PROCEEDINGS OF NATIONAL CONFERENCE ON

Techno –Traditional Indian Knowledge Systems on Eco-Sensitive Coastal Settlement Planning

26-27 September 2024

Krishnaveni Sabhagaar, SPA Vijayawada

TTIKS 2024

Organized By

School of Planning and Architecture, Vijayawada

In association with

Institute of Town Planners, India &

Andhra Pradesh Regional Chapter, Vijayawada

Jointly Organized By

School of Planning and Architecture, Vijayawada

Institute of Town Planners India

NATIONAL CONFERENCE ON

TECHNO-TRADITIONAL INDIAN KNOWLEDGE SYSTEMS ON ECO-SENSITIVE COASTAL SETTLEMENT PLANNING

TTIKS – 2024

National Conference Proceedings 2024

Sy. No. 4/4 ITI Road, Vijayawada 520008, Andhra Pradesh, India

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About the Conference

The planning and design of coastal zones - with respect to constantly changing eco-systems, demographic requirements, economic potentials and threats due to climate hazards – is a domain of intense intellectual speculation, administrative potential and research dimension. Further, incorporating Indian Knowledge Systems can provide useful insights and approaches to coastal planning and design. Traditional methods such as Vastu Shastra and Traditional Ecological Knowledge (TEK) can help to harmonize human settlements with natural surroundings by considering ecological balance, resource sustainability, and climatic resilience.

In this regard, the two-day 'National Conference on Techno-Traditional Indian Knowledge Systems for Eco-Sensitive Coastal Settlement Planning' was organised by the School of Planning and Architecture, Vijayawada (SPAV) in collaboration with the Institute of Town Planners, India (ITPI) and ITPI Andhra Pradesh Chapter. The conference was conducted at the School of Planning and Architecture, Vijayawada on 26th and 27th September 2024.

The conference brought together professionals, practitioners, academicians and researchers working in the realm of coastal corridors and embracing aspects of traditionality and vernacularity in settlement planning and design, a theme highly pertinent in the current scenario. The conference offered a dynamic platform to explore the synergy between modern technology and ancient wisdom in fostering sustainable development and resilience along India's coastal regions.

The Conference had a total of 71 registered participants, 14 paper submissions, and 2 poster presentations, hosted 7 technical sessions chaired by eminent person from the field of planning and architecture featuring 13 expert speakers and 9 young planners. The experts and stakeholders delved into innovative technical and methodological approaches that integrate digital mapping, GIS applications, and early warning systems with indigenous knowledge systems. Discussions revolved around reviving traditional practices and traditional knowledge systems that enhance disaster preparedness and promote sustainable livelihoods in coastal corridors. Through case studies and collaborative sessions, the conference aimed to empower coastal communities, bridging the gap between innovation and heritage for a resilient coastal future.

Organisers

School of Planning and Architecture, Vijayawada – A Brief

School of Planning and Architecture, Vijayawada (SPAV) was established in 2008 by the Ministry of Human Resource Development (MHRD), Ministry of Education (MoE), Government of India, as an autonomous institution. SPAV is a premier Centrally Funded Technical Institution (CFTI) for excellence in the fields of Planning and Architecture.

Institute of Town Planners, India – A Brief

Institute of Town Planners, India (ITPI) is the apex body of town planners in India & was constituted in the year 1951. ITPI has a vision to promote dynamic, inclusive and integrated town and country planning practice, education, research and institutional mechanism for vibrant, sustainable and resilient spatio-economic development of towns, cities and regions.

Message from Patron

Dr. Ramesh Srikonda
Patron TTIKS 2024
Director, SPA Vijayawada

It is with great joy that we present the conference proceedings of extended abstracts for the National Conference on **'Techno-Traditional Indian Knowledge Systems on Eco-Sensitive Coastal Settlement Planning'**, jointly organized by the School of Planning and Architecture (SPA), Vijayawada and Institute of Town Planners India (ITPI).

As environmental challenges continue to grow, particularly in our vulnerable coastal regions, the importance of eco-sensitive settlement planning cannot be overstated. Rising sea levels, erratic weather patterns, climate change, and frequent natural disasters threaten both the environment and the lives of people who inhabit these areas. These challenges underscore the need for innovative planning models that prioritize sustainability and resilience, ensuring development occurs without compromising natural ecosystems. By learning from traditional Indian knowledge systems, we can rediscover age-old practices that offer solutions to creating settlements in harmony with nature, reducing the risk of damage and promoting long-term sustainability. The setting up of a Centre for Capacity Building in Urban Planning in SPA Vijayawada funded by the Ministry of Housing and Urban Affairs is a step towards this fulfilment.

This conference brings together architects, planners, engineers, and policymakers to explore how traditional coastal settlement practices, when combined with modern technological approaches, can guide the development of sustainable and adaptive urban and regional planning strategies. The objective is to inspire a shift in how we approach urbanization in coastal areas, advocating for planning that is energy-efficient, climate-adaptive, and sensitive to the ecological context. Through this event, we seek to foster meaningful dialogues on implementing these concepts, ensuring that future development is both environmentally conscious and socially equitable. This fusion of tradition and technology is key to preparing our coastal settlements for the challenges of tomorrow.

Wishing the conference all success and sincerely hoping it imparts enhanced knowledge on the subject to everyone attending it.

Message from Patron

Shri N.K. Patel
Patron TTIKS 2024
President, ITPI

I am happy that Institute of Town Planners India is collaborating with various planning institutes like SPAS, NITs and other Universities in organising Conferences/ Seminars/ Workshops etc.to promote planning education and profession in the country. Present Council of ITPI has initiated many professional and administrative reforms to achieve objectives more effectively.

The theme selected by SPA Vijayawada and ITPI as Techno-Traditional Indian Knowledge Systems for Eco-Sensitive Costal Zone Planning is pertinent in the present national and global context as half of the world's population lives within the 200 kms of coastline. Coastal areas attract the human settlements as they provide abundant opportunities of livelihood.

In India there are 13 coastal states/UTs which are affected by cyclones and threatened by Natural Hazards result into loss of human life and properties in these states. Andhra Pradesh is highly vulnerable to such hazards. India faced super cyclone. In 1999, Tsunami in 2004 and Bhuj earthquake in 2001 which led to shift the focus from emergency response to rescue and rehabilitation to proactive preparedness, capacity building and mitigation measures.

These days due to impact of climate change the pattern of rainfall has changed which resulted into unscheduled rainfall and it leads to urban flooding. Urban infrastructures are most affected due to urban flooding in most of the cities in the country. The problem of urban flooding has tremendous impact on urban population which needs to be addressed in urban areas in general and coastal cities in particular as their problem gets further aggravated being located along the coast.

To address the above requirements of mitigation of coastal hazards, application of latest technology along with the traditional ecological knowledge is the effective tool. On the one hand it is imperative to adopt latest technologies to develop early warning system and on the other traditional Indian Knowledge System to sensitize coastal communities, go hand in hand to pave the future way for developing an Integrated model for Disaster Risk Reduction, hence the theme of this conference is justified. I hope with the deliberations during the conference certain useful take-aways will be available for the participants and other stakeholders will also be benefitted.

I wish the Conference a great success.

Message from Patron

Shri Pradeep Kumar
Patron TTIKS 2024
Coordinator, ITPI

The coasts are one of the highly dynamic parts of the earth surface. About half of the world's population lives within 200 kilometres of a coastline. Approximately 8000 km long coastline of India is threatened by many natural hazards resulting in the loss of life and property. About 40% of the total population of India lives within 100 km of coastline. There are 13 coastal states/UTs encompassing 84 coastal districts which are affected by cyclones. Amongst them **Andhra Pradesh**, Odisha, Tamil Nadu and West Bengal and Puducherry (UT) on the East Coast and Gujarat state on the West Coast are more vulnerable to cyclone disasters as compared to other coastal states like Maharashtra, Goa, Kerala and other UTs.

As a result of climate change, rise in sea level will be a serious threat for India with its coastline. To reduce the loss of life and properties in the event of future cyclones and related hydro-met hazards, the National Cyclone Risk Mitigation Project (NCRMP) was launched by the Ministry of Home Affairs, with support from the World Bank, in the cyclone-prone coastal states. The objective of the project was to reduce the vulnerabilities of the coastal population by undertaking various structural and non-structural measures Building capacity and capability of local communities to respond to disasters; strengthening Disaster Risk Mitigation (DRM) capacity at Central, State and local level to mainstream risk mitigation measures in development agenda.

Besides the use of latest technology for early warning systems all the effective traditional knowledge that exists has to be documented and captured by using modern techniques. As traditional knowledge holds vast observational data of natural phenomenon, it can help the modern conventional science to understand and analyse natural hazards in more precise ways. Modern technological data alone will not be able to contribute to improve people’s lives unless these are combined with an understanding of local contexts and needs.

In the light of the above the theme selected by SPA Vijayawada and ITPI as **‘Techno-Traditional Indian Knowledge Systems on Eco-Sensitive Coastal Settlement Planning’** will help sensitizing not only the planners but also other stakeholders. The presentations and panel discussions during the two-day conference will formulate useful recommendations for all stakeholders to respond to mitigate coastal disasters in future and develop a sustainable coastal community.

Message from Dean Academic

Prof. Dr. Ayon K Tarafdar
Dean (Academic)
SPA Vijayawada

Any congregation of academics, researchers, and professionals from practise is always an ideal platform of fruitful exchange that can help academics identify a focus as needed by the industry and practitioners identify innovative solutions as offered by educational and research institutions. The "2-day National Conference on Techno-Traditional Indian Knowledge Systems for Eco-Sensitive Coastal Settlement Planning" as envisioned by SPA Vijayawada in collaboration with the Institute of Town Planners, India (ITPI) is such an initiative where practitioners, academics and researchers will mingle, deliberate and share their experience and knowledge for a particular cause.

The theme was an outcome of several discussions between SPAV and ITPI whereby it was felt that there is a need to put into attention, the 'Traditional Indian Knowledge Systems' that exist in the domain of Planning particularly in aspects of dealing with Ecology, Hazards and Coastal belts. Andhra Pradesh has one of the longest coastlines of the country and is often witness to harsh climatic phenomena arisen out of climate deviations. Traditionally, the settlements along the coast and in the region in general, had been dealing with natural hazards and development over centuries in a particular manner. Modern techniques that employ the advanced computing, simulations and remote sending data can help and align with many of the traditional methods in innovative manners and there is always a possibility to find areas of synergy between the modern and the orthodox.

This platform for 2 days shall open up the window to bring in lights of both dimensions – that is research and practise that is rooted in the traditional Indian Knowledge Systems and the modern, stemming from algorithms that can evolve artificial patterns. I congratulate the presenters and have confidence that this conference shall build the right networks for problem solving and for innovation.

Conference Schedule

Inaugural Session

Welcome Address by Shri V. P. Kulshrestha, Secretary General, ITPI

Address by Dr. Ayon Kumar Tarafdar, Dean Academic, SPA Vijayawada

Address by Shri Pradeep Kapoor, Council member and Ex-Secretary General, ITPI and BoG Member, SPA, Vijayawada

Inaugural Address by Dr. Ramesh Srikonda, Director, SPA Vijayawada

Presidential Address by Shri Anoop Srivastava, Vice President, ITPI

Address by Chief Guest Dr. P. Narayana, Hon'ble Minister for Municipal Administration & Urban Development, Government of Andhra Pradesh

Felicitation of the Dignitaries

Vote of Thanks by Shri K. V. Uma Maheswara Rao, Registrar, SPA Vijayawada

National Anthem

Day 1 - Theme 1: Exploring the Intersection of Technology and Traditional Knowledge in Coastal Area Planning

TECHNICAL SESSIONS		
Technical Session 1a: Reviving Traditional Indian Knowledge Systems: Lessons from Coastal Communities Addressing Functional, Spatial, Economic, and Social Needs		
A. Session Chair:	Dr. Iyer Vijayalaxmi Kasinath, Professor, SPA Vijayawada	(5 mins)
B. Expert Speaker 1:	Dr S. Mohammed Irshad, Faculty, Centre for Disasters and Development, Jamsetji Tata School of Disaster Studies	(15 mins)
C. Expert Speaker 2:	Dr. Janmejoy G, Dean Research, SPA Vijayawada	(15 mins)
D. Paper Presentation by Young Planner:	Ar. Sheetal Kalbandhe, Young Planner	(10 mins)
E. Paper Presentation by Young Planner:	Ms. Srajati Tiwari, Young Planner	(10 mins)
F. Rapporteur:	Mr. Rajeev R., Faculty, SPA Vijayawada	(5 mins)
Felicitations		
Technical Session 1b: Technological Innovations in Coastal Settlement Planning: Opportunities and Challenges		
A. Session Chair:	Dr. Sanjay Gupta, Professor, SPA, Delhi	(5 mins)
B. Expert Speaker 1:	Dr. Ajay Katuri, Consultant, Climate Change and Technical Facilitation Expert	(15 mins)
C. Expert Speaker 2:	Dr. RNS Murthy, Faculty, SPA Vijayawada	(15 mins)

D. Paper Presentation by Young Planner:	Ms. Akkala Bhavitha, Young Planner	(10 mins)
E. Rapporteur:	Dr. Arpan Paul, Faculty, SPA Vijayawada	(5 mins)
Felicitations		
Technical Session 1c: Sustainable Resource Management: Combining Modern Technology with Indigenous Practices		
A. Session Chair:	Shri V. P. Kulshrestha, Secretary General, ITPI	(5 mins)
B. Expert Speaker 1:	Shri Rajneesh Sareen, Program Director, CSE, New Delhi	(15 mins)
C. Expert Speaker 2:	Ar. Xavier Benedict, AARDE Foundation	(15 mins)
D. Paper Presentation by Young Planner:	Ms. Shreedha S., Young Planner	(10 mins)
E. Rapporteur:	Dr. Subhashish Banerjee, Joint Director, Town & Country Planning, Indore, MP	(5 mins)
Felicitations		

Day 2 – Theme 2: Disaster Mitigation and Resilience through Techno-Traditional Approaches

Keynote Speech - Dr. Amir Ali Khan, Faculty, NDMA, New Delhi (online)		
Technical Session 2a: Indigenous Perspectives on Coastal Disaster Risk Reduction: Harnessing Traditional Wisdom for Resilient Communities		
A. Session Chair:	Dr. Ayon Tarafdar, Dean Academic & Professor, SPA Vijayawada	(5 mins)
B. Expert Speaker 1:	Dr. Aparna, Faculty, NIRMA University, Ahmedabad	(15 mins)
C. Paper Presentation by Young Planner:	Mr. Hanumanth Ram, Young Planner	(10 mins)
D. Paper Presentation by Young Planner:	Ms. Dhanushyaa, Young Planner	(10 mins)
D. Rapporteur:	Ms. Ekta, Faculty, SPA Vijayawada	(5 mins)
Felicitations		
Technical Session 2b: Early Warning Systems and Remote Sensing: Enhancing Coastal Disaster Preparedness with Modern Technology		
A. Session Chair:	Dr. N. Sridharan, Former Director, SPA Bhopal and SPA Vijayawada	(5 mins)
B. Expert Speaker 1:	Dr. Faiz Ahmed C, Faculty, SPA Vijayawada	(15 mins)
C. Expert Speaker 2:	Dr. Prashanti Rao, Faculty, SPA Vijayawada	(15 mins)
D. Paper Presentation by Young Planner:	Mr. Yamin R, Young Planner	(10 mins)
E. Rapporteur:	Mr. Rajeev R., Faculty, SPA Vijayawada	(5 mins)
Felicitations		

Technical Session 2c: Sustainable Livelihoods and Economic Resilience: Techno-Traditional Solutions for Coastal Communities		
A. Session Chair:	Dr. Adinarayanane R, Dean (P&D), SPA Vijayawada	(5 mins)
B. Expert Speaker 1:	Dr. Panneerselvam A, LEA Associates, New Delhi	(15 mins)
C. Expert Speaker 2:	Dr. Solanki Ghosh, Faculty, SPA Delhi	(15 mins)
D. Paper Presentation by Young Planner:	Mr. Saishree Naik, Young Planner	(10 mins)
E. Rapporteur:	Dr. Prasanth Vardhan, Faculty and HoD, DoP, SPA Vijayawada	(5 mins)
Felicitations		
Technical Session 2d: Capacity Building and Knowledge Transfer: Empowering Coastal Settlements for Effective Disaster Response		
A. Session Chair:	Shri V. P. Kulshrestha, Secretary General, ITPI	(5 mins)
B. Expert Speaker 1:	Dr. Anurag Bagade, Faculty, SPA Vijayawada	(15 mins)
C. Expert Speaker 2:	Dr. Naina G., Faculty, SPA Vijayawada	(15 mins)
D. Paper Presentation by Young Planner:	Ms Lipi Shrivastava, Student, SPA Vijayawada	(10 mins)
E. Rapporteur:	Dr. Rajakumari M., Faculty, SPA Vijayawada	(5 mins)
Felicitations		

Valedictory Session & Closing Ceremony

Welcome Address by Dr Prasanth Vardhan, Head-DoP, SPA Vijayawada

Concluding Remarks by Dr. Ramesh Srikonda, Director, SPA Vijayawada

Address by Shri Pradeep Kapoor, Council member and Ex-Secretary General, ITPI and BoG Member, SPA, Vijayawada

Felicitation of the Chief Guest

Address by the Chief Guest, Dr. P. B. Vijayakumar, Senior Designated Counsel in the Hon’ble High Court of Andhra Pradesh and Telangana

Release of Deliberations by Chief Guest, Director SPA Vijayawada, and Dignitaries on the dais

Vote of Thanks by Shri V. P. Kulshreshtha, Secretary General, ITPI

National Anthem

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PROCEEDINGS

TECHNICAL PAPERS OF THE CONFERENCE

THEME 1

EXPLORING THE INTERSECTION OF TECHNOLOGY AND TRADITIONAL KNOWLEDGE IN COASTAL AREA PLANNING

Reviving traditional Indian knowledge systems for enhanced Coastal planning

Sheetal Kalbandhe [a*]

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Abstract

Coastal regions have historically depended on Indigenous Knowledge Systems (IKS) to ensure long-term viability and catastrophe resilience. This study investigates several traditional approaches used in disaster management in coastal Tamil Nadu, the Andaman and Nicobar Islands, and the Mumbai area of Maharashtra. This project will identify these traditions and investigate their possible integration with current technology by analyzing publicly available material such as scholarly publications, reports, and case studies. The study will look at how these ancient techniques may complement modern technical approaches, as well as provide insights into their practical use in current coastal management policies. The study emphasizes the significance of maintaining these rich information systems, which, although being passed down orally through generations, are at risk of extinction. Consider the confluence of old knowledge with contemporary tools,this paper contributes to the on-going discourse on enhancing resilience and sustainability in coastal regions.

Keywords: Indigenous knowledge, Costal planning, Climate resilience, Technological Integration

1. INTRODUCTION

Coastal regions are among the most vulnerable to natural disasters, facing threats from cyclones, tsunamis, and sea-level rise. For generations, indigenous communities have developed a wealth of knowledge to predict, manage, and mitigate risk o disaster. These traditional practices, comes from understanding of local environment, have been passed down through stories, songs, and oral traditions, forming an integral part of the cultural heritage of these communities which can be seen in many parts of the world.

However, as modern technology has taken precedence in disaster management, the invaluable insights offered by Indigenous Knowledge Systems (IKS) are increasingly at risk of being lost. In Bangladesh it has been observed that local communities demonstrated an uncanny ability to anticipate disasters—sometimes more accurately than modern early warning systems. IK is being lost because we are not maintaining it properly. Such examples underscore the critical importance of preserving and integrating this traditional knowledge into contemporary coastal management strategies.

The purpose of this research paper is to identify and document the indigenous practices related to disaster management in coastal regions, with a focus on the fisheries sector as discussed in the works of Sethi et al. and Nirmale et al. By analyzing the effectiveness of these practices, the study aims to propose a model for integrating them with modern technological tools, thereby enhancing the resilience and sustainability of coastal communities. In doing so, this paper advocates for the preservation of these traditional knowledge systems, which, despite their declining presence in the modern world, hold immense potential for improving contemporary disaster management frameworks. Through this exploration, the research seeks to contribute to the broader discourse on sustainable coastal management and the role of traditional knowledge in shaping a resilient future.

2. PROBLEM STATEMENT

Research on indigenous knowledge (IK) in disaster management is currently limited, with available data often scattered and difficult to access, posing significant challenges for further study and application. This fragmentation hinders the integration of IK with modern strategies, limiting its potential for creating sustainable, culturally sensitive disaster management solutions. To address this gap, my research consolidates and organizes relevant information. This effort aims to provide a more cohesive and accessible resources that can facilitate future research and enhance the understanding and application of IK in disaster management.

3. METHODOLOGY

The methodology for this research is primarily based on secondary source data collection. This involves gathering, analyzing, and synthesizing existing information from a wide range of academic articles, books, reports, and credible online resources related to indigenous knowledge (IK) in disaster management. The research draws on published studies, historical accounts, and documented practices of traditional communities. By collating data from these diverse sources, the study aims to provide a comprehensive understanding of indigenous practices and their potential integration with modern disaster management strategies. The secondary data was meticulously selected and reviewed to ensure relevance and accuracy, with the goal of creating a more cohesive resource for future research in this underexplored field.

4. LITERATURE REVIEW

The literature on Indigenous knowledge (IK) in coastal disaster management reveals a valuable yet underexplored area of study. This review synthesizes existing research, focusing on how IK contributes to resilient and sustainable coastal communities, especially in disaster-prone regions. By examining historical contexts and integrating case studies, this review highlights the effectiveness of traditional practices and identifies areas for further research.

Director General of UNESCO (Mayor, 1994) defined traditional knowledge as:

…The indigenous people of the world possess an immense knowledge of their environments, based on centuries of living close to nature. Living in and from the richness and variety of complex ecosystems, they have an understanding of the properties of plants and animals, the functioning of ecosystems and the techniques for using and managing them that is particular and often detailed. Equally, people's knowledge and perceptions of the environment, and their relationships with it, are often important elements of cultural identity.

4.1.1 What is indigenous knowledge?

The terms 'traditional,' 'local,' and 'indigenous' knowledge are often used interchangeably in academic discourse, yet ‘indigenous knowledge’ (IK) has emerged as the more prevalent term. However, this term is sometimes mistakenly applied to categories of locally produced information that do not truly constitute IK. For example, the development of local literature databases or the creation of institutional repositories, as discussed by Sukula (2006) and TJiek (2006), fall outside the scope of what should be considered IK. Indigenous knowledge specifically refers to the culturally distinct knowledge inherent to a particular community, setting it apart from the global knowledge systems developed by universities, research institutions, and private enterprises. This knowledge is crucial for local-level decision-making in areas such as agriculture, healthcare, food preparation, education, and natural resource management within rural communities (Warren, 1991, as cited in World Bank, 1998). Furthermore, Flavier et al. (1995) describe IK as a dynamic information base for societies, one that not only facilitates communication and decision-making but also evolves through internal innovation and external interactions.

4.1.2 Meaning of Traditional Knowledge

Traditional Knowledge (TK), variously referred to as ‘traditional knowledge‘, ‘traditional ecological knowledge‘, ‘local knowledge‘, ‘folk knowledge’ is knowledge developed by local and indigenous communities over time in response to the needs of their specific local environment. The World Intellectual Property Organization (WIPO) defines traditional knowledge as “indigenous cultural and intellectual property,” indigenous heritage,” and customary heritage rights.2 The need to protect the traditional knowledge captured the attention of the international community. Indigenous knowledge (IK) is the local knowledge-knowledge that is unique to a given culture or society. Warren (1991) IK refers to the unique, traditional, local knowledge existing within and developed around the specific conditions of women and men indigenous to a particular geographic area.

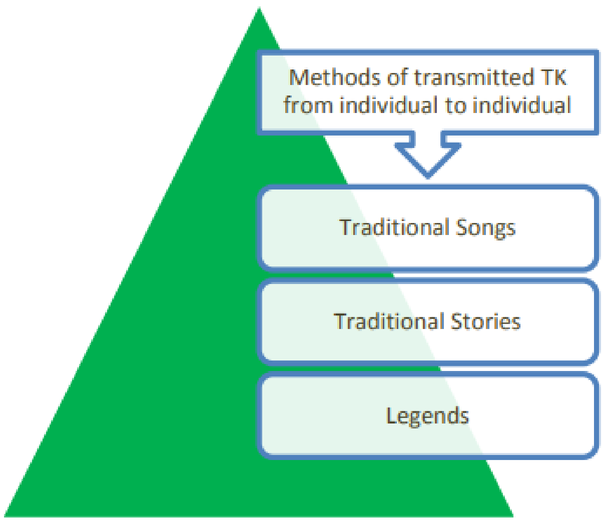

Figure 4.1: Method of Transmission of IK

“Each time an elder dies it is as if a library had burned down.” ***Amadou Hampate Ba***

4.1.3 Special Features of Indigenous Knowledge

Several authors have identified some special features of IK. Mearns, Du Toit and Mukuka (2006) have summarized these as follows:

- IK is local, holistic, and integrative because it is rooted in a particular community and its experiences are situated within broader cultural traditions of the people living in that place.
- IK is essentially functional and is geared to practical response and performance.
- IK is experiential rather than theoretical and is reinforced through continuous experience, trial and error.
- IK is learned through repetition, which aids in its retention and reinforcement.
- IK is constantly changing by way of being produced and reproduced, discovered and lost.
- IK is characteristically shared to a greater degree than other forms of knowledge, although its distribution is socially differentiated, based on gender and age.
- The distribution of IK is always fragmented. It does not exist in its totality in either one place or one individual.
- IK is tacit and cannot easily be codified.
- IK is transmitted orally, or through imitation and demonstration and the process of codification may lead to the loss of some of its properties.

4.2. The Global Benefits of Indigenous Knowledge

4*.2.1. Disaster Management*

Indigenous knowledge has been instrumental in disaster management, particularly in regions where modern early warning systems may be lacking or less effective. In Bangladesh, local communities have long used traditional methods to predict cyclones, such as observing changes in animal behavior and weather patterns. For instance, indigenous fishermen and farmers use specific signs, like the behavior of birds and fish, to forecast impending storms, often with remarkable accuracy (Sethi et al., 2010). This knowledge has been crucial in developing community-based early warning systems and preparedness strategies, complementing modern meteorological approaches.

4.2.2. Agriculture and Food Security

In agriculture, indigenous practices have contributed significantly to sustainable farming and food security. In the Andean highlands of Peru, indigenous farmers have developed sophisticated terracing and irrigation techniques that prevent soil erosion and optimize water use. These practices, such as the use of raised beds and contour plowing, have been essential for maintaining soil fertility and productivity in challenging mountain environments (Guillet, 1992). The integration of these traditional methods with modern agricultural technologies has led to improved crop yields and resilience against environmental stressors.

4.2.3. Environmental Conservation

Indigenous knowledge also plays a vital role in environmental conservation. In Australia, Aboriginal communities employ traditional fire management practices known as "cool burns" to prevent larger, uncontrolled wildfires. These controlled burns are conducted during cooler, wetter periods to reduce the accumulation of flammable vegetation, thereby mitigating the risk of catastrophic fires (Gammage, 2011). This knowledge has been increasingly recognized and integrated into contemporary fire management strategies, enhancing biodiversity and reducing fire risks in Australian landscapes.

4.2.4. Medicinal Practices

Indigenous knowledge of medicinal plants and healing practices has been valuable in medical research and public health. For example, in the Amazon rainforest, indigenous communities use a variety of plants for treating ailments and promoting health. The knowledge of medicinal plants like Cinchona, which is used to treat malaria, has led to significant advancements in pharmaceuticals (Brunton, 2010). Collaborations between indigenous healers and scientific researchers have led to the development of new treatments and pharmaceuticals, highlighting the importance of integrating traditional medicinal knowledge with modern medical practices.

4.2.5. Water Management

In arid regions, indigenous water management techniques have been crucial for ensuring water availability and sustainability. The "qanat" system used in Iran and other Middle Eastern countries involves an ancient technique of channeling groundwater through underground tunnels to the surface, allowing for irrigation in otherwise dry areas. This method has been used for thousands of years to manage water resources efficiently (Barber, 1985). Modern studies have shown that qanats can still be effective and sustainable, especially when combined with contemporary water management practices.

The literature review highlights the profound impact of Indigenous Knowledge Systems (IKS) on various domains, including disaster management, agriculture, environmental conservation, medicinal practices, and water management. Indigenous knowledge, characterized by its local, holistic, and experiential nature, offers valuable insights into sustainable practices and disaster preparedness. For example, traditional cyclone prediction methods in Bangladesh, sophisticated terracing techniques in Peru, and fire management practices in Australia demonstrate the practical benefits of IKS. Despite its effectiveness, the challenge remains in documenting and integrating this knowledge with modern technology. This review underscores the importance of preserving and leveraging indigenous practices to enhance contemporary coastal planning and sustainability.

5. CASE STUDY

5.1.1. Traditional Disaster Management Practices in Andaman and Tamil Nadu

The Andaman and Nicobar Islands and Tamil Nadu, situated in India's southeastern region, are prone to various natural disasters such as cyclones, tsunamis, floods, and monsoons. The Andaman Islands, located in the Bay of Bengal, frequently experience cyclones and tsunamis due to their tectonic and climatic conditions. Tamil Nadu, with its extensive coastline, is similarly affected by cyclones and flooding. Indigenous communities in these regions have developed nuanced traditional practices to manage and mitigate these disasters.

Traditional Practices in the Andaman and Nicobar Islands:

1. **Tsunami Prediction Techniques:**

- Indigenous communities monitor specific fish species such as mullets and groupers. Prior to a tsunami, these fish often display erratic behavior, such as swimming rapidly or congregating in unusual patterns. The sudden absence of fish close to the shore or their swift movement away from coastal areas can indicate underwater disturbances.
- Crabs and clams show heightened sensitivity to changes in sea conditions. An observed retreat of these animals from the shore or unusual digging behavior can signal approaching tsunamis.

2. **Cyclone Prediction and Response:**

- Sea turtles, particularly green turtles, exhibit changes in behavior before cyclones. They may be observed moving rapidly towards the shore or appearing agitated on the beach. Their nesting patterns may also change, with females abandoning nesting sites or relocating to safer areas.
- The appearance of unusually dark clouds, rapid changes in cloud cover, and the formation of specific cloud patterns like a dense cloud cover or an "onion-shaped" formation can signal an approaching cyclone. Indigenous communities use these patterns to prepare for severe weather.
- The wilting of certain coastal plants, such as pandanus and hibiscus, is noted as a sign of impending storms. The leaves of these plants may droop or change color in response to increased humidity and atmospheric pressure changes. Additionally, the breaking of small branches and the increased fall of leaves from trees like coconut palms can indicate strong winds.

3. **Community-Based Warning Systems:**

- Indigenous methods include the use of conch shells and drums to disseminate early warnings. These loud signals are used to alert community members of impending disasters, especially when visual indicators are observed.

Traditional Practices in Tamil Nadu:

1. **Cyclone Prediction Techniques:**

- Indigenous knowledge includes monitoring specific plant behaviors such as the drooping of the leaves of banana plants and the bending of rice stalks. These plants often exhibit changes in their physical state, such as leaf curling or wilting, in response to high wind speeds and increased humidity. Similarly, the change in color and texture of certain tree leaves, like those of the neem tree, can signal approaching storms.
- The behavior of birds, such as sudden flight patterns or unusual vocalizations, is used to predict weather events. For instance, migratory birds changing their flight paths or showing increased activity can indicate changes in weather conditions.

2. **Flood Management Practices:**

- Traditional knowledge involves observing changes in river water levels and flow patterns. Indigenous communities monitor the rising of river waters and shifts in water flow direction, which are used to predict flooding. Increased water turbulence and unusual rises in river levels are taken as indicators of imminent floods.

- Communities use traditional rainwater harvesting techniques such as constructing small ponds, check dams, and water storage tanks. These structures help manage and store excess water during monsoons, preventing flood damage and ensuring water availability during dry periods.

3. **Community-Based Risk Management:**

- Community meetings and gatherings are used to share and update knowledge about disaster risks. Information about observed indicators is communicated through local networks to ensure that everyone is prepared and aware of potential threats.
- Indigenous knowledge includes the use of herbal remedies for treating injuries and illnesses related to disasters. For example, traditional treatments using turmeric and neem leaves are applied to wounds and infections, leveraging their known antiseptic properties.

Indigenous Disaster Management Practices in Mumbai, Maharashtra

Mumbai, a bustling coastal metropolis in Maharashtra, India, is vulnerable to various natural disasters including cyclones, floods, and heavy monsoons. The Mumbai district, with its extensive coastline along the Arabian Sea, experiences frequent and intense weather events due to its geographical location. Coastal fisher folk in this region have developed a rich repository of indigenous knowledge to predict and manage these disasters. This traditional knowledge, honed over generations, involves detailed observations of environmental cues and animal behavior, which are crucial for disaster preparedness and response.

Traditional Practices in Mumbai:

1. **Cyclone Prediction Techniques**

- Fisher folk monitor the behavior of marine fish, particularly their swimming patterns and proximity to the shore. For example, an increase in the erratic movement of fish, or a noticeable migration of fish away from the shore, is taken as an early sign of impending storms or cyclones.
- Changes in sea turtle behavior, such as increased nesting activity or unusual movement patterns, are observed. For instance, if sea turtles are seen coming to shore in greater numbers or altering their nesting sites, it could indicate a coming storm or cyclone.
- Local communities pay attention to cloud formations and their colors. The appearance of thick, dark clouds or a red hue in the sky is noted as an indicator of severe weather conditions. Specifically, a sudden accumulation of cumulus clouds or the presence of cirrus clouds in the absence of a clear weather pattern is considered signs of a potential cyclone.

2. **Flood Management Practices:**

- Fisher folk observe the wilting or drooping of leaves in coastal plants such as coconut palms, banana plants, and bamboo. For instance, if banana plant leaves start to drop significantly, or if the leaves of coconut palms turn yellow or fall prematurely, it is interpreted as an indication of heavy rain or flooding.

- Changes in the health of mangrove trees, such as unusual leaf drop or changes in the color of leaves, are also observed. Mangroves serve as a natural buffer against flooding, and their condition can signal impending flood risks.
- Traditional practices include observing fluctuations in tide levels and water flow. Rapid rises in tide levels or unusual turbulence in the water are monitored closely. For example, a sudden increase in water level in the river estuaries or coastal areas is an indication of potential flooding.

3. Monsoon Preparation:

- Indigenous communities track changes in rainfall intensity and frequency. An unusual increase in rainfall, especially when it follows a period of dry weather, is used to predict the likelihood of flooding and prepare accordingly.
- Traditional rain gauges, often simple devices made from local materials, are used to measure and monitor rainfall. The data collected helps in predicting heavy monsoon rains and potential flooding.

4. Community-Based Disaster Management:

- Fisher folk use traditional communication methods such as blowing conch shells, beating drums, or using loud voices to alert the community about impending disasters. These methods are effective in quickly spreading information and mobilizing the community.
- Regular meetings are held to discuss observations and predictions based on environmental signs. These meetings serve as a platform for sharing knowledge and coordinating disaster response efforts.

5. Herbal Remedies and Safety Measures:

- Indigenous knowledge includes the use of local herbs and plants for treating injuries and ailments caused by disasters. For example, turmeric and neem leaves are used for their anti-inflammatory and antiseptic properties.
- Traditional construction methods involve building elevated shelters using local materials to protect against floodwaters and strong winds. These shelters are designed to provide safety during high tides and storms.

6. DISCUSSION

Coastal regions globally face a range of natural disasters, and indigenous knowledge systems (IKS) have proven invaluable in managing and mitigating these challenges. This paper explores the traditional disaster management practices employed by communities in Tamil Nadu, the Andaman & Nicobar Islands, and Mumbai district in Maharashtra, showcasing their intricate understanding of environmental indicators and sophisticated methods for predicting and responding to natural calamities.

In Tamil Nadu, traditional cyclone prediction techniques include observing plant and animal behaviors, such as the drooping of banana leaves and changes in bird flight patterns. Flood management strategies involve monitoring water levels and employing traditional rainwater harvesting methods. The integration of these practices with modern technology could enhance their effectiveness. For instance, satellite data and weather prediction models could be used to validate and complement local observations, such as changes in plant behavior and water levels (Mearns, Du Toit, & Mukuka, 2006). Remote sensing technology could also help monitor large-scale environmental changes that correlate with traditional indicators, improving the accuracy of predictions.

Similarly, the Andaman and Nicobar Islands' communities use marine and terrestrial indicators to predict tsunamis and cyclones. The erratic behavior of fish and changes in turtle behavior are crucial for early warning systems. By integrating these observations with modern sensors and early warning systems, such as automated tsunami detection buoys and real-time weather monitoring systems, the accuracy and reliability of disaster predictions could be significantly enhanced (Sethi et al., 2010). The use of geographic information systems (GIS) could map historical patterns of marine animal behavior against meteorological data, providing a more comprehensive understanding of disaster risks.

In Mumbai, traditional cyclone and flood prediction practices involve observing marine animal behavior and plant wilting. These observations can be supplemented with technology by employing oceanographic sensors and environmental monitoring stations to track changes in marine conditions and vegetation health. For example, integrating traditional plant indicators with remote sensing data on vegetation health could provide more precise flood forecasts (Gammage, 2011). Additionally, mobile applications could be developed to provide real-time alerts based on both indigenous knowledge and modern meteorological data, bridging the gap between traditional practices and technological advancements.

7. CONCLUSION

This study underscores the importance of Indigenous Knowledge Systems (IKS) in coastal disaster management and illustrates how these traditional practices can be integrated with contemporary technologies to enhance disaster preparedness and response. The rich observational techniques employed by communities in Tamil Nadu, the Andaman & Nicobar Islands, and Mumbai provide valuable insights that, when combined with modern tools, can offer more robust and effective disaster management strategies.

By integrating traditional knowledge with advanced technologies such as satellite imagery, remote sensing, and GIS, disaster management strategies can benefit from a more holistic approach that leverages both historical wisdom and modern innovation. This integration not only preserves these invaluable knowledge systems but also improves their practical application in contemporary coastal management. As these practices are transmitted orally and face the risk of disappearing, documenting and combining them with modern tools is crucial for ensuring their continued relevance and effectiveness in disaster management.

8. REFERENCES

1. Sethi, S. N., Sundaray, J. K., Panigrahi, A., & Chand, S. (2010). Prediction and management of natural disasters through indigenous technical knowledge, with special reference to fisheries. Central Marine Fisheries Research Institute.
2. Nirmale, V., Sontakki, B. S., Biradar, R. S., Metar, S. Y., & Charatkar, S. L. (2007). Use of indigenous knowledge by coastal fisher folk of Mumbai district in Maharashtra. Indian Journal of Traditional Knowledge, 6(2), 378-382.

3. NBC News. (2005, December 30). Stone Age cultures survive tsunami waves. NBC News. https://www.nbcnews.com/news/world/stone-age-cultures-survive-tsunami-waves-rcna256600
4. United Nations Office for Disaster Risk Reduction (UNDRR). (Year). The wave that eats people – The value of indigenous knowledge for disaster risk reduction. UNDRR. https://www.undrr.org/news/wave-eats-people-value-indigenous-knowledge-disaster-risk-reduction
5. Bhushan, S., Swami, S., Sharma, S. K., & Mohan, A. (Year). Indigenous knowledge management for disaster mitigation and sustainable development in the eco community villages of India. Dayalbagh Educational Institute (Deemed to be University). University Grants Commission, Government of India.
6. Barber, E. J. W. (1985). The archaeological evidence for early irrigation systems in the Middle East. Oxford University Press.
7. Brunton, L. (2010). Pharmacognosy: A brief introduction to medicinal plants. Routledge.
8. Gammage, B. (2011). The biggest estate on earth: How Aborigines made Australia. Allen & Unwin.
9. Guillet, D. (1992). Andean terraces: The future of the past. University of Arizona Press.

Future Proofing Coastal Settlements: Application for Technological Innovations in Planning

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Abstract

The coastal zones, inhabited by nearly 45 percent of the world's population and expected to overflow with 75 percent by mid-century, face increasing threats from climate change. Tailored into these are a set of particular challenges, of which the most important are sea-level rise, coastal erosion, warming ocean temperatures, acidification of the ocean, and increasing intensification of extreme weather events like tropical cyclones and storm surges. The research that follows is on both traditional and digital technologies for adaptation in coastal settlement planning, aiming to build a conclusive evidence base of the effectiveness, feasibility, and benefits of the respective integrated strategies. Informed by data sourced from research papers, UNFCCC conferences, and focused studies on Cuddalore, technologies available for monitoring, data collection, analysis, and dissemination are examined for information. This paper considers their effectiveness to solve some of the most important issues, like erosion, adverse weather conditions, and sea-level rise, drawing from far-reaching desktop studies in different coastal regions of the world. Key smart infrastructure technologies—including UAVs, GIS, and Virtual Reality—shall be considered for their part in different stages of adaptation. The study further interrogates drivers of technology needs and elicits expert views on ways forward to advance technologies for adaptation of coasts in Cuddalore. By way of emphasizing the need to mainstream these innovations into the planning of coastal settlements, this research underpins their centrality to achieving sustainable development and management of the Coastal zone. It provides valuable guidance to policymakers, urban planners, and stakeholders in calling for the implementation of new technologies as a means of protecting coastal communities from the effects of future climate threats.

Keywords: Climate Change; Cuddalore; Adaptation Technologies; Smart Infrastructure Technologies; Coastal Settlement Planning.

1. Introduction

Forty percent of the world's growing population and approximately sixty percent of the world's urban areas with populations of over five million people are located in coastal zones within 100 kilometers of the coastline (UNFCCC, 2020). Coastal areas are highly vulnerable to the impacts of climate change. More than 600 million people reside in coastal zones that are less than 10 meters above sea level (UNFCCC 2020), leaving many coastal communities and Small Island Developing States (SIDS) particularly vulnerable to a combination of slow-onset climate impacts, including sea level rise, coastal erosion, warming the ocean temperatures and the ocean acidification, and fast-onset hazards, including extreme weather events such as storm surges and tropical cyclones (Mycoo et al., 2022). India is exposed on all fronts to the impacts of climate change due to its unique geographical features like a long coastline of 7500kms (5,423 km in peninsular India and 2,094 km in the Andaman, Nicobar land Lakshadweep Islands), Himalayan Mountain ranges and vast desert stretches. These impacts include melting glaciers, accelerated desertification, sea level rise and intense storm surges. According to the Inter-governmental panel on Climate Change (IPCC, 2013), by 2030s, temperatures are expected to increase in India by 1-4° c, with maximum increase in coastal regions. While only about 250 million people, or roughly 3.5 percent of the world's population, live within 50 km of India's coast, its nine coastal states and two union territories host 77 coastal towns and cities, including megacities like Mumbai, Chennai, and Kolkata, along with 75 coastal districts. Some of the economically important infrastructure along India's coastline include oil and gas, power plants, ports and harbors, aquaculture, agriculture, marine fishing, tourism, mining, and reclamation. Its present status has 12 major and 187 minor ports, a few industries, and urban sprawl occupying 43 per cent of the coast. These activities significantly add to the country's economy, which occupies one of the largest places in the South Asian Region. According to the National Disaster Management Authority, the Indian coastline features among the worst hit areas of the world and faces exposure to almost 10 per cent of the world's tropical cyclones. The temperature, rainfall, and tropical cyclone extremes during 2009-2016 have resulted in enhanced exposure to multi-hazard vulnerability, hitting hard at the natural resources, agriculture, and related livelihoods in India. One of the reasons that coastal adaptation is of such importance is that it involves the development of strategies aimed at lessening and dealing with the impacts of natural disasters and climate change in coastal areas by trying to protect communities and infrastructures from sea level rise, erosion, and extreme weather. Climate change and human-induced drivers of environmental degradation pose a serious and long-term threat to the country's economic growth, potentially negating India's efforts toward attaining the Sustainable Development Goals. Such novel climate adaptation pathways bridge the gap between technology and nature-based solutions, contributing to a more resilient, holistic, and cost-effective strategy than relying on one or the other. These solutions incorporate strategies, such as early warning systems for extreme weather events in nearshore and ocean settings, hybrid methods, and investment in nature-based infrastructure.

2. Methodology

This study employed a theoretical desk research approach, systematically progressing through several key steps.

- Initially, the research focused on understanding coastal vulnerabilities and disasters through comprehensive preliminary studies on need for Coastal adaptation.
- Literature study on the traditional and digital technologies in Coastal adaptation.
- Choosing a site area with high vulnerability towards disasters and analyzing its existing disaster management techniques
- Exploring the ways to incorporate the integrated approach towards increasing the resilience of the study area.

3. Literature Review

It is in this respect that traditional and digital knowledge systems in the settlement of coastal areas have to be adapted to help reduce the adverse impact of disasters and take a preventative approach. On the other hand, traditional knowledge evolved over generations and has valuable lessons on sustainable practices and natural indicators in enhancing community resilience. The practices, though good in themselves, are optimized to real-time data, improved risk assessment, and disaster management when coupled with digital technologies that provide for early warning systems, GIS mapping, and remote sensing. This integrated approach therefore does not simply strengthen the coastal communities in terms of preparedness and timely response to disasters but also supports long-term planning and sustainable development. In that sense, adaptive, resilient, and sustainable coastal settlement making requires both traditional and modern practices.

3.1 Traditional technologies in Coastal Adaptation

The knowledge of traditional societies is important to fill up the gaps that have been created by the modern society. Traditional knowledge has different sets of ingredients that foster the development of the relational or holistic approach. It involves, interacts, and interconnects humans, non-humans, and nature together and thus sets a perfect balance for sustainable development and disaster risk reduction. It has vast undocumented observational data related to changing natural phenomena, and in today's scenario of climate change and uncertainty, it can create a way out for reliable adaption measures from climate-induced disasters. (Pribat Rai, 2019). Numerous traditional technologies play a vital role in disaster risk reduction, ranging from structural interventions to comprehensive settlement-level strategies.

- *Bio-Fencing:* Bio fencing is a way of creating boundary by planting trees and/or shrubs at relatively close spacing (Sreedevi S Kumar, 2020). Vegetation, including trees and shrubs, on the seashore can cushion the effect of storm surges, which involve sudden rises in sea level due to a storm. The impact of the water reaching the area is deadened, and the vegetation largely absorbs and dissipates its energy, hence reducing the blow of the impact inland, thereby preventing or minimizing the degree of flooding.

- *Anti-seismic architecture:* The Minoan civilization building facades had a different orientation of wall elements that helped resist the shock from any direction. The absence or near absence of windows in the ground floor of the building helped in sustaining the lower floor wall by not weakening it by any opening. This was mitigated in Minoan houses, where the dimension of the room was much smaller to increase lateral resistance and also to reduce the structural weight of the construction. Lastly, the big houses were designed to have a very low number of storeys, as houses which are too slender and too high bend more easily during an earthquake. (Pribat Rai, 2019). Anti-seismic architecture is one where the building design, at construction, can resist all the resultant forces because of the earthquake. With these elements in place, therefore, the building will better withstand the tremors and reduce damages, hence ensuring the safety of the people inside, thereby contributing to enhance a community that is resistant to earthquakes.

- *Drought mitigation strategy:* The shortage of water motivated the local people to develop a local soil management practice. The agricultural field is covered with dried Guinea grass, not only to lessen the moisture of the soil but also for the purpose of reducing soil erosion on sloping land. Without any involvement of scientific technology, they changed the rainfall deficiency area into a lucrative agro-activity area. (Pribat Rai, 2019). Drought mitigation strategies help reduce the risk of disasters because they increase the ability of the soil to retain water and encourage agriculture in areas with low rainfall. The practices contribute to food security and economic stability by maintaining productive agricultural activities without necessarily adapting advanced technologies. Such a proactive approach contributes to lessening exposure to drought-related disasters such as crop failure and economic decline, hence strengthening community resilience.

- *Early warning and preparedness:* The Chitral district barely has 3.5% suitable agricultural land and comprises steep mountain slopes, largely unsuitable for settlement, with a high risk of flash flooding. Due to knowledge from history about the flash flooding, local people here have gathered adaptation measures to floods by reading the landscape and hence interpretation of where to build and not to build their houses. The practical lesson learned from the historical flood experience has also enabled them to understand and interpret early signs of potentially destructive floods too. In 2005 Glacial Lake Outburst Flood in Brep village of Chitral district, not a single life was lost because the interpretation of stream behaviour acted as the early warning and the village was evacuated in time. (Pribat Rai, 2019). Indigenous communities normally rely on environmental cues, such as animal behavior and changes in the weather, among others, to monitor the onset of various phenomena such as flooding, drought, or storms. These forms of traditional early warning are usually very well integrated into community practice and tend to have timely and culturally appropriate responses.

- Traditional house construction in Navala village, known as a bure, is an ingrained cultural practice that improves disaster resilience against cyclones. It brings together the whole community with traditional techniques passed on from generation to generation and includes local materials like bamboo reeds and hardwood. Among the features in the design of the bure, such as the hipped roof and flexibility of the structure, many make it very strong during strong winds and rains. While this construction is based on traditional techniques, some construction principles of the bure make it inherently resistant to cyclones and therefore a very sustainable housing approach in cyclone-prone areas.. (Mohamed Elkharboutly*, 2022).

3.2 Digital technologies in Coastal Adaptation

The accelerating disaster impacts in coastal communities signal the need for cutting-edge digital solutions as well as strong coastal adaptation. The future-proofing of these vulnerable areas will be secured through state-of-the-art digital technologies that enhance their resilience to ensure sustainable development in such weak areas. This chapter discusses some ways in which certain digital technologies are applied in coastal adaptation, ranging from data collection and processing to management and visualization. Accurate and real-time data collection is the basic mechanism of any effective strategy for coastal adaptation. The following technologies may be used to get critical information:

- *Internet of Things sensors*: The Internet of Things sensors installed along the coastlines continuously monitor the environment for parameters that relate to sea level, temperature, humidity, and wave activity. These sensors record this information in real-time, ensuring timely responses to dynamically changing coastal conditions and hence an improvement in understanding the long-term trends (Kaljot Sharma, 2021).

- *Lidar Sensors:* Light Detection and Ranging technology is applied to develop high-resolution, three-dimensional mapping of coastal topography. By developing laser pulses and measuring the time taken to return after hitting an object, Lidar produces extremely exact elevation data. This is vitally important for determining rates of erosion, risks of flooding, and changes in landforms over time (David M. TralliT, 2005) (Klemas, 2013).

- *Uncrewed Aerial Vehicles (UAVs)*: Nowadays, drones are in use to capture high-resolution views of the coast from an aerial perspective. They can be used to cover extensive remote areas and provide ultra-high-resolution imagery and video data that can complement the information obtained from the ground-based sensor networks. This information can be highly central for keeping track of erosion along the coastlines, changes in vegetation, and possible vulnerabilities in infrastructure (Sarah Kandrot, 2022).

- *Remote Sensing*: It refers to measuring information acquired from satellites that orbit the earth or aerial sensors, which produce descriptive and monitoring services for vast coastal regions. The received information is useful for the identification of changes in the quality of landscapes, water resources, and other coastal features. It is also useful in monitoring the predisturbance observations that result from the potential effects of a coastal hazard (Yaw A. Twumasi, 2016).

- *Geographic Information Systems (GIS):* GIS technology assumes significance in the integration and analysis of spatial data from numerous data sources. GIS helps in visualizing these complex coastal phenomena through the overlay of several datasets, the modeling of possible future scenarios, and the identification of risk areas. GIS tools play a vital role in designing spatially informed adaptational strategies that consider the characteristics of unique coastal settlements (Yaw A. Twumasi, 2016).

- *Blockchain:* Blockchain is designed to be a distributed and immutable ledger, which establishes the basic element of decentralized management of data regarding coastal adaptation. The fact that blockchain has an immutable ledger for data transactions makes it certain that what is shared among relevant parties is the accurate and bona fide information since interested parties can confirm both the data and the entity's origin. Besides that, the technology enhances data security and keeps the data away from unauthorized access, among other cyber threats (Emanuele Vannucci, 2021).

- *Virtual Reality (VR):* VR is a computer technology that uses VR headsets and sometimes multi-projected environments to create realistic, three-dimensional environments. The stakeholders are taken through simulated coastal scenarios in a three-dimensional setting. It is thus very pertinent in explaining to stakeholders the plausible impact of climate change and the effectiveness of adaptation measures. Such interactive visualization showed decision-makers, planners, and the public deeper insight into the coastal risks and explored various adaptation options (Tina Korani, 2023).

Every procedure in planning and ensuring the protection of the adaptation of vulnerable coastal settlements involves the application of digital technologies. In handling data from collection to visualization, IoT sensors, Lidar, UAVs, remote sensing, GIS, blockchain, and VR all have roles to play at different stages. They increase the precision and efficiency of strategies for adaptation to the coast, meanwhile enhancing community empowerment with informed choices for the future. Digital integration of such tools is increasingly being realized as one way toward effective resilient and sustainable human habitation of coasts as climate change challenges increase in strength.

4. Case Study Area

Cuddalore district is situated on the southeastern coast of Tamil Nadu, India, and forms one of the most natural disaster–prone districts. The topography is generally low-lying land with gentle slopes, and the district is prone to wide-scale flooding, especially during cyclonic events. The history records that this Cuddalore coast has faced the wrath of about 60 cyclones and severe cyclonic surges in the past century itself, causing immense loss to life and property. With a total geographical area of 3,698.68 square kilometers, the district has a population of 2,605,914 according to the Census of 2011. Its geographical location, between 11°45' and 12°27' North latitude and 78°48' and 80°12' East longitude, places it within a region characterized by a tropical wet and dry climate. The district is one of heavy rainfall during the northeast monsoon season and falls under the category of rainfall surplus areas. The 52 km long coastline along the Bay of Bengal in this district is divided into four coastal taluks, namely Cuddalore, Kurinjipadi, Bhuvanagiri, and Chidambaram, which are prone to high winds and cyclones. All other six taluks lie in the flood-prone areas of the district. In fact, the 2004 Indian Ocean tsunami was very devastating and reflected the level of exposure of this district. This was among the worst-affected districts, with 610 people reported dead and 38 missing. These are the factors that can place Cuddalore at the forefront of scientific study concerning the interrelationship between coastal hazards, vulnerability, and disaster risk. A vulnerability assessment conducted by (S. Saxena V. G., 2013) revealed a complex coastal dynamic in the Cuddalore region. Shoreline analysis indicated an average accretion rate of 0.15 meters per year, with 40.5% of the coastline experiencing accretion, 25.5% remaining stable, and 34% undergoing erosion. The study further projected a 1-in-100-year extreme flood level of 3.62 meters above Mean Sea Level (MSL) for the region, considering both local and global sea-level rise factors. Moreover, the composite Vulnerability Index (CVI) classified a majority of coastal settlements within the district as highly vulnerable. A broader assessment of multi-hazard vulnerability along the Cuddalore coast revealed that river systems act as conduits for extensive and prolonged inundation. These flood events can induce alterations in elevation and consequently modify the coastal geomorphology (Subbarayan Saravanan, 2018).

4.1 Review on Cuddalore Disaster Management Plan

It is an exhaustive document for the Cuddalore District Disaster Management Plan for enhancing resilience to multiple disasters. The District Collector, under the leadership of the District Disaster Management Authority, injects strategies on prevention, preparedness, mitigation, and response to disasters in general and particularly in this impending monsoon season. It identifies the vulnerabilities of different parts of the district to various disasters—floods, cyclones, and drought—and defines roles that community members, NGOs, and government departments can play toward risk management. Indeed, one of the important approaches upheld in this plan is CBDM, which involves active engagement of at-risk communities in identification, analysis, treatment, monitoring, and evaluation of disaster risks. The approach reduces vulnerabilities and at the same time strengthens community capacity to proactively face disasters. It elaborates specialized response forces like NDRF, SDRF, and technological support by agencies like INCOIS for early warnings and monitoring of disasters. It also draws on past disaster experiences from events such as the 2004 Tsunami, Cyclone Nisha in 2008, and Cyclone Thane in 2011 in informing present and future strategies for disaster management. This includes hazard, risk, vulnerability, and capacity analysis, mainly on the 12 flood-prone basins in the district. The Cuddalore DDMP is a living document, consolidating lessons from the past, experiences at hand, and present-day risk assessments toward empowering the district for effective preparation, response, and recovery in the event of disasters, ensuring protection of citizens' lives and livelihoods.

5. Research Gap

Although disaster management is intrinsically a part of coastal adaptation, however, there is an enormous gap between state-of-the-digital technologies in integration with the traditional practices. Most of the current strategies have been developed around post-disaster response and preparedness, whereas the development of resilience has had a short shrifted share and very little focus as such to mitigate impact. This gap is further compounded by a lack of documentation and integration of traditional adaptation techniques with modern technologies. The work is going in line with the exploration in which mileage digital tools can be used in meshing with the traditional practice to help build more resilient, proactive, and sustainable coastal adaptation. This work of research tends to bridge the gap that lies between technology and tradition through innovative solutions, which enhance disaster resilience and rich valuable indigenous knowledge.

6. Integrated Coastal Adaptation Approach

The Integrated Coastal Adaptation Approach works to bridge the gap between traditional and digital technologies in ensuring that coastal settlement entities are disaster-resilient from pre-disaster to during the disaster and post-disaster. This would fill up those gaps with strategies for the recognition of vulnerabilities in the disaster management plans drawn to date and strategies for risk reduction beforehand through pre-disaster mitigation measures.

6.1 Application

A digital twin is a kind of virtual model replicating any asset, environment, or process under real-time situations to monitor, analyze, and manage. Coastal adaptation digital twins combine more conventional coastal protection measures with new sophisticated digital technologies into a very dynamic system that enhances disaster resilience in the pre-disaster, during disaster, and post-disaster stages.

Seawall with IoT: Real-time data from wave gauges and cameras are near real-time in nature, drive detailed accounts of wave run-up and resultant forces on the sea wall that have been critical in understanding how each of the structures performed under these extreme events. This data-driven approach can be used to improve the predictions of wave impacts on those structures, ultimately aiming to develop more resilient coastal structures. (Maximilian Streicher, 2018), (Kaljot Sharma, 2021), (R. G. Prabhudesai, 2006).

Lidar and UAVs: LiDAR (Light Detection and Ranging) and UAVs (Unmanned Aerial Vehicles) together offer a powerful combination for coastal zone management. UAVs equipped with LiDAR sensors can capture high-resolution, three-dimensional data of coastal areas, providing detailed topographic maps that are essential for monitoring shoreline changes, erosion patterns, and vegetation cover (David M. TralliT, 2005) (Klemas, 2013). These data can be further used to create highly accurate DEMs, outlining vulnerable zones and projecting sea-level rise, storm surges, and other coastal hazards. Moreover, UAVs allow accessing remote or dangerous places; hence, it is definite that the data shall be collected efficiently and safely, even from places inaccessible by conventional means. (Sarah Kandrot, 2022). Integration of LiDAR and UAVs thus enables the precised real-time monitoring and management of coastal resources like mangroves and coral reefs, which act as natural shields, thus helping in habitat conservation, sustainable development, and also providing necessary information for the policy makers and responsible authorities to take proper decisions.

Remote Sensing & GIS with IoT: Remote sensing, GIS, and IoT technologies, when integrated, Present a robust framework for coastal zone management. In the aspect of remote sensing, there has been continued monitoring over large areas of coastline by means of satellite and aerial images, which capture the major data related to land use, water quality, and erosion. This spatial data is then processed and visualized with GIS, allowing the trend, pattern, and vulnerable areas to be identified. (Yaw A. Twumasi, 2016). Complementing this, IoT sensors deployed along the coast collect real-time environmental data, such as temperature, sea level, and wave height (Kaljot Sharma, 2021). This makes it possible for IoT data, integrated with remote sensing and GIS, to provide an integral near real-time understanding of coastal dynamics for improvement in predictive modeling toward timely and informed decision-making related to sustainable coastal development and disaster risk reduction.

Early Warning System and ICT: Early Warning Systems (EWS) integrated with Information and Communication Technology (ICT) are essential for effective coastal zone management (Madhubhashini, 2019). ICT enables real-time data collection and analysis from both sensors and monitoring stations. This makes it quite easy to detect hazards, such as storms, tsunamis, and sea-level rise, in advance. (D.-J. Doong, 2012). The information is quickly passed to authorities and vulnerable communities through various channels, guaranteeing alerts in time and offering possibilities for quick evacuation and protective measures. Inclusion of EWS with ICT has significantly increased the acts of mitigating disaster impacts and saves lives with property on coastal regions.

Lidar and VR: The combination of 3D LiDAR maps with virtual reality provides a very excellent tool in the context of coastal zone management. LiDAR itself delivers accurate, detailed topographic data, capturing key features within a coastline (David M. TralliT, 2005). Further, by coupling with VR, these 3D maps are in a position to make it feasible for coastal environments examination and interaction by the policymakers in a real and interactive way (Tina Korani, 2023). This makes it possible to comprehend sea-level rise, erosion, and storm surge impacts at a finer scale and to understand the resultant appropriate measures. Integration also facilitates rational decision-making up to the extent possible, as it allows authorities to properly assess the risks, prioritize interventions, and come up with policies for more effective and resilient approaches to coastal management measures.

Blockchain: Blockchain technology can significantly improve the efficiency and transparency of humanitarian aid distribution in post-disaster scenarios (Emanuele Vannucci, 2021). Insecure, decentralized platforms allow blockchain to follow funds and resources directly to recipients of any area, taking care that there are minimal delays, fraud, and misallocations. The transaction would be noted down on an immutable ledger, depicting real-time accountability and vividness. This also enables the direct aid transfer with digital wallets and smart contracts for automated disbursement based on criteria spelled out in advance. Therefore, it ensures that help is disposed of swiftly and equitably. This will bring about coordination to the stakeholders, enhance trust, and provide a much more potent humanitarian response.

7. Outcomes

The integrated approach proposed herein can be utilized to enhance coastal resilience through the synergistic application of advanced digital technologies and conventional methodologies. In this respect, we intend to show that with this integrated framework of IoT, GIS, remote sensing, LiDAR, and traditional approaches, an improvement in accuracy and efficiency related to disaster prediction, early warning, and response can be achieved. It is expected that this enhanced understanding of the dynamics of coastlines will open up ways for proactive risk reduction measures so that disaster risks for coastal communities could be actually reduced. Further, blockchain and virtual reality technologies in post-disaster management and policymaking will foster transparency, accountability, and informed decision-making for resilient, sustainable, and adaptive coastal management strategies.

8. Way Forward

Further research in the integrated approach's effectiveness, cost-benefit analysis to ascertain the economic viability and long-term return on investment of implementing the integrated approach, identification of key factors influencing applicability of the approach in varying contexts, and developing guidelines for its adaption and implementation are some ways forward with this study. That could be explored: benefits in undertaking this integrated approach for coastal adaptation.

9. Limitations

Advanced technologies for coastal adaptation and management need to be adaptable to the dynamic coastal environment. These technologies have to be developed strong and reliable to provide accurate and consistent data under very difficult conditions. At the same time, the issue of cost-effectiveness related to an initial investment and further operational expenses should not be insignificant. Compatibility with the existing systems in place at all levels in order to ensure trouble-free integration and data exchange is another precondition. Finally, policy that is supportive of coastal management with respect to the adoption and use of these technologies needs to be appropriate.

10. Conclusion

The paper highlights the urgent need for coherent coastal adaptation strategies in a bid to offset the rising menaces of climate change in high-risk coastal areas. In seeking to harmonize indigenous knowledge with leading-edge digital technology, this approach delivers a holistic framework for improving disaster resilience, mitigating risks, and protecting coastal communities. The integration of technologies such as IoT, GIS, remote sensing, and LiDAR into traditional practices offers insight into dynamics taking place on coastlines, hence providing informed decision-making and proactive planning. Additionally, blockchain and virtual reality technologies can make post-disaster management more transparent, accountable, and participatory. The results of the study reiterate that there has to be strong backing or potential impetus for technology in the fight against challenges affecting the coast, with specific reference to Cuddalore District of India. In fact, advanced technologies combined with traditional knowledge have the ability to significantly enhance early warning systems and long-term planning. In this direction, the policymakers and the coastal communities can join forces to construct resilient, sustainable, and adaptive settlements for coastal settlements that guarantee the protection of lives and livelihoods from the impacts of climate change. It is further foreseen that future research shall be directed toward cost-effectiveness analysis of the integrated approach, assessing its applicability in a variety of coasts, and development of guidelines pertaining to its implementation. Such areas, if looked into by policymakers and other stakeholders, can result in making informed decisions about adopting and scaling up this transformative approach to coastal adaptation.

References

1. D.-J. Doong, L. Z.-H.-C.-M.-H. (2012). Development of an operational coastal flooding early waring syatem. *Natural Hazards and Earth System Sciences*, 379–390.
2. David M. TralliT, R. G. (2005). Satellite remote sensing of earthquake, volcano, flood, landslide and coastal inundation hazards. *ELSEVIER*.
3. eAtlas, I. (2011). *Tracks of Cyclones and depressions over North Indian Ocean (from 1891 to 2011)*. Cyclone eAtlas - IMD.
4. Emanuele Vannucci, A. J. (2021). Climate change management: a resilience strategy for flood risk using Blockchain tools. *Springer*, 177-190.
5. Kaljot Sharma, D. A. (2021). A Disaster Management Framework Using Internet of Things-Based Interconnected Devices. *Hindawi*, 8-18.
6. Klemas, V. V. (2013). Remote Sensing of Coastal Hazards. Chapter 2.

7. Madhubhashini, G. T. (2019). The Use of Information and Communication Technologies (ICTs) for Natural Disaster Management in Sri Lanka. *Interdisciplinary Global Studies*, 28–29.
8. Maximilian Streicher, A. K. (2018). PREDICTION OF DYNAMIC AND QUASI-STATIC IMPACTS ON VERTICAL SEA WALLS CAUSED BY AN OVERTOPPED BORE . *COASTAL ENGINEERING*, 1-15.
9. Mohamed Elkharboutly*, S. W. (2022). Cyclone resistant housing in Fiji: The forgotten features of. *ScienceDirect*, volume 82.
10. Pribat Rai, V. K. (2019). Traditional knowledge system in disaster risk reduction: Exploration, acknowledgement and proposition. *Researchgate*, 1-7.
11. R. G. Prabhudesai, A. J. (2006). Development and implementation of cellular-based real-time reporting and Internet accessible coastal sea-level gauge – A vital tool for monitoring storm surge and tsunami. *RESEARCH COMMUNICATIONS*, 1413-1418.
12. S. Saxena, V. G. (2013). Development of habitation vulnerability assessment framework for coastal. *Weather and Climate Extremes 2*, 48-57.
13. S. Saxena, V. G. (2013). Development of habitation vulnerability assessment framework for coastal. *Weather and Climate Extremes*, 48-57.
14. Sarah Kandrot, S. H. (2022). Applications of Uncrewed Aerial Vehicles (UAV) Technology to Support Integrated Coastal Zone Management and the UN Sustainable Development Goals at the Coast. 1230–1249.
15. Sreedevi S Kumar, V. T. (2020). Ethnobiological survey and documentation of traditional knowledge from the coastal areas of Thrissur district, Kerala. *Journal of Traditional and Folk Practices*, 80-88.
16. Subbarayan Saravanan, J. J. (2018). Cyclone vulnerability assessment of cuddalore coast in Tamil. *MATEC Web of Conferences 229, 02022*.
17. Tina Korani, A. M. (2023). A Framework for Creating Virtual Reality Models for More Effective Coastal Flood Risk Communication. 13-23.
18. UNFCCC. (2020). *UNITED NATIONS CLIMATE CHANGE ANNUAL REPORT 2020.* UN Climate Change.
19. Yaw A. Twumasi, E. C.-S. (2016). Coupling GIS and remote sensing techniques for coastal zone disaster management: the case of Southern Mississippi. *Springer open*, 1-9.

Geospatial Approach to Assessing the Flood Risk in Sangli City, Maharashtra

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Abstract

Floods significantly challenge economic growth in India, causing substantial losses in crucial sectors like agriculture and aquaculture. The most affected regions include the Deccan and Central India, the Ganga and Brahmaputra basins, and Statistics reveal that floods account for 40% of all natural disaster-related deaths in India. This study focuses on river-induced floods in Sangli, particularly those exacerbated by the Almatti Dam's obstruction in Karnataka State. Sangli, located on the Krishna River in Maharashtra, faces a heightened risk of flooding during intense rainfall. The closure of the Almatti Dam and upstream conditions along the river intensify the rise in water levels, leading to the city's inundation. To address these flood risks, the study employs a geospatial approach to assess flood hazard, vulnerability, and risk. It begins with flood hazard mapping to visualize water spread and ide ntify at-risk areas. The study's core is flood vulnerability assessment, which evaluates the city's flood risk and inherent vulnerability based on three key indicators: Exposure, Susceptibility, and Resilience. The investigation provides a comprehensive understanding of Sangli's flood vulnerability by utilizing a combination of diverse data sources, including topographic maps, satellite imagery, and census data. The methodology integrates GIS-based spatial analysis, multi-criteria evaluation, and analytical hierarchy processes to assess flood risk across physical, environmental, social, and economic dimensions.

The study's risk map, derived from hazard and vulnerability assessments, identifies areas in Sangli City prone to floods, requiring immediate attention and regulatory measures to enhance coping capacity. This results in strategic recommendations that include structural measures such as dams and blue-green infrastructures, along with nonstructural measures like development control regulations, an early warning system, regulation of reservoirs, and flood insurance schemes aimed at effective flood management in Sangli City.

Keywords: Flood Vulnerability; Flood Hazard; Flood Risk; Exposure; Susceptibility; Resilience.

1. INTRODUCTION

Floods, the most common natural disasters, occur when an excessive amount of water covers land that is typically dry. They are typically triggered by heavy rainfall, rapid snowmelt, or storm surges from tropical cyclones or tsunamis along coastal areas. These events can lead to widespread destruction, causing loss of life and damage to personal property and essential public health infrastructure. From 1998 to 2017, floods affected over 2 billion people globally. Individuals residing in floodplains or structures lacking flood resistance, as well as those without access to warning systems or knowledge of flood risks, are particularly vulnerable to these disasters. (World Health Organization, 2024).

1.1 Floods in India - Statistical Overview

Floods stand out as the deadliest natural disasters in India. From 1980 to 2017, the country witnessed 235 floods, resulting in 126,286 fatalities and impacting 1.93 billion individuals. These disasters also incur substantial economic losses, totaling a staggering $58.7 billion, comprising about 68% of all economic losses due to disasters according to the Emergency Events Database.

In 2018 alone, India faced economic losses of approximately Rs 95,000 crores and mourned the loss of 1,808 lives due to floods across the country, as reported in the Rajya Sabha. Floods account for over 40% of deaths from natural disasters in India. Moreover, research indicates that flood damage has long-term detrimental effects on economic growth and significantly reduces female employment opportunities in the agricultural sector.

The National Commission on Floods estimated in 1980 that about 40 million hectares of land in India are flood-prone, equivalent to 12% of the country's total area. This figure was later revised to 45.64 million hectares by the Working Group on Flood Control Programme for the Tenth Five-Year Plan, with about 80% of this area, approximately 32 million hectares, potentially benefiting from improved flood protection measures.

Recent data from the Ministry of Home Affairs shows that as of August 27, 2020, floods and landslides in 14 Indian states claimed the lives of 1,153 individuals and adversely affected around 17.3 million people. The states most affected include West Bengal, Maharashtra, Bihar, Gujarat, Assam, Madhya Pradesh, Kerala, Karnataka, Jammu and Kashmir, and Chhattisgarh.

Government records indicate that between 1953 and 2011, floods caused an average of 1,653 deaths annually and resulted in damages worth Rs. 3,612 crores every year, including losses to houses, public infrastructure, and crops. Additionally, in Assam alone, more than 1.25 lakh families have lost either their agricultural or residential land due to floods since 1947. (Prep, 2024).

Floods in India is a huge obstacle to achieving economic growth

This natural disaster resulted in enormous annual investments in aquaculture, agriculture, and other sectors being wasted. India's principal flood-prone areas are the Deccan and Central India, the Ganga, the Brahmaputra, and the Northwest. Based on statistical studies, 40% of all natural disaster-related deaths in India are attributed to flooding. 235 floods devastated India between 1980 and 2017, killing 126,286 persons and lowering the level of living for 1.93 billion people. (statista, 2023)

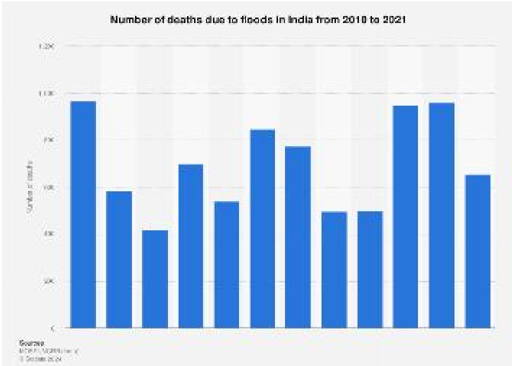

Figure 1: Number of deaths due to floods in India from 2010 to 2021

1.2 Causes of Flood

There are numerous factors contributing to floods in India, each associated with different flood types. However, most floods can be attributed to the following causes:

- **Heavy Precipitation**: Excessive rainfall can lead to floods, as the ground becomes saturated and cannot absorb all the water, resulting in runoff and potential flooding, including flash floods.
- **Overflowing Rivers**: River flooding can occur due to debris accumulation or dam obstructions, disrupting the natural flow of water.
- **Dam Failures**: Dam collapses, particularly in old or poorly maintained infrastructure, can release large volumes of water downstream, causing flooding in surrounding areas.
- **Storm Surges and Tsunamis**: Coastal areas can experience flooding due to storm surges from hurricanes or tsunamis, resulting in a rise in sea levels and inundation of dry land.
- **Channels with Steep Banks**: Fast runoff into rivers and lakes, often caused by steep terrain, can lead to flooding as water levels rise rapidly.
- **Snow or Ice Melting**: Rapid melting of snow or ice can result in significant runoff, particularly in mountainous regions, leading to floods in lower-lying areas.
- **Deforestation and Vegetation Loss**: Deforestation and lack of vegetation can contribute to soil erosion and increase runoff, reducing the land's ability to absorb water and increasing flood risk.
- **Poor Farming Practices**: Improper farming practices such as leaving fields bare or plowing in the wrong direction can contribute to soil erosion and increase the risk of flooding.
- **Urbanization**: The introduction of non-porous surfaces in urban areas reduces the land's ability to absorb water, leading to increased surface runoff and flooding..

1.3 Flood Risk Assessment

Flood risk assessment is a method used to assess the potential risks and impacts of flooding on communities and infrastructure. It involves combining information about flood hazards with vulnerability assessments to determine the likelihood and consequences of flooding in a particular area. The formula used here is, FRI = FHI x FVI, where, FRI = Flood Risk Index, FHI = Flood Hazard Index, and FVI = Flood Vulnerability Index (UNESCO-IHE) . Vulnerability is considered in the study of the Flood Vulnerability Index (FVI) as the extent of harm, which can be expected under certain conditions of exposure, susceptibility, and resilience. (UNESCO-IHE) The goal of vulnerability studies is to identify appropriate responses that can be implemented to lessen risk before potential harm materializes. FVI increases the transparency of the decision-making process and is a potent instrument for policy and decision-makers to prioritize investments.

Vulnerability equation:

Vulnerability = Exposure + Susceptibility – Resilience

Every society has some degree of vulnerability to flooding, albeit in varied ways depending on the circumstances. By recognizing these differences, policies and plans can be developed to enhance the lives of those who live in these cultures.

One method of identifying susceptibility stems from natural disasters like floods: The extent to which a system is sensitive to flooding due to exposure, a disruption, in connection with its ability (or inability) to cope, recover, or adapt.

Three key elements make water resource systems susceptible to flooding: exposure, susceptibility, and resilience.

Comprehending every notion and taking into account specific indicators could aid in defining the susceptibility of various systems, hence enabling the identification of specific measures to mitigate it.

- **Exposure:** The values that exist at the site where floods may occur are referred to as exposure. These qualities can be found in products, facilities, cultural assets, agricultural areas, or most importantly, people. The indicators for this component can be divided into two groups: the first group deals with the exposure of various elements that are at danger, and the second group provides information on the overall features of the flood. Exposure refers to a system's inclination to experience disruptions from flooding events since it is situated within the same area of influence.
- **Susceptibility:** Susceptibility is related to system features, such as the social setting in which flood damage develops. particularly the affected people's knowledge and readiness about the risk they live with (before to the flood), the organizations that work to mitigate and lessen the consequences of the hazards, and the availability of potential countermeasures like evacuation routes to be deployed in the event of flooding. (UNESCO-IHE,) The components exposed within the system that affect the likelihood of being affected during dangerous floods are referred to as susceptibilities**.**
- **Resilience:** Since the main focus is on the experiences encountered during and after the floods, resilience to flood damages can only be examined in places with past incidents. Resilience is described in this study as a system's ability to withstand any disturbance, such as floods while retaining a high degree of efficiency in all of its social, economic, environmental, and physical components.
- **Indicators**: Vulnerability needs to be reflected through indicators. An indicator, or set of indicators, can be defined as an inherent characteristic that quantitatively estimates the condition of a system; they usually focus on small, manageable, tangible, and telling pieces of a system that can give people a sense of the bigger picture. The vulnerability indicators should provide additional information to set more precise and quantitative targets for vulnerability reduction. System indicators facilitate the analysis of the relative state of the overall system and they should reflect the socio-

economic, environmental, and physical condition of the geographic region. (UNESCO-IHE)

1.4 Case Area Description

Sangli is a city and the district headquarters of Sangli district in the state of Maharashtra, in Western India. It is known as the Turmeric City of Maharashtra due to its production and trade of the spice. Sangli is situated on the banks of rivers Krishna and Warna. The physical settings of Sangli show the contrast of immense dimensions of climate and vegetation.

The study area is located near the banks of the Krishna River. The **Krishna River** is a river in the Deccan plateau and is the third-longest river in India, after the Ganges and Godavari. The river is **1,400 kilometers** long and its length in Maharashtra is **282 kilometers**. It is a major source of irrigation in the Indian states of Maharashtra, Karnataka, Telangana, and Andhra Pradesh.

Sangli, situated on the banks of the Krishna River in Maharashtra, faces the risk of flooding during periods of **intense rainfal**l. The rise in water levels is intensified by the combined effects of **upstream conditions along the river and the closure of the Almatti Dam,** leading to the city's inundation.

Area of Sangali City = 200.2 sq. km

Population = 6,12,000 (1.66% from 2022)

= 502793 (Census 2011)

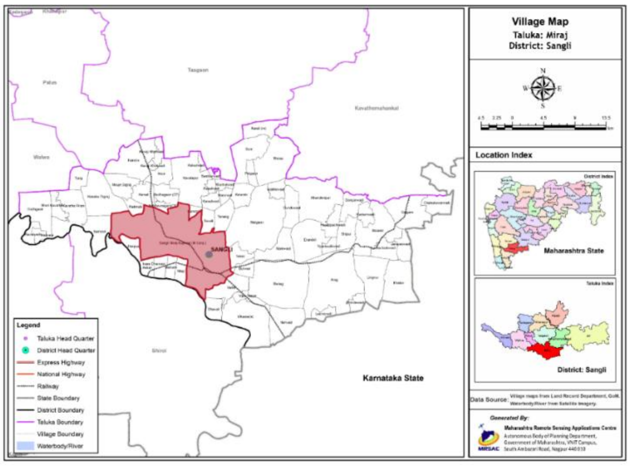

Figure 2: Sangli Miraj Kupwad Corporation in Miraj Taluka

There are various reasons for floods in Sangli, those are listed below:

- Generation of backwater effect in the tributaries and nallas meeting the River Krishna
- Inadequate discharge carrying capacity of river Krishna to accommodate the releases of Koyna dam, the contribution of tributaries and the runoff of the free catchment.
- Reduced discharge carrying capacity of river Warna and Panchganga due to siltation, vegetation growth and encroachments further delayed the reception of floods
- Flow stagnation in River Krishna from Sangli city to the State border, due to confluence effect.

The graph describes a period of rainfall from June 1st to August 10th in 2019, stating that the total rainfall during this period was 523.2 units, which exceeded the average rainfall for the same period, which is noted as 236.4 units. This indicates that in 2019, there was a significantly higher amount of rainfall during this period compared to the typical or average amount of rainfall for that time frame.

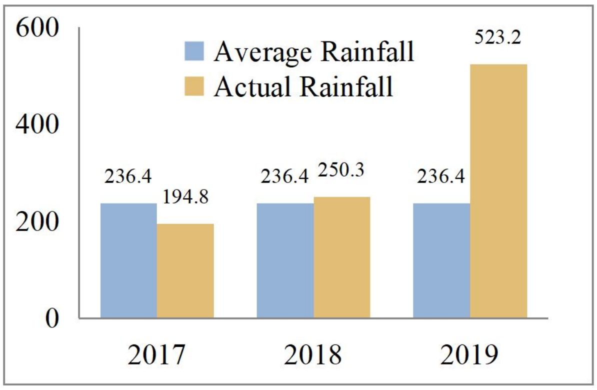

Figure 3: Rainfