significant role in selecting the study area, contributed to the research, data collection and creating the paper.

Agrima J. S.: Pursued Bachelor's Degree in Geography and is a student of First MSc Geography, Government College chitter, Palakkad. Contributed in methodology, analysis and background work of the paper.

Mereena C. S.: Assistant professor in Geography, Government College Kariavattom have significantly contributed in ordering the paper, rectifying the errors and providing necessary suggestions.

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URBAN FLOOD VULNERABILITY MAPPING OF THRISSUR CORPORATION USING WEIGHTED OVERLAY ANALYSIS

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Abstract:

Floods are one of the most catastrophic disasters that cause destruction to both natural and man-made structures which results in loss of life and property. Climate change-induced increases in the intensity and frequency of rainfall extremes, as well as increased paving and loss of water storage space in urban areas, make cities more vulnerable to pluvial flooding. The present study was carried out with the objective of identifying areas vulnerable to urban flood and to make an urban flood vulnerability map for Thrissur corporation, Kerala using weighted overlay analysis. LULC, elevation, slope, curvature, stream density, building density, road density, population density, soil type, soil depth, geomorphology, average rainfall, distance from waterbodies, distance from locations of market places, bus stand and railway station and distance from sewage line were the factors considered in the study. Each of the seventeen conditioning factors were assigned weightages based on their impact on flooding and combined using the weighted overlay method to generate a composite flood vulnerable zonation map. The flood hazard map thus generated delineates areas in Thrissur corporation that are most vulnerable to flooding. The study identified areas prone to flooding hazards and assist in a comprehensive planning process.

Keywords:

Urban flood, Weighted Overlay Analysis, Flood hazard map, Thrissur Corporation, Pluvial flood.

INTRODUCTION

Floods are one of the most catastrophic disasters that cause destruction to both natural and manmade structures which results in loss of life and property. According to WHO in terms of occurrences, climate-related disasters dominate the picture over the past 20 years, accounting for 91% of all 7,255 recorded events between 1998 and 2017. Within this total, floods were the most frequent type of disaster, 43% of all recorded events. Floods are now more frequent, and it will increase as part of climate change. Flood can be defined as an overflow of water onto normally dry land. The inundation of a normally dry area caused by rising water in an existing waterway, such as a river, stream, or drainage ditch. Floods can occur due to many reasons but mostly it is due to heavy rainfall (G. Zhao, 2019). The damage caused by flood depends on many factors such as rainfall duration and intensity, Land Use Land Cover, elevation, slope, soil type, population density etc.

Urbanization is the process by which the proportion of the total population concentrated in the urban settlements increase (Davis, 1965). Area under urban settlements (7933 towns) in

India has increased from 77370.50 sq. km in 2001 to 102220.16 sq. km in 2011 showing 24850.00 sq.km of additional land area being brought under urban use (Ministry of Urban Development, GoI). The average population density of India as per 2011 census was 382 person per square km, with the highest population density of 11297 PP km² in NCT of Delhi and the lowest (42 PP km²) in Andaman and Nicobar Islands (State Urbanisation Report Kerala,2012). Kerala and Tamil Nadu, two southern most States shows high population density, whereas majority of the States in India belongs to the low population density category. A notable instance of rapid urbanization happened in Kerala. The urban population grew from 25.9 per cent in 2001 to 47.7 per cent. Thrissur is among the million plus urban agglomeration from Kerala according to the rank of census of India (2011).

Climate change-induced increases in the intensity and frequency of rainfall extremes, as well as increased paving and loss of water storage space in urban areas, make cities more vulnerable to pluvial flooding (Ozkan and Tarhan, 2016). The Federal Emergency Management Agency (FEMA) report 2016 defines urban flooding as: the inundation of property in a built environment, particularly in more densely populated areas, caused by rain falling on increased amounts of impervious surfaces and overwhelming the capacity of drainage systems. Urban flood risk in India shows an increasing trend over the past several years whereby major cities in India have been severely affected. The most notable amongst them are Hyderabad in 2000, Ahmedabad in 2001, Delhi in 2002 and 2003, Chennai in 2004, Mumbai in 2005, Surat in 2006, Kolkata in 2007, Jamshedpur in 2008, Delhi in 2009 and Guwahati and Delhi in. The most recent devastating ones were Srinagar in 2014 and Chennai in 2015 (NDMA). Increasing trend of Urban flooding poses great challenge to Urban planning. Unplanned development and encroachments of sprawling habitations alongside rivers and watercourses have meddled with the natural streams and watercourses. New and intensified phase of urbanization during 2001-2011 coupled with spatial expansion of urban extents have compounded flood risk in the urban centres. India receives rainfall during monsoons, but due to climate change and changed weather patterns high intensity rainfall occurs in a short period of time. The management of urban flooding is an emerging subject, and as such it has to be treated holistically in a multi-disciplinary manner.

The present study was carried out with the objective of identifying areas vulnerable to urban flood and to make an urban flood vulnerability map for Thrissur corporation, Kerala using weighted overlay analysis. Standard software package ArcGIS 10.3.1 was employed for GIS operations including database generation and spatial analysis.

STUDY AREA

Geographically, the city of Thrissur is situated at 10.52°N latitude and 76.21°E longitude, with an altitude of 2.83m above the mean sea level, and is a part of the midland regions of Kerala and an extended part of Palakkad plains. The city has progressed along the road networks, taking the ring and radial pattern emerging from the 'Swaraj round' surrounding ‘Thekkinkadu Maidan’, a 65-acre prominence situated centrally. The Kole lands which lie adjacent to Thrissur city, are a unique wetland 5 agroecosystem facing severe pressures due to urbanization. The Kole wetlands that extend over 136 sq.km satisfies 40% of Kerala’s rice requirement and occupies 1.07% of the total land area of Thrissur, distributed across the Chavakkad and Thrissur taluks of the district. The Kole lands provide a natural fresh-water reservoir for ground water recharge. They also provide a sink for the large surface run-off from the eastern highlands every monsoon, and keep Thrissur city free from floods. Several housing complexes have sprung up in areas of the wetland in and around Thrissur Municipal

Corporation in the last 20 years. Jeena T. Srinivasan's study on land use changes in the Kole wetlands from 1981 to 2007 was a pioneering effort to understand the ecological and economic importance as well as the associated property rights issues of wetlands in general and the Kole wetlands in Thrissur, Kerala in particular.

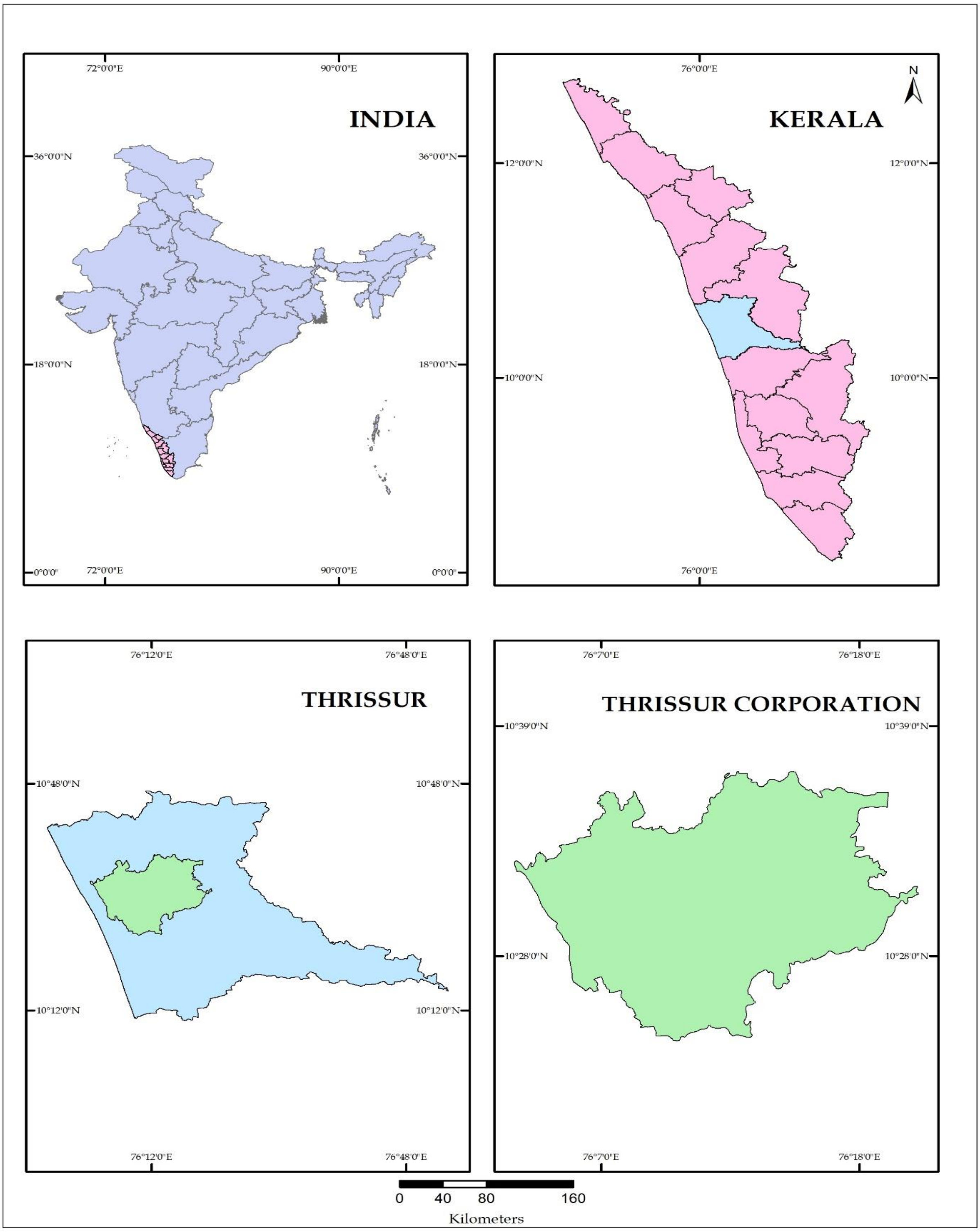

Fig.1.1 Study Area

OBJECTIVES

To identify areas vulnerable to urban flood, to make an urban flood vulnerability map for Thrissur corporation, Kerala.

REVIEW OF LITERATURE

GIS and a remote sensing-based approach for urban flood-plain mapping for the Tapi catchment, India was done (Singh and Sharma, 2009). In this paper, geospatial technologies such as remote sensing, GIS, and GPS have been utilised to prepare urban flood hazard maps and to handle entity-specific query and analysis. The research methodology employed was based on statistical probabilities of flood frequency, maximum discharge carrying capacity at river cross-section, mapping of inhabited areas based on high-resolution images, and terrain mapping using global position system.

Shahapure et al., (2013) studied Flood Simulation in an Urban Catchment of Navi Mumbai City with Detention Pond and Tidal Effects Using FEM, GIS, and Remote Sensing. In this paper, the flood simulation is analysed with the help of an in-house-developed simulation model that accounts for the tidal variation with the provision of a detention pond. The developed models were verified with models from the literature. The model was used to simulate four rainfall events of the urban catchment. Out of four events, three were non flooding and one was a severe flooding event. The model could simulate the flooding event showing the flooded stretch of the channel. By using the flooding event, the location and size of the possible detention pond are also simulated and their effects have been analysed.

Urban flood vulnerability zoning of Cochin City, southwest coast of India, using remote sensing and GIS was conducted to identify the various zones vulnerable to urban flood in Cochin City. The analysis and assessment of vulnerability was done through the application of multi-criteria evaluation approach in a geographical information system environment with inputs from remotely sensed images. The major factors contributed are the blockage of drainage channels and the proximity to coastal waters where there is influence of tides (Soumya et al.,2015).

Abebe et al., (2017) assessed urban areas vulnerable to pluvial flooding using GIS applications and Bayesian Belief Network Model. The technique can quantify uncertainty and capture the unintentional relationship between pluvial flood affecting elements. In a case study, the model was used to determine the cause of differences in the number of reported basement flooding in different districts of Toronto and to forecast Flood Vulnerability Index (FVI). The suggested methodology's key advantage is that it can be used to any urban area depending on its characteristics and data availability, and it can quantify uncertainty in decision-making.

A GIS based weighted multi-criteria analysis to determine flood prone areas in Harris County, Texas was done by integrating nine flood conditioning factors such as slope, elevation, soil type, rainfall intensity, flow accumulation, LULC, NDVI and distance from river and distance from road and a flood hazard map thus generated delineated areas in Harris County most susceptible to flooding. GIS based methods are extremely useful in identifying areas prone to flooding hazards and this study supports the use of GIS-based modelling methods to identify such areas and assist in comprehensive planning process (Mukherjee and Singh, 2019).

Urban food hazard index (UFHI) of Dehradun city using GIS and multi-criteria decision analysis was evaluated by Bansal et al., (2021) by linear combination of weighted overlay analysis of indicators using multiple criteria decision analysis, where Satty's AHP matrix is used for determining the weightage of each indicator. These indicators are integrated as layers, resulting in a composite index map. Remote sensing data are used for creating base layer of the city. Six indicators which include, elevation, slope, drainage density, land use/land cover (LULC) runoff, flood water depth, and distance from river, are used for evaluation. As a result of analysis, urban food hazard zones are identified and classified.

Urban flood susceptibility mapping of Kochi Taluk using Remote Sensing and GIS was done by Shreekumar et al., (2021) using AHP method and Weighted Overlay Analysis had been incorporated to classify the land for urban flood susceptibility.

METHODOLOGY

Datasets used

Parameters were handled one by one in the process to determine the vulnerable zones. The basic components of flood risk are constituted by the flood characteristics and the geographic properties of the area. Satellite image (band 3, band 4, and band 5) of Landsat 8 (OLI/TRS) was downloaded from USGS Earth Explorer (https://earthexplorer.usgs.gov/). Aster DEM was taken from (https://earthdata.nasa.gov/). The layer of geomorphology (scale-1:50,000) was collected from Geological Survey of India (https://bhukosh.gsi.gov.in/). Soil texture and Soil depth (scale-1:2,50,000) was collected from benchmark soils of Kerala. Roads, sewage line and locations of railway stand, major bus stand and main markets were digitized from Google Earth. Climatic factor which includes rainfall data (2021) was collected from GESDISC. (https://disc.gsfc.nasa.gov/). Population data was collected from Census of India 2011 (https://dop.lsgkerala.gov.in/en/node/1051).

Thematic Layers prepared

The thematic layers prepared for the study area are given in table 1.

Table 1. Thematic layers prepared

Sl No	Theme	Geometry
1	Location (railway, bus stand, market)	Point
2	Road	Line
3	Sewage Line	Line
4	LULC	Polygon
5	Soil Texture	Polygon
6	Soil Depth	Polygon
7	Geomorphology	Polygon

Analysis performed

The current study is being conducted in order to process flood vulnerability zones for which various basic thematic layers were created from different sources using the software ArcGIS 10.3.1, QGIS 3.16.11, and Google Earth. The study was conducted by weighted overlay analysis. The remotely sensed image acquired by the OLI sensor of Landsat 8 satellite with a spatial resolution of 30m of February 14,2021, was used for visual interpreting the present land use/land cover. The supervised classification method was adopted for the LULC map of the study area. Slope, Elevation and Stream are taken from Aster DEM. The rainfall distribution map was prepared from GESDISC. Annual average rainfall of 3 years (2018-2020) was calculated using raster calculator. Sewage line, roads and locations of major markets, bus stand and railway station were digitized from Google Earth. Soil texture and soil depth were obtained from Benchmark Soils of Kerala (Department of Soil Survey and Soil Conservation). Buildings were extracted from the LULC map, and building density was computed using the Density Tool. Similarly, the density of roads and streams was computed using the density tool by entering the respective vector layers. Water bodies were also extracted from the LULC map, and distances from them were obtained using the Euclidean Distance (Distance Tool). Euclidean distance was used to compute the distance from the sewage line, market, bus stand, and railway station. The population data was collected from the census of India Report 2011 and joined to the study area attribute table using the join tool. This layer is further used to derive the influencing raster layer of population density. The vector layers such as soil texture, soil depth, geomorphology was projected and rasterized for analysis. The basic and derived influencing thematic raster layers are then reclassified to a vulnerability score based on their vulnerability to urban floods using the Reclass tool in the spatial analyst toolbar. Weighted Overlay Analysis was used to prepare the resulting map by integrating the data layers into the GIS environment. By assigning a weight to each raster during the overlay process, you can control the impact of various criteria in the suitability model.

Table 2. Ranks and weightages assigned for various thematic layers used for analysis

Sl No	Layers	Weightage	Individual Classes	Vulnerability Score
1	Slope	10	0-8	5
			8-16	4
			16-24	3
			24-32	2
			>32	1
2	Elevation	10	0-8	5
			8-16	4
			16-24	3
			24-60	2
			60-451	1
3	curvature	2	-3.2222- -1	2
			-1-1	3
			1-4.33	1
4	Stream density	10	0-2	4
			2-4	3
			4-6	2
			6-8.91	1
5	geomorphology	5	Tidal flat	5
			Inselberg	1
			Active flood plain	5
			Valley fill	2
			Rolling Plain	3
			Pediplain	3

			Active quarry	1
			swale	3
			Residual mound	1
			River	5
			Beach ridge swale complex	3
			Younger deltaic plain	3
			pond	3
			Dissected hills	1
			Pediment	3
6	LULC	5	Built up	5
			Water body	5
			Water logged	5
			fallow	4
			barren	3
			Mixed crop with built up	2
			Quarry	1
			Paddy field	3
			Forest	1
7	Rainfall	5	3805-3882	1
			3882-3935	2
			3935-3981	3
			3981-4024	4
			4024-4089	4
8	Distance from sewage	10	0-200	5
			200-500	5
			500-800	4
			800-1500	2
			1500-4842	1
9	Distance from waterbody	5	0-200	5
			200-400	4
			400-600	3
			600-800	2
			>800	1
10	Distance from railway	4	0-200	4
			200-400	4
			400-600	3
			600-800	2
			>800	1
11	Distance from market	2	0-200	4
			200-400	3
			400-600	2
			600-800	1
			>800	1

12	Distance from bus stand	2	0-200	4
			200-400	4
			400-600	3
			600-800	1
			>800	1
13	Population density	5	843-921	1
			921-1218	1
			1218-1584	3
			1584-1950	4
			1950-3067	4
14	Building density	10	0-8	1
			8-19	2
			19-30	3
			30-42	3
			42-65	4
			65-105	5
15	Road density	10	0-2	1
			2-4	1
			4-6	2
			6-8	4
			8-9.6	5
16	Soil texture	3	Gravelly clay	3
			clay	5
			sandy	2
17	Soil depth	2	Very deep	3
			deep	2

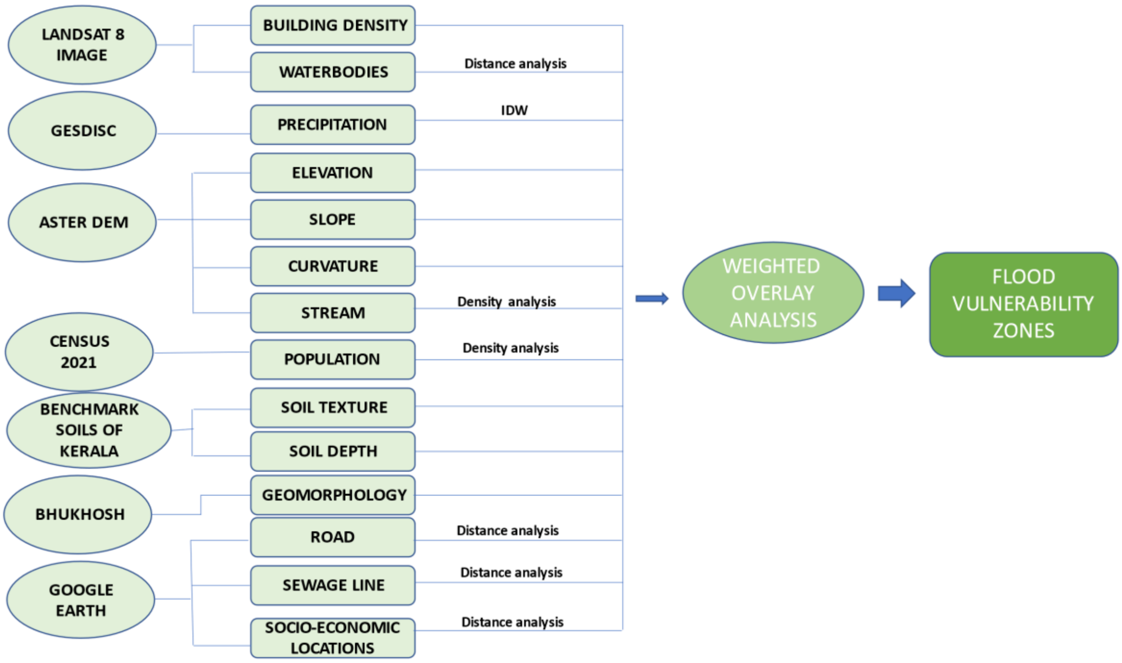

Fig.2. Methodology adopted for the work

RESULTS AND DISCUSSION

Flooding can be caused by a variety of factors that differ depending on region. In the present study urban flood vulnerable zones of Thrissur Corporation has been created using weighted overlay analysis and MCDMA (Multi-Criteria Decision-Making Approach) method. The parameters must be chosen carefully in order to identify the appropriate features of flood-prone areas. Following the selection of the study area a set of indicators was chosen that was thoroughly grounded in literature review. Following review of literature works dealing with similar situations several parameters such as LULC, elevation, slope, curvature, stream density, building density, road density, population density, soil type, soil depth, geomorphology, average rainfall, distance from waterbodies, distance from locations of market places, bus stand and railway station and distance from sewage line are used in this present study.

The study area was classified into 9 classes: paddy field, fallow land, barren land, built up, mixed crop with built up, quarry, waterbody, waterlogged and forest. LULC was reclassified into five classes according to their vulnerability. The dominant LULC in the study area includes barren land and paddy field followed by mixed crop with built up. The reclassified class with highest vulnerability includes waterbody, waterlogged and built up. LULC is an important factor in determining flood-prone areas. Vegetated areas are less prone to flooding, so there is a negative correlation between a flood event and the density of vegetation. Urban areas are affected by storm water runoff as it covered with extensive impervious surfaces (Tehrany et al., 2017). The reclassified class with highest vulnerability includes waterbody, waterlogged and built up. Urban geomorphology examines the conditions that lead to flooding problems in urban regions (Folorunsho and Awosika, 2001). Tidal flat, active flood plains in the low-lying areas are more vulnerable to flooding which covers an area of 104.76km².

Urbanization results in conversion of agricultural land, natural vegetation and wetlands to built-up environments, construction on natural drainages as well as increase in the population of those living in flood vulnerable areas such as flood plains and river beds (Adeoye et al., 2009). The resident population is an integral part of the flood disaster-bearing body, flooding may lead to casualties, and so population density is an important socioeconomic factor contributing to the physical vulnerability of a food hazard (Lin et al., 2019). Population density is reclassified into 3 classes, with a weightage of 5. The area with highest population density covers 224.73km².

Building density is extracted from LULC map, it is important because it has significant impacts on the damage caused by urban floods. Building density is reclassified into 5 classes and classes having high values was assigned higher rank while the class having low values was categorized as lower rank. The highest vulnerable area covered an area of 3.98 km².

Impervious surfaces such as roads, pavements and parking lots increase surface water runoff, as they do not allow rainwater to percolate through the soil. Conversion of natural terrain to paved and tarred roads increase runoff two to six times more than would normally occur (Etuonovbe, 2011). Thus, road density is important in urban flood and given a weightage of 10, and reclassified into 4 classes and highest vulnerable class is 8-9.6 km², which covers an area of 2.358 km².

Stream density represents the length of stream channels in a basin relative to total drainage area. Stream density is an inverse function of infiltration (Periyasamy et al., 2018). The less the infiltration of rainfall, which conversely tends to be concentrated in surface runoff. High stream density values are favourable for runoff, and hence less chances for flood. The density analysis tool in GIS is applied to calculate the stream density, the values varied from 0.047km/ km² to 8.91km/ km². Higher ranks are assigned to poor drainage density area and lower ranks were given to areas with adequate drainage. Stream density was reclassified into 4 classes in which 0-2 km/km² density class was given higher rank. The highest vulnerable area consists of 129.83km².

Slope is another factor that serves as a strong benchmark to indicate flood susceptibility. The value of slope in the study area ranges between 0°-50.6°. But in the study area most of the slope is in between 0°-8, which covers an area of 373.81km². Slope is the most significant factor in hydrology and it is directly proportional to surface run off, and, thus influences floods (Meraj et al., 2015). The slope influences the direction of and amount of surface runoff or sub-surface drainage reaching a site. Low gradient slopes are highly vulnerable to flood occurrences compared to high gradient slopes. Rain or excessive water from the river always gathers in an area where the slope is usually low. Areas with high slope do not permit the water to accumulate and result into flooding. The slope classes having less values were assigned higher rank due to almost flat terrain while the class having maximum value was categorized as lower rank (>32°) due to relatively high run-off.

The elevation is a key factor in controlling the flow direction of the flood and the level of submerged water depth (Ouma and Tateishi, 2014). Topography plays an important role in flood susceptibility. Areas in low elevations and in flat areas are particularly prone to flooding hazards (Tehrany et al., 2017). Water flows down from higher elevations to lower ones, and the probability of flood hazard is very high in low lying areas. Elevation is obtained from DEM data. Elevation is inversely proportional to flooding (Kwak and Kondoh, 2008). The elevation of Thrissur Corporation ranges in between 0 and 451m. The elevation of the area is reclassified into 5 classes, most of the area shows an elevation 8-16m which covers an area of 176.26km², followed by the highest vulnerable area with an elevation between 0-8m which covers an area of 120.21km².

Curvature helps us to understand the geomorphological characteristics (Rahmati and Pourghasemi, 2017). Curvature is reclassified into three classes: concave, flat and convex. A positive value of curvature represents convex surface, zero a flat surface and negative value a concave surface. The study area shows flat curvature dominantly and it is given the highest rank because it is more vulnerable to flooding, it covers an area of 413.39km².

Soil is one of the natural resources, which has the most direct impact on flood as they control the amount of water that can infiltrate into the soil and hence the amount of water which becomes flow (Nicholls and Wong 1990). Soil type and soil depth is used in this analysis. Three soil types were seen in the study area clayey soil, sandy soil and gravelly clay. Clayey soil and gravelly clay are less permeable to infiltrate thus clayey soil was given a higher rank and sandy soil is given lower rank. Soil depth was one of the factors causing flood in the study area. When water is supplied at a rate that exceeds the soil's infiltration capacity, it moves downslope as runoff on sloping land and can lead to flooding (Lowery et al.,1996). Very deep soil is dominant in the study area which consists of 415.78km² area.

Rainfall is an important factor that leads to flood generation. It is directly proportional to flooding (Tehrany et al. 2017). Several authors have studied increase in frequency of very heavy rainfall and impact of urbanization on meteorological variables (Guhathakurta et al. 2011; Gosh et al. 2009). The study area receives precipitation between 3805mm and

4089mm.The highest rank is given to 3981mm - 4089mm which covers an area of 195.06 km².

Distance from market places, railway station and major bus stands were included in the study, and these layers were reclassified into five layers with highest vulnerable area is choosed as class 0-200m which is covering an area of 0.61km²,2.48km² and 1.90km² respectively. Distance from water body has a significant impact on the flood spread and magnitude (Glenn et al., 2012). Riverside urban settlements are more susceptible to flood. Areas near waterbody was given a higher rank and covers 17.89km² which is 0-200m from water body.

One of the key layers required for this particular study is distance from drainage lines. They are the artificial drains made for transporting sewage from household to treatment facilities or disposal. These are special man-made drains which helps transport and drain the excess storm water or runoff from the surface to the water bodies to avoid and reduce flooding. It is important to include this factor in flood vulnerability mapping as the water logging in most of the areas was the result of the over flow from these drains mainly due to the inability to hold or drain water. The distance from drainage line was reclassified into 5 classes and the class with highest vulnerability covers an area of 230.19km²which was 0-200m from the drainage line.

Four vulnerability zones such as low, moderate, high and very high zones for urban flood are identified from Thrissur corporation area. The urban flood vulnerability zone map indicates 14% of the study area was coming under a very high vulnerability zone which covers an area of 58.68km² and 45% of the study area can be moderately affected by urban flood (189.6km²). Urban flood vulnerability was low for 31% of the study area which covers an area of 134km² and 9% of the study area was least affected by urban flood which covers an area of 38.7km². Thrissur Corporation consists of 55 wards, in which 12 wards are highly vulnerable and others were at moderate and highly vulnerable category (Fig.3).

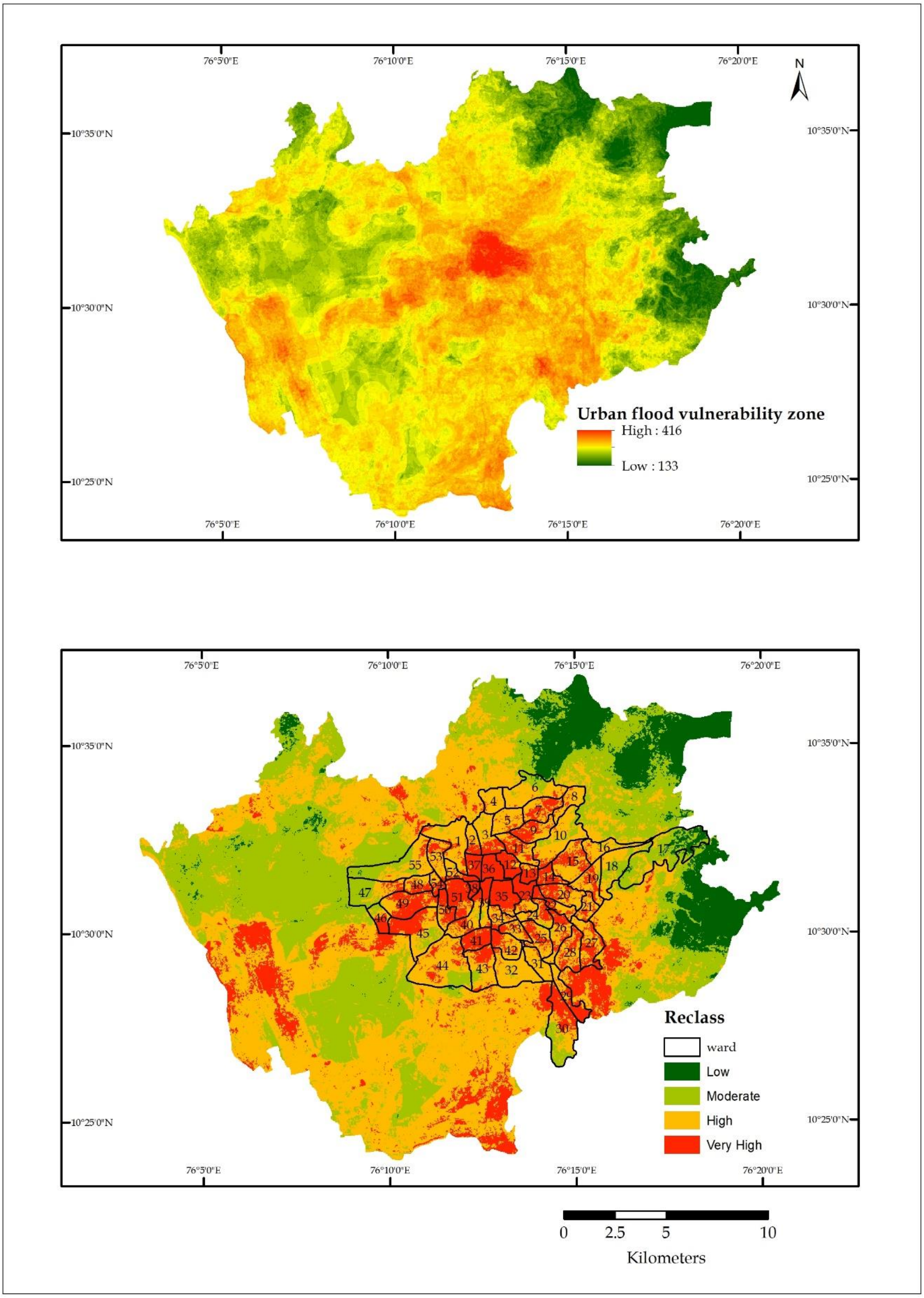

Fig.3. Thematic layer and reclassified layer of extent of vulnerability in Thrissur Corporation

CONCLUSION

Flooding is a disastrous natural calamity causing loss of life and properties every year. The natural disaster can occur in any geographic location. In recent years, loss due to flooding events have increased exponentially.

The goal of this study was to delineate areas in Thrissur Corporation area that are vulnerable to flooding by integrating seventeen flood conditioning factors within GIS and remote sensing environment using weighted overlay analysis. Several studies proved that flood risk mapping based on GIS and multi-criteria analysis was a very efficient tool for estimating areas prone to flood risk (Batbold and Bolorchuluun, 2021). LULC, elevation, slope, curvature, stream density, building density, road density, population density, soil type, soil depth, geomorphology, average rainfall, distance from waterbodies, distance from locations of market places, bus stand and railway station and distance from sewage line are used in this present study. Each of the seventeen conditioning factors were assigned weightages based on their impact on flooding and combined using weighted overlay method to generate a composite flood vulnerable zonation map. The flood hazard map thus generated delineates areas in Thrissur corporation that are most vulnerable to flooding with areas shown in the map in red and orange.

GIS based methods are extremely useful in identifying areas prone to flooding hazards and this study supports the use of GIS-based methods to identify such areas and assist in comprehensive planning process. However, the accuracy of the results depends on the error in the input data as criterion weights and criterion attributes. Furthermore, precision of the results can be enhanced by improving the quality of data used in the study.

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AUTHOR CONTRIBUTION

Ajeena Hussain Z.: Investigation, Visualization, Methodology, Formal Analysis, Writing-Original Draft.
Ancy Joseph: Investigation, Visualization, Methodology, Formal Analysis.
Abin Varghese: Conceptualization, Supervision, Reviewing and Editing.
Baiju K. R.: Expert Consultant

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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UTILIZATION OF THE FERN *ADIANTUM LATIFOLIUM* FOR CADMIUM REMEDIATION FROM WASTEWATER AND NANO PARTICLE SYNTHESIS

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Abstract:

This study aimed to develop an environment friendly and cost-effective approach to remove organic matter ,heavy metal from wastewater and to synthesize silver nanoparticles using the fern Adiantum latifolium. The Adiantum latifolium possess the potential to accumulate Cd in the tissues particularly in the rhizomes. During phytoremediation 6 litres of synthetic wastewater was prepared which was dosed with heavy metal Cd at 4ppm concentration , the plant remained healthy and survived well in the synthetic wastewater spiked with 4ppm Cd till the end of the 20th day experiment which is a positive indication for the purpose of remediating polluted wastewater. The changes in pH of the synthetic wastewater with plant and control(without plant) during the experiment was estimated .The heavy metal accumulation is maximum in rhizome (2.91mg/g dry weight) and minimum accumulation is seen in leaves (0.76mg/g dry weight). Green synthesis of silver nanoparticles using the leaf extract of Adiantum latifolium fern was successful .For the synthesis of silver nanoparticles, the fern extract was mixed with silver nitrate solution at 2:8 (v/v) ratio .From visual identification , the colour change from light yellow to brown shows the synthesis of silver nanoparticles through the reduction of silver nitrate metal solution under sunlight irradiation. Silver nanoparticles synthesized from Adiantum leaf extract had a polydispersity index of 0.484. The size of the nanoparticles produced from Adiantum extract is more homogeneous because it has a polydispersity index value of less than 0.5. FTIR analysis confirmed that the bio reduction of Ag^+ ions to silver nanoparticles are due to the reduction by capping material of fern extract. It is evident that the biosynthesis of silver nanoparticles is based on their secondary metabolites present in the fern extract. The powdered X-ray Diffraction spectrum of Adiantum based silver nanoparticles shows distinct peaks at 2θ position. The TEM images of silver nanoparticles synthesized in the present study shows that the nanoparticles were spherical in nature. The image signify that the synthesized silver nanoparticles size was 10nm.

Keywords:

Nanoparticles, wastewater treatment, Cadmium, phytoremediation, heavy metal pollution.

INTRODUCTION

Phytoremediation

The environment is deteriorating due to rising urbanization, industrialization, and overpopulation. Heavy metals and other organic materials make up the majority of the water contamination. Macrophytes are important in recycling heavy metals and nutrients in many aquatic eco-systems(Pip and Stepaniuk, 1992). Heavy metal pollution in water bodies is a serious environmental problem, threatening not only the aquatic ecosystems, but also human health (Ramasamy *et al*.,2009).

Contamination of soil and water bodies with toxic heavy metals has often resulted from human activities. Conventional technologies for treatment of heavy metals polluted soil require a huge capital cost. Use of plants which are non-edible crops for the treatment of heavy metals polluted land is a sustainable, aesthetic and environmental friendly technique.. Among all the available technologies for the removal of heavy metals from polluted sites, phytoremediation is considered as an effective, low cost, environmental friendly and preferred clean-up option for contaminated areas. Many plant species are able to grow under heavy metals polluted environments. These plants must have specific adaptations to survive there; they must be metallophytes, , or hyperaccumulators(Gupta *et al*.,2013).

Cadmium uptake by cultures of transformed hairy-roots of *Solanum nigrum* was studied by Macek et al., (1994). The effect of pH, buffer type, temperature, exposure time and Cd^{2+} content ranging from 0.2 to 2000 ppm was measured. Cd^{2+} uptake was dependent on increasing metal concentration and it was time dependent. From the variety of buffers tested, MES(morpholino ethane sulfonic acid) buffer and borate ions were found to be beneficial for the Cd^{2+} uptake. The high effectivness of Cd^{2+} accumulation in the roots decreased significantly after increasing the Cd^{2+} content in the buffer over 2 ppm.

Phytoremediation, a plant-based method, is employed to remediate contaminated soils in order to address soil pollution. The processes of phytodegradation, phytovolatilization, phytoaccumulation, and phytoextraction are the foundation of phytoremediation. These techniques are effective, sustainable, and affordable (Muthusaravanan *et al* .,2018).

In soil-plant systems, cadmium (Cd) is one of the heavy metals that is most easily absorbed and swiftly translocated. Species of aquatic plants are crucial to the removal of Cd from wastewater that passes through wetlands. The main factors discussed include Cd-induced growth suppression, modifications to water and ion metabolism, impacts on photosynthesis, modifications to enzyme activity, and production of free radicals. Understanding the effect of Cd in altering the rhizospheric pH is also crucial for understanding remediation, thus this chapter will focus on that topic. (Tanwir *et al*.,2019).

The present study examines the potential of *Adiantum latifolium* in removing the organic matter and the heavy metal from the wastewater. Also the comparison is made on the performance of wastewater with plants and without plants (Control). There are many studies conducted on phytoremediation with pteridophytes while studies on phytoremediation with Adiantum latifolium are scarce.

Nanoparticle synthesis

Green synthesis of nanoparticles has received increasing attention due to the growing use of environmentally benign technology in nanoparticle synthesis. Silver nanoparticles (Ag-NPs) are important nano materials that have been studied extensively. Such nanoscale materials possess unique electrical, optical ,as well as biological properties and are thus applied in catalysis, biosensing, imaging, drug delivery, nanodevice fabrication and medicine (Smith *et al*.,2010). Due to strong antimicrobial activity .Ag-NPs are also used in clothing, the food industry, sunscreens and cosmetics (Kokura *et.al*.,2010). Additionally, Ag-NPs have been shown undergo size-dependent interactions with HIV-1 and inhibit binding to the host cell *in vitro* (du Tort *et al*., 2010; Shegokar *et al*.,2011).

A critical milestone in the realm of nanotechnology is the creation of dependable and environmentally friendly processes for the synthesis of nanoparticles. Due to their outstanding chemical, physical, and biological characteristics and consequent applications, silver nanoparticles are significant. There have been many efforts over the past ten years to create environmentally friendly ways to synthesis Ag-NPs for various applications. Additionally, it compares green approaches to efficient synthesis methods over physical and chemical ones, which offers convincing support for choosing an appropriate strategy for the synthesis of AgNPs. .(Rafique *et.al* , 2017).

The researchers were driven to create biologically active nanoparticles due to the expansion of infectious diseases and the rise in medication resistance among microorganisms. A Juliet *et al*., (2020) study describes the creation of a procedure to biosynthesize copper nanoparticles (CuNPs) by combining copper chloride solution with aqueous *Marselia quadrifolia* rhizome extract.

The present study combines the phytoremediation with green synthesis of silver nanoparticles. The fern *Adiantum latifolium* used in phytoremediation has been used to synthesize silver nanoparticles, so that the harvested plants from phytoremediation system can find a useful application or utilization by means of green synthesis of silver nanoparticles.

OBJECTIVES

- To study the potential of *Adiantum* in the removal heavy metal Cd from the wastewater.
- To study the synthesis of silver nanoparticles using the plant extract of *Adiantum latifolium.*
- To characterize the synthesized silver nanoparticle

REVIEW OF LITERATURE

Phytoremediation

Using plants to remove toxins from wastewater, soil, and sediments, phytoremediation is gaining popularity as a practical technology. Hegazy *et al*.,(2011) studied *Typha domingensis* capacity to absorb heavy metals as well as its potential use in phytoremediation. Pollutant element concentrations were analyzed in the samples of wastewater, sediments, and *Typha domingensis* obtained from industrial wastewater ponds in El-Sadat city, Egypt. *Typha domingensis* was able to accumulate the heavy metal ions preferentially from wastewater as opposed to sediments. The highest levels of metal buildup in plant tissues were found in the roots, rhizomes, and aged leaves. (Hegazy *et al*., 2011).

Heavy metals, including Pb, Zn, Cd, and As, are among the most poisonous contaminants which are danger to all living things. One such pollutant that upsets the food chain and is deadly even at low doses is lead. The goal of the Singh *et al*.,(2012) study was to evaluate phytoremediation's current status as an innovative technology and its potential and usefulness in the cleanup of lead-contaminated water.

Gupta *et al*.,(2013) study the suitability of aromatic plants for phytoremediation of heavy metal contaminated areas as a sustainable approach. Aromatic plants can be used for the remediation of contaminated sites as they are non-food crops thus minimizing the risk of food chain contamination and the essential oils from aromatic crops is not contaminated by heavy metals significantly. Thus aromatic plants are emerging as an ideal candidate for phytoremediation.

For the removal of cadmium and other heavy metals from the environment, many systems have been developed that use living or non-living microbes instead of plants. Using media containing cadmium infected with 14-day-old roots in the ratio of 1 g fresh weight to 50 mL of liquid medium, cadmium uptake by hairy roots was monitored for a period of up to 50 hours. Triplicates of each accumulation study were completed. After initial screening, the Solanum nigrum clone SNC-90 was mostly used to study the uptake of cadmium from liquid media by hairy root cultures. High branching frequency allowed this clone to grow healthily. With the help of 0.1 M MES, 0.1 M acetate, 0.1 M citrate, 0.1 M phosphate buffers, and a 0.05 M sodium borate solution with pH regulated by HNO_3, researchers looked at the impact of various test solution compositions on cadmium uptake by roots (Macek *et al.*,2020).

Echinochloa crus galli and *Hibiscus cannabinus* plants were used to study the phytoremediation potential of municipal sewage sludge, with particular attention paid to total organic carbon, total Kjeldahl nitrogen, total phosphorus, sodium uptake ratio, pH, electrical conductivity, and lead and cadmium heavy metals. Throughout the studies, the removal effectiveness of lead and cadmium dramatically improved. It may be concluded that the investigated plants can be used to remove nutrients, total organic carbon, and heavy metals like lead and cadmium from municipal sewage sludge. The output of plants, however, varied depending on the culture medium. Additionally, it grew as ripening time, electrical conductivity, and pH decreased (Almasi *et al*.,2021). d

Nanoparticle synthesis

Nanotechnology is the technological innovations in the 21st century. Research and development in this field is growing rapidly throughout the world. The current study focuses on the environmentally friendly manufacturing of ZnO nanoparticles using zinc nitrate and the bioactive ingredients in *Calotropis gigantea* leaf extract. The ZnO nano crystallites, with an average size range of 30-35 nm, were created quickly, easily, and sustainably. X-ray diffraction and scanning electron microscopy (SEM) were used to characterise zinc nanoparticles (XRD). The resulting particles are agglomerates of nanocrystallite and are spherical in shape. The hexagonal crystal form of ZnO is revealed by the X-ray patterns. The outcomes match the hexagonal wurtzite ZnO XRD pattern in the literature. Using Debye-Formula, Scherrer's the size of nano crystallites is determined by taking into account XRD data (C Vidhya *et al*.,2012).

Ecofriendly methods of green mediated synthesis of nanoparticles are the present research in the limb of nanotechnology. The goal of is Lalitha *et al*.,(2013) study is to create nanoparticles from a 1 mM $AgNO_3$ solution using an aqueous leaf extract of *Azhadirachta indica* as a reducing and capping agent. Synthesized nanoparticles are characterized under UV-Vis spectroscopy at the range of 350-420nm. .The peak showed at 351nm. Particle Size Analyzer further confirmed this range of size. the chemical groups analyzed by FT-IR. A zone of inhibition was visible against isolated Gram-positive (*Salmonella typhi*) and Gram-negative (*Klebsiella pneumoniae*) bacteria in a green-synthesised silver nanoparticle. The leaf extract shows higher antioxidant activity found by DPPH assay and Hydrogen Peroxide assay. Based on the results, it can be concluded that plant resources can be effectively employed in the production of silver nanoparticles and can be applied in a variety of domains, including biomedicine, nanotechnology, and other areas.

Allafchian *et al.*,(2016)study found that phlomis leaf extract decreased silver ions after 5 minutes, resulting in the creation of crystalline silver nanoparticles. The Phlomis species is renowned for being a great source of phenolic compounds like flavonoids and phenylpropanoids. Several methods, including UV-vis spectrophotometry, X-ray diffraction, scanning electron microscopy (SEM), transmission electron microscopy (TEM), and FT-IR, were used to analyze the silver nanoparticles made by the phlomis extract. AgNPs were primarily spherical in shape and had an average particle size of 25 nm, according to the SEM and TEM data. Additionally, it was demonstrated that biologically produced nanoparticles have antibacterial action against both Gram-positive (*Staphylococcus aureus* and *Bacillus cereus*) and Gram-negative (*Salmonella_typhimurium* and *Escherichia coli)* bacteria. As a result, this work demonstrated that phlomis leaf extract could be employed for the environmentally friendly manufacture of silver nanoparticles with the necessary antibacterial activity.

MATERIALS AND METHODS

Phytoremediation

Adiantum latifolium Lam

Pteridophytes are primitive vascular plants which flourish well in terrestrial habitat and possess medicinal values . *Adiantum latifolium Lam*., a common terrestrial herb, belongs to family Pteridaceae with long creeping rhizome and dark brown scales. The whole plant parts of *A. latifolium* employed as medicine. *A. latifolium* (Figure 1) used in Brazil to reduce different types of pain, but in Colombia the plant was used for the treatment of skin conditions in connection with inflammation and infection. Latin American traditional medicine utilized *A.latifolium* as anxiolytic, analgesic, and anti-inflammatory (Thomas, 2017)

Fig 3.1 *Adiantum latifolium Lam*

Systematic position of *Adiantum latifolium*

Kingdom - Plantae

Phylum - Tracheophyta

Class - Polypodiopsida

Order - Polypodiales Family - Pteridaceae

Genus - *Adiantum*

Species - *latifolium Lam.*

Collection of Plants

Adiantum latifolium were collected from the University campus and were washed thoroughly in running tap water followed by double-distilled water before introducing them into the Cd heavy metal spiked synthetic wastewater containing beakers (500ml).

Preparation of metal spiked synthetic wastewater

Six litres of synthetic wastewater was prepared. The composition of synthetic wastewater is provided in the Table 3.1 (Hyungseok Yoo et al.,1999). This synthetic wastewater is dosed with heavy metal Cd in 4ppm concentration by using $CdCl_2$ salt (analytical grade).

Table 3.1:Composition of synthetic wastewater

Sl No	Added Compounds	Synthetic wastewater (mg/l)
1.	CH_3COONa	129.205
2.	CH_3COONH_3	121.44
3.	$KH2PO_4$	22.97 63.5
4.	$NaHCO_3$	6
5.	$CaCl_2$	1.1875
6.	$FeCl_2$	1.019
7.	$MnSO_4$	1.0175
8.	$ZnSO_4$	13.5
9.	$MgSO_4$	26
10.	Yeast extract	

Experiment design and operation

In this study, ten beakers (500ml) were used and all the ten beakers were filled with 500ml of 4ppm Cd heavy metal spiked synthetic wastewater in which. *Adiantum latifolium* plants (Two plants per beaker) were cultured hydroponically (without substratum). Out of ten beakers, six beakers were planted with two *Adiantum latifolium* while the others were operated without plants (control). 5 ml of samples were collected on 0^{th} day, 5^{th} day, 10^{th} day, 15^{th} day, 20^{th} day the analysis of Cd content. pH was measured periodically using a pH probe directly in the beaker. Plants samples were also analyzed for determining the Cd content towards the end of the experiment (20^{th} day of experiment). The whole experiment was conducted in the laboratory with a photoperiod of 8 hrs. (10am to 6 pm).

Analytical methods

Analysis of plant samples

Twelve plants are representative samples, were taken from the beakers. The sample plants were washed in tap water followed by double distilled water, dried with paper toweling, separated into leaves, shoot and root fractions and oven dried at 50^0 C till constant weights were attained. Oven dried and powdered plant samples (1g) were digested with 8ml HNO_3 and 2ml H_2SO_4 (selectipur high- purity grade without heavy metals) solutions. Cd present in the digested solutions were determined using ICPMS (Make Thermo Model iCAP Q)

Analysis of wastewater

Two ml of synthetic wastewater were collected on 0^{th} day, 5^{th} day, 10^{th} day, 15^{th} day, 20^{th} day from the beakers and were acidified with selectipur HNO_3.The acidified samples were digested and analyze for metal content.

Nanoparticle synthesis

Collection of plants

The plant *Adiantum latifolium* was collected from the University Campus, Kottayam . The fresh and dried leaves of *Adiantum latifolium* is used for the study.

Extraction of plant materials

Fresh leaves of Adiantum latifolium were washed with tap water and then with distilled water to remove dust before use. Washed leaves were air dried in the shades and powdered using mortar and pestle. This dried powder was used for further studies.

Experimental design and operation

a) Preparation of plant extract

To 5gm of dried leaf powder,100ml of distilled water was added and solution was heated for 20min at 60˚C.Then the supernatant was filtered using Whatsman No. 1 filter paper and the filtrate was stored at 4˚C for further use.

b) Preparation of silver nitrate solution

In this study, silver nanoparticles were synthesized using silver nitrate solution which is used as precursor metal salt solution and distilled water was used throughout the experiment. 1 Mm solution of silver nitrate solution was prepared by dissolving 0.084935g of silver nitrate salt in 500ml distilled water and stored in a amber colored bottle.

c) Synthesis of silver nanoparticles

For the synthesis of silver nanoparticles, the plant extract is mixed with silver nitrate solution at ratios of 9E:1M, 8E:2M, 7E:3M, 6E:4M, 5E:5M , 4E:6M, 3E:7M , 2E:8M and 1E:9M. E denotes the plant extract and M denotes the metal salt solution in ratios. The reaction mixtures were kept at sunlight until the formation of colour change. After that , the synthesized silver nanoparticles were subjected to UV-Vis spectroscopy(Shimadzu UV-1800 spectrophotometer and dynamic light scattering (Model-HORIBA SZ- 100) which gives the primary confirmation of silver nanoparticles synthesize. The biosynthesized silver nanoparticles were collected after proper reaction period and further characterization were done.(DLS,FTIR,XRD,TEM)

Characterization techniques

a) UV-Vis spectrophotometry

The synthesis of silver nanoparticles were done using the leaf extract of *Adiantum latifolium* and were confirmed by the UV- Visible spectroscopy using a Shimadzu UV- 1800 Pharma spec spectrophotometer. The colour change from golden yellow to brown colour was noticed when the leaf extract was treated with silver nitrate metal salt solution and the synthesized silver nanoparticles was subjected to UV- Vis spectroscopy at a range 200-800 nm. UV-Visible spectroscopy was the primary characterization techniques, which confirm the synthesis of nanoparticles by monitoring Plasmon resonance and analyzing the collective oscillation of conduction band electrons in response to electromagnetic waves (Ingale *et al.*, 2013).

b) Dynamic Light Scattering (DLS)

The distribution and the particle size of silver nanoparticles were analyzed using Dynamic Light Scattering measurement, Model – HORIBA SZ-100. DLS is widely used for the measurement of size of the Brownian nanoparticles in colloidal suspension .Fluctuations of elastic laser light scattering due to the particles individual Brownian motion in a solvent can be utilized to determine particles size distributions in real- time. DLS usually uses non-invasive visible laser light that is focused on a sample solution, suspension, emulsion or aerosol inside a sample container, commonly a cuvette or a capillary (Falke and Betzel,2019)

c) Fourier Transform Infrared Spectroscopy (FTIR)

The FTIR analysis of leaf extract and synthesized silver nanoparticles were carried out between 4000 and 600 cm^{-1} to detect the functional groups responsible for reduction of metal salt solution, and to find the capping and stabilizing agent of silver nanoparticles in the given sample (Emeka *et al*.,2014). FTIR provides information about the surface chemistry and bulk properties of simple and functionalized polymers(Parpinello *et al*., 2015).

d) X-Ray Diffraction Analysis (XRD)

X-ray powder diffractometry analysis is used for the determination of crystal structure, particle size, crystallinity, and material identification of various particles including nanoparticles. When X-ray light reflects on any crystal, it leads to the formation of many diffraction patterns, and the patterns reflect the physico-chemical characteristics of the crystal structures. In a powder specimen, diffracted beams typically come from the sample and reflect its structural physicochemical features. Each material has a unique diffraction beam which can define and identify it by comparing the diffracted beams with the reference database in the Joint Committee on Powder Diffraction Standards (JCPDS) library (Zhang et al., 2016).

e) Transmission Electron Microscopy (TEM)

TEM is a technique which uses an electron beam to image a nanoparticle sample, providing much higher resolution than is possible with light- based imaging techniques. TEM is the preferred method to directly measure nanoparticle size, grainsize distribution and morphology.The modification of pellicle ultrastructure was evaluated by transmission electron microscopy. TEM images indicated that rinsing with *R. nigrum* leaves/ *Origanum* yielded a distinctly thicker and more electron- dense pellicle(Weber *et al*.,2015).

RESULT AND DISCUSSION

Phytoremediation

Plant response to heavy metal

The visual changes were observed in *Adiantum latifolium* grown in six beakers with same concentration of Cd heavy metal is recorded. Towards the end of the 20^{th} day ,some leaves show yellowing but the plant looked healthy.

pH

The pH of the wastewater sample was determined using probe. The pH of the wastewater where *Adiantum* plant grown was taken on 5^{th} day, 10^{th} day,15^{th} day and 20^{th} day and the pH of the wastewater without plant (control) was taken in 0^{th} day, 10^{th} day and 20^{th} day. The pH of the wastewater with plant on 5^{th} day, 10^{th} day, 15^{th} day and 20^{th} day is 7.89, 7.80, 7.74, 7.66 respectively and pH of the wastewater without plant (control) on 0^{th} day, 15^{th} day and 20^{th} day is 7.56, 7.55 and 7.54 .Changes in pH values were not significant between control and *Adiantum* grow in wastewater.

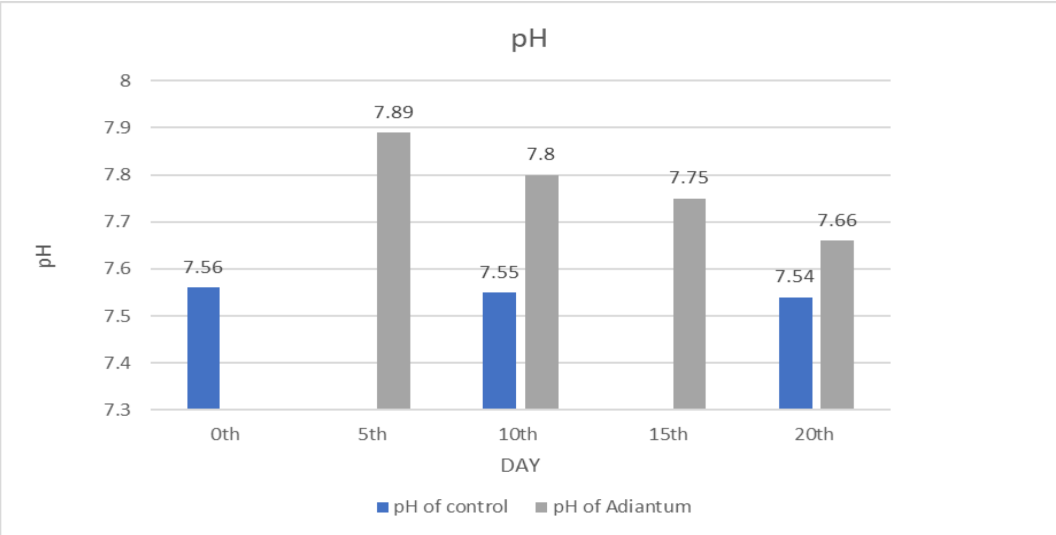

Figure 4.1 Changes in pH of the wastewater with and without *Adiantum* species during the experiment.

Heavy metal content in wastewater

The Cd heavy metal content in wastewater with *Adiantum* was estimated on 5th day, 10th day, 15th day and 20th day. Heavy metal content in wastewater without plant(control) is estimated on 0th day, 10th day and 20th day. The heavy metal content of control on 0th day, 10th day and 20th day is 2.99ppm, 1.60ppm , 1.02ppm. The heavy metal content in wastewater with plant estimated on 5th day , 10th day, 15th day and 20th day is 2.48ppm,1.33ppm,0.26ppm,0.31ppm respectively.

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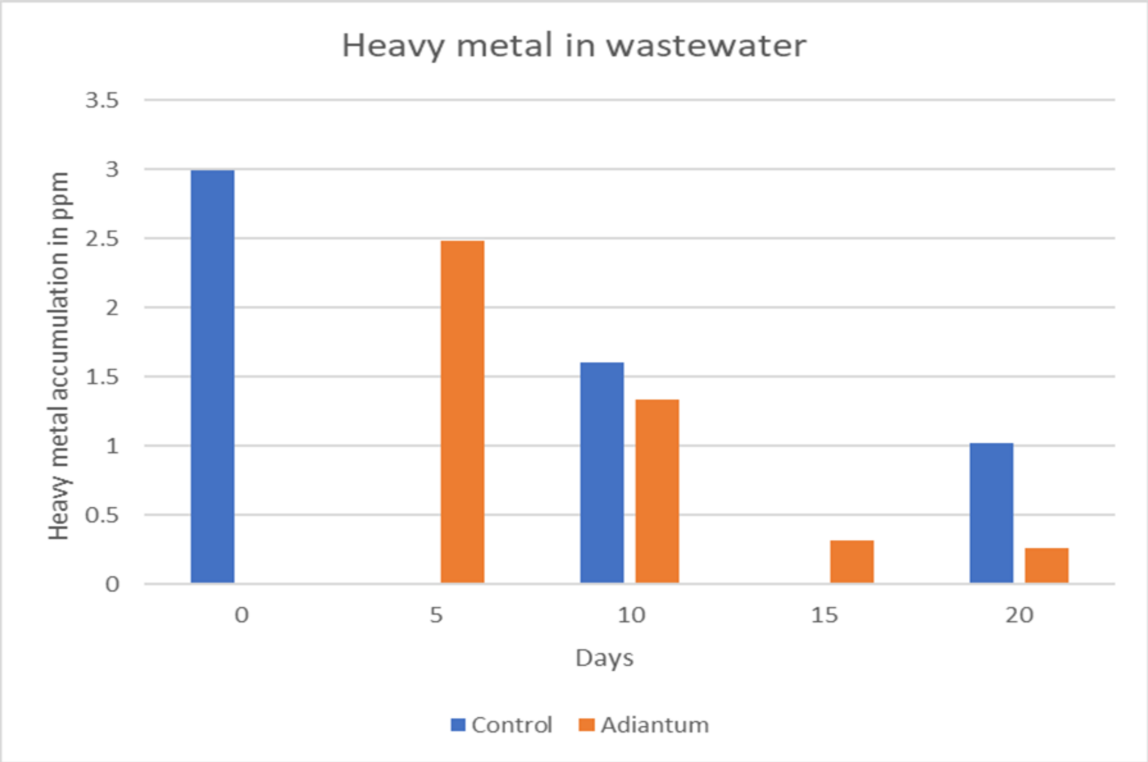


Figure 4.2 Changes in heavy metal content in wastewater with *Adiantum* and without *Adiantum*(control)

Heavy metal content in *Adiantum latifolium*

Cd accumulation in the rhizome, petiole and leaves of *Adiantum latifolium* is estimated on the 20^{th} day which is shown in Figure 4.3.It could be observed that the maximum accumulation (2.91mg/g dry weight) of Cd was observed in the rhizomes; leaves exhibited the least accumulation of metals(0.76mg/g dry weight).

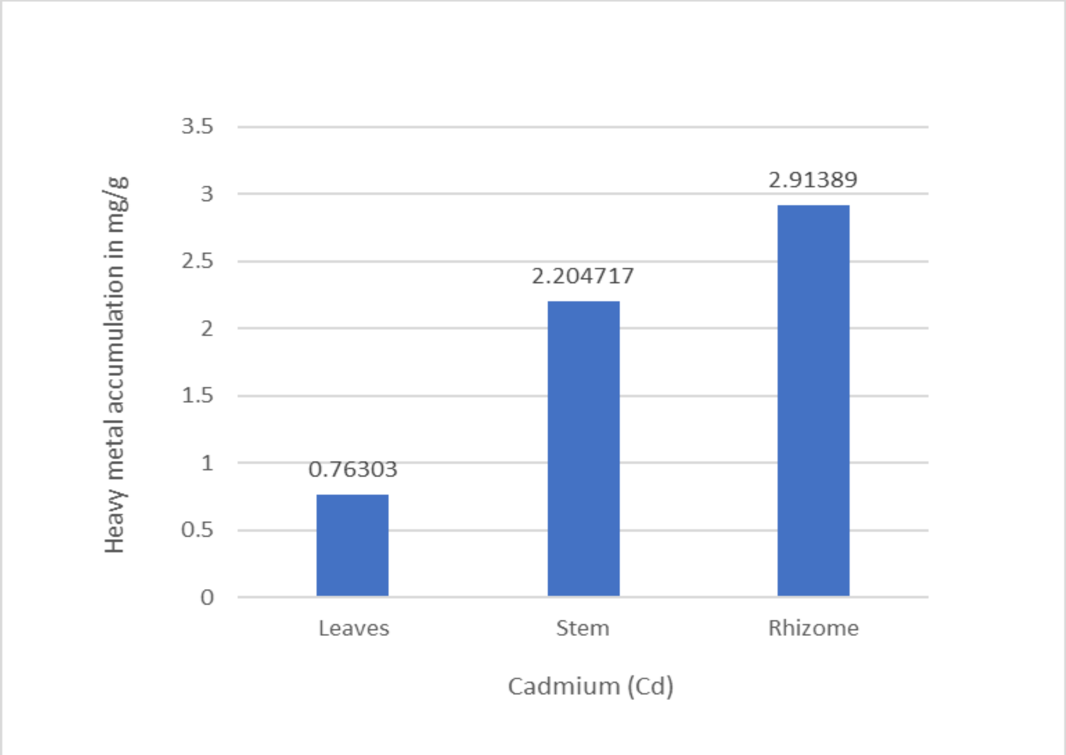


Figure 4.3 Shows the accumulation of heavy metal Cd in leaves, stem and rhizome

NANOPARTICLE SYNTHESIS

Visual Identification

Visual Identification is the primary characterization method that indicates synthesis of silver nanoparticles using leaf extract. The silver nanoparticles were synthesized when the combination of silver nitrate solution and the plant extract were exposed under sunlight. It was visually identified from the colour change of solution from light yellow to brown colour. The above process was very slow in the absence of sunlight, and it takes half an hour for the production of silver nanoparticles.

Optimization of silver nitrate: leaf extract ratio

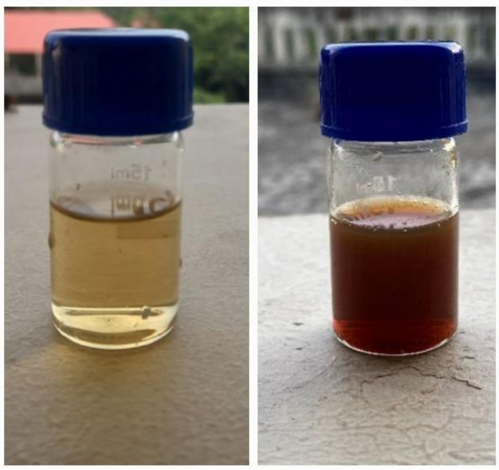
After designing different ratios of silver nitrate solution and plant leaf extract ,2:8 ratio of plant leaf extract and silver nitrate solution was selected for the synthesis of *Adiantum* based silver nanoparticles. 2:8 i.e.ratio of plant leaf extract to 1 mM $AgNO_3$ concentrated solution was found to be ideal for the synthesis of silver nanoparticles and they were exposed under bright sunlight for the Surface Plasmon Resonance. Table 4.1 describes about the optimization ratio of both the reaction media and their time consumed for the reaction to synthesis the silver nanoparticles.

Table 4.1 The optimization ratio of plant leaf extract to metal solution

SL No	Reaction media	Concentration of $AgNO_3$ solution	Optimized volume ratio of plant extract and $AgNO_3$	Reaction time
1	*Adiantum* reaction media	1mM	2:8	30 min of irradiation

UV-Visible spectral analysis of *Adiantum* based reaction media

UV-Visible spectroscopy is based on the absorption of electromagnetic radiation in UV-Visible region with a peak range of 200 to 800 nm wavelength to confirm the synthesis of silver nanoparticles. Stable silver nanoparticles were formed by treating aqueous solution of $AgNO_3$ with the plant extract as reducing agent for reduction of Ag^+ ions(Anarkali *et al*., 2012). The quantitative formation of synthesized silver nanoparticles were primarily examined by Ultraviolet-Visible (UV-Vis) spectroscopy. $AgNO_3$ shows surface plasmon resonance peaks between 420-460. The absorption spectrum of silver nanoparticle is shown in figure 4.6:UV– visible spectroscopic analysis of synthesized silver nanoparticles showed an absorbance peak at 420 nm. The UV-Vis spectrum of reaction media indicates the reduction silver nitrate to silver nanoparticles within 30 min of sunlight irradiation.



a) b)

Figure 4.4: Visual identification of silver nanoparticles synthesized by using *Adiantum latifolium* leaf extract. a) Initial colour of solution containing mixture of leaf extract and silver nitrate solution .b) Mixture showing colour change after 30 min of sunlight irradiation.

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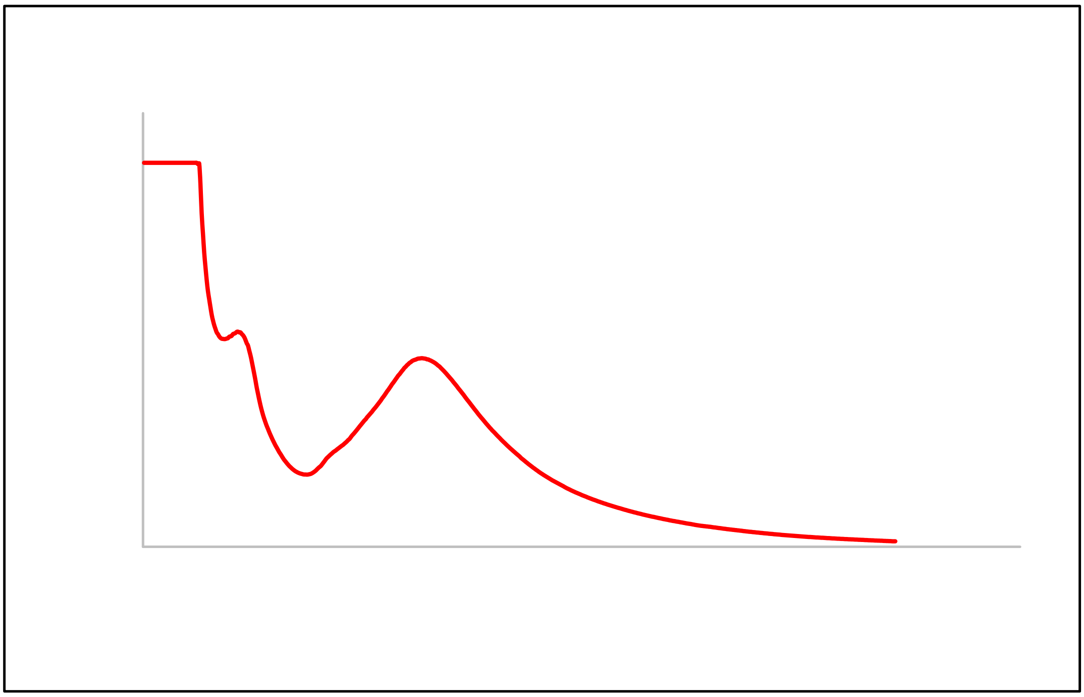

Fig 4.5: UV-Visible spectral analysis of silver nanoparticles of *Adiantum* based reaction media. The synthesized AgNPs using *Adiantum latifolium* leaf extract showed its spectral peak at 420 nm.

Dynamic Light Scattering (DLS) Technique

Dynamic light scattering was used to measure the distribution of the synthesized nanoparticles. The hydrodynamic diameters of *Adiantum latifolium* leaf extract based AgNPs in aqueous solution shown in figure 4.6 and DLS result shows that the synthesized silver nanoparticles meet nanoparticles range (<100 nm). Silver nanoparticles synthesized from *Adiantum* leaf extract had a polydispersity index of 0.484. The polydispersity index shows a homogeneous picture of the size distribution of particles in the solution phase and it generally calculated by dividing the average weight of the nanoparticles by the average amount of weight of the nanoparticles. If the value of polydispersity index is higher, then the size of the synthesized nanoparticles and it is not uniform. The recommended value for nanoparticle polydispersity index value is less than 0.5.

These results of present study indicate that the size of the nanoparticles synthesized from *Adiantum* leaf extract is more homogeneous because it has a polydispersity index value of less than 0.5 (Song et al., 2014; Sundeep et al., 2017; Roddu et al., 2019).

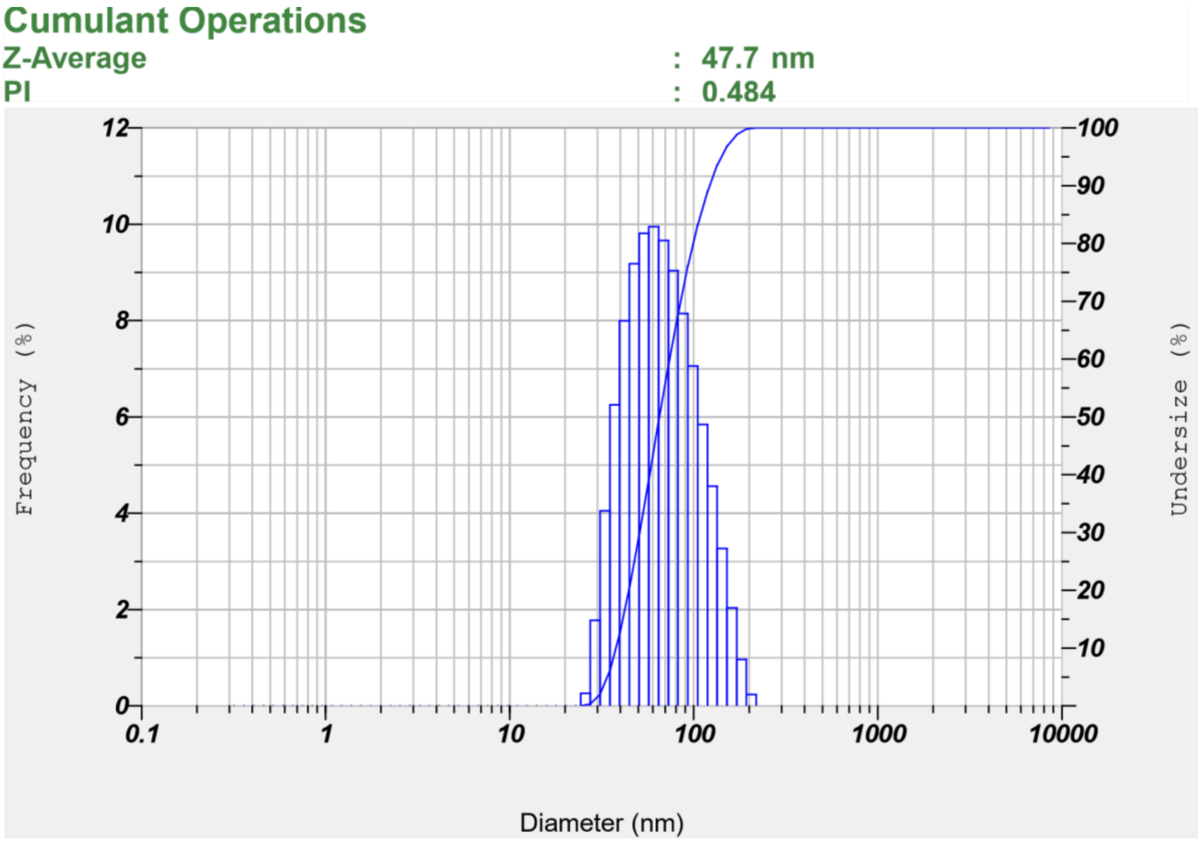

Fig 4.6: Particle size of *Adiantum latifolium* leaf extract mediated synthesized silver nanoparticles.

Fourier Transform Infrared (FTIR) spectroscopy

FTIR measurements were carried out to identify the presence of various functional groups in biomolecules responsible for the bio reduction of Ag+ and capping/stabilization of silver nanoparticles. The FTIR spectra of *Adiantum* leaf extract and biosynthesized silver nanoparticles are shown in Fig 4.7 FTIR spectra of synthesised AgNPs showed absorption peaks at 3325.02, 2609.61, 1651.65, 1082.07cm^{-1}. FTIR spectra of *Adiantum* leaf extract showed absorption peaks at 3300.47, 2585.79, 1640.10, 1069.80cm^{-1}. A broad peak at 3300.47cm^{-1} for *Adiantum* leaf extract and 3325.02cm^{-1} for synthesized silver nanoparticles is characteristic of the O-H stretching vibration, presence of carboxylic acid and H- bonded, O-H stretch hydroxyl compound, alcohols , phenols. The peaks at 2585.79cm^{-1} for plant leaf extract and 2609.61cm^{-1} for synthesized silver nanoparticles is the characteristic of O-H stretch and presence of carboxylic group. The peak at 1640.10$cm^{-1} and$ 1651.65cm^{-1} is due to the presence of C=C stretch and alkenes. The peak at 1069.80cm^{-1} and 1082.07cm^{-1} is the characteristic of C-O stretch and presence of alcohols, carboxylic acids, esters and ethers. It is evident that the biosynthesis of silver nanoparticles is based on their secondary metabolites present in the plant leaf extract. According to different research works, the presence of these important secondary metabolites have major role in biosynthesis of nanoparticles and may play a significant role in the formation, reduction, capping and stabilization of silver nanoparticles. It is evident from the foregoing that the leaves of *Adiantum* are rich in biomolecules that served as bio reductants to synthesize AgNPs.

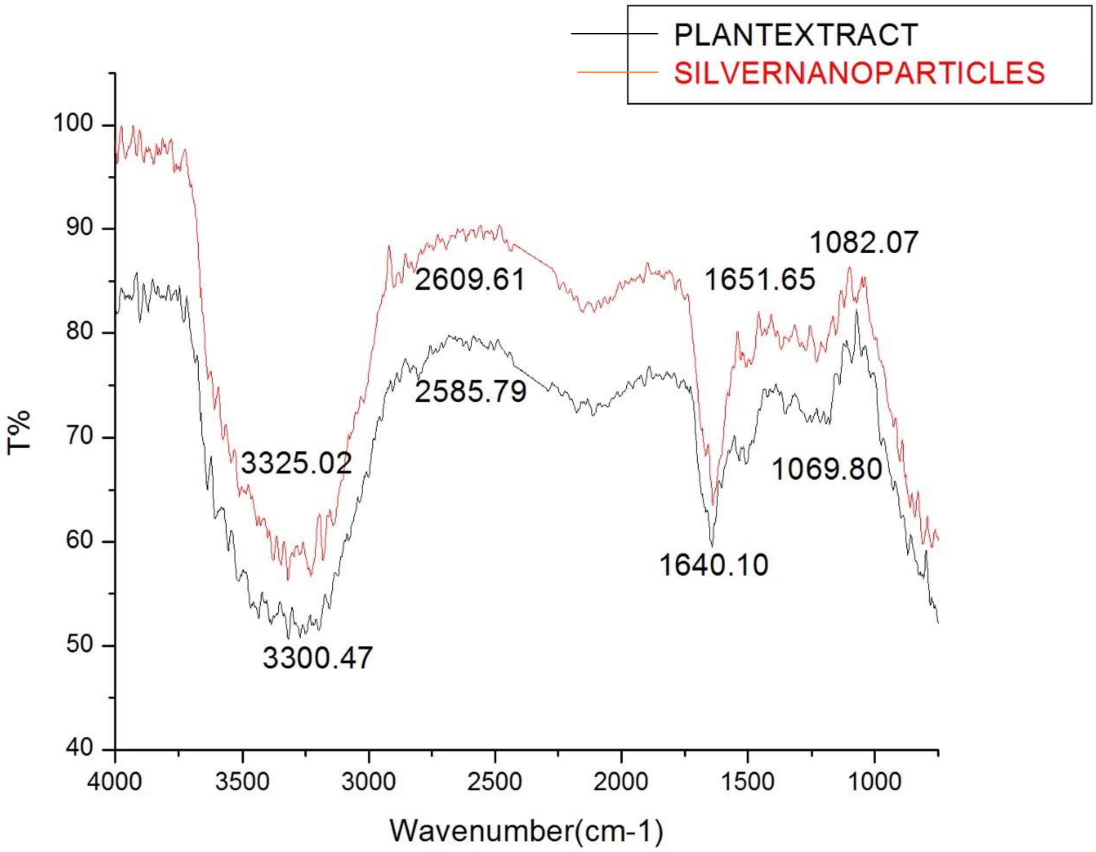

Fig 4.7: FTIR spectra of silver nanoparticles and *Adiantum* plant extract.

XRD Analysis *Adiantum* Based silver nanoparticles

The XRD spectrum was recorded to confirm the crystalline structure of the biosynthesized silver nanoparticles using *Adiantum* leaf extract. The XRD pattern of silver nanoparticles show number of Bragg's reflection and revealing its crystallite nature in the nano-regime. The powdered X-ray Diffraction spectrum of *Adiantum* based silver nanoparticles shows distinct peaks at 2θ position. From the obtained results of diffractogram shown in figure 4.8 six peaks at 2θ values of 21.17 ,27.62 , 32.05 ,37.89 ,46.03 , 54.63 degree in the experimental diffractogram have been identified to be due to silver metal and corresponding to planes of to (hkl) values - (100), (110), (111) , (121) , (200) , (220) of the cubic face centered silver.

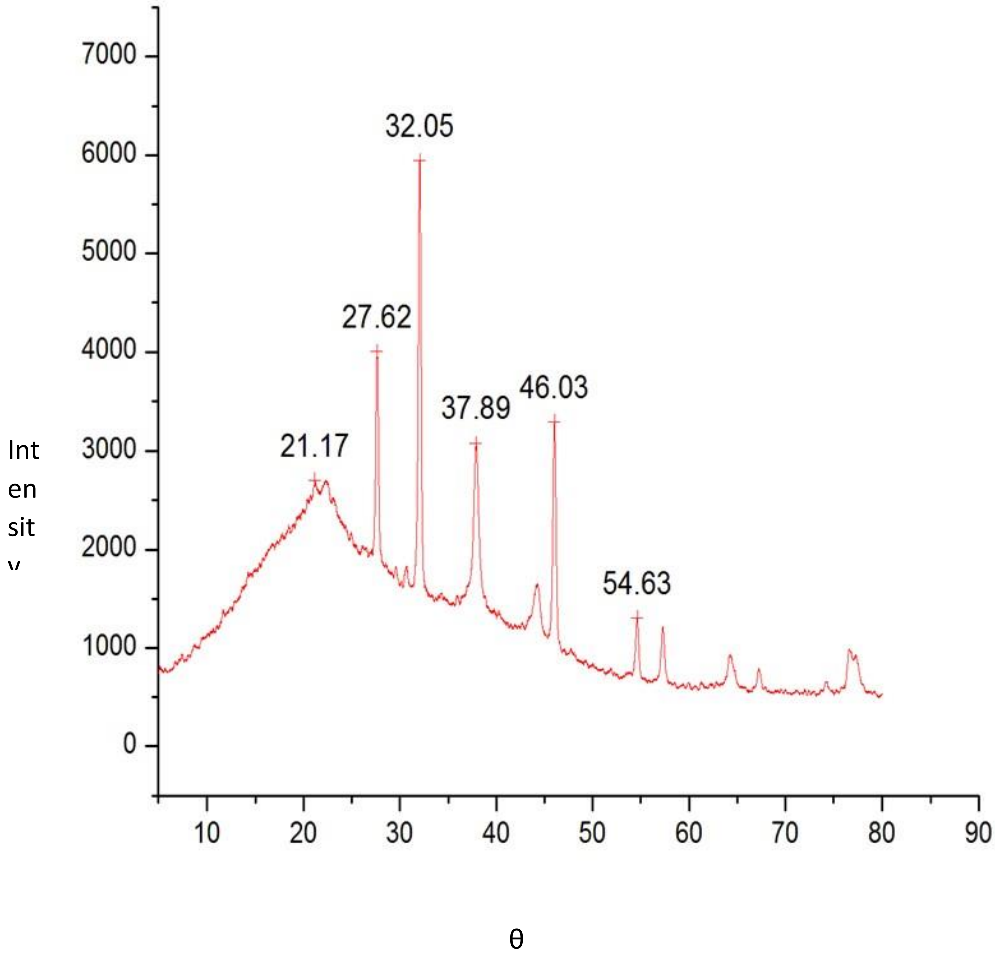

Figure 4.8: Shows the X-ray diffractogram of Ag NPs synthesized from *Adiantum latifolium*

Transmission Electron Microscope (TEM)

Transmission Electron Microscope was used to determine the size and shape of the nanoparticles. TEM analyses confirmed the presence of synthesized silver nanoparticles in sample which is the mixture of *Adiantum* leaf extract and silver nitrate solution. The Transmission electron microscope image of *Adiantum latifolium* leaf extract synthesized silver nanoparticles was shown in figure 4.9. The TEM images of silver nanoparticles synthesized in the present study shows that the nanoparticles were spherical in nature. The image signify that the synthesized silver nanoparticles size was 10nm.

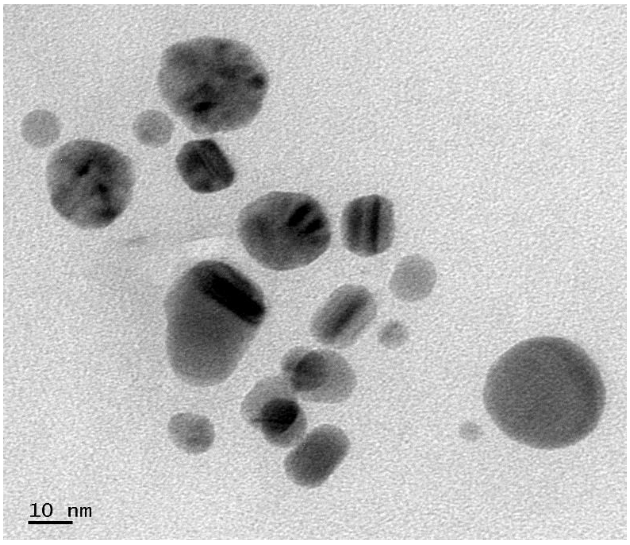

Fig 4.9: TEM micrograph of *Adiantum* based silver nanoparticles.

SUMMARY AND CONCLUSION

Phytoremediation

Phytoremediation is a cost- effective method for environmental redressal that use plants to clean up the soil, air and water that have been contaminated by the chemicals.The effect of Cd on synthetic wastewater is decreased as the exposure time increased . The heavy metal content in wastewater is estimated .The maximum accumulation of Cd heavymetal is observed in rhizome (2.91389mg/g dry weight) and minimum accumulation is observed in leaves(0.76303mg/g dry weight). pH of the wastewater was examined and shows that changes in pH values were not significant between control and *Adiantum* grow in wastewater. The overall result of this study indicates that *Adiantum latifolium* possess the potential to accumulate Cd in its tissues particularly in the rhizomes .The plants could survive well for 20 days.

Nanoparticle synthesis

Green synthesis of nanoparticles refers to the synthesis of different metal nanoparticles using bioactive agents such as plant materials, microorganisms, and various biowastes including vegetable waste , fruit peel waste ,eggshell etc is biologically safe ,cost effective and environment friendly. The present study confirmed the synthesis of silver nanoparticles from plant leaf extract of *Adiantum latifolium* through the reduction of silver nitrate metal solution under sunlight irradiation. The synthesized nanoparticles were characterized through visual identification by the colour change in the sample media then it is subjected to UV- Visible spectroscopy ,Dynamic Light Scattering, Fourier – Transform Infrared Spectroscopy, X- ray diffraction and Transmission Electron Microscopy.

The quantitative formation of synthesized silver nanoparticles were primarily examined by Ultraviolet-Visible (UV-Vis) spectroscopy for surface plasmon resonance (SPR) peak at 420 to 460 nm. UV–visible spectroscopic analysis of synthesized silver nanoparticles showed an absorbance peak at 420 nm.

From DLS result it was found that silver nanoparticles synthesized from *Adiantum* leaf extract had a polydispersity index of 0.484 and has an Z-average 47.7nm. Present study indicate that the size of the nanoparticles produced from *Adiantum* leaf extract is more homogeneous because it has a polydispersity index value of less than 0.5.

FTIR spectra of synthesised AgNPs showed absorption peaks at 3325.02, 2609.61, 1651.65, 1082.07cm^{-1}. FTIR spectra of *Adiantum* leaf extract showed absorption peaks at 3300.47, 2585.79, 1640.10, 1069.80cm^{-1}.It is evident that the biosynthesis of silver nanoparticles is based on their secondary metabolites present in the plant leaf extract. . FTIR analysis confirmed that the bio reduction of Ag^{+} ions to silver nanoparticles are due to the reduction by capping material of plant extract. The powdered X-ray Diffraction spectrum of *Adiantum* based silver nanoparticles shows distinct peaks at 2θ position. The TEM images of silver nanoparticles synthesized in the present study shows that the nanoparticles were spherical in nature. The image signify that the synthesized silver nanoparticles size was 10nm.

CONCLUSIONS

The potential of *Adiantum latifolium* in removal of heavy metal Cd from wastewater is encouraging.

The plant remained healthy and survived well in the synthetic wastewater spiked with 4ppm Cd which is a positive indication of using this plant for the phytoremediation of wastewater polluted with 4ppm of concentration.

The leaf extract of the fern, *Adiantum latifolium* are appropriate for the synthesis of silver nanoparticles.

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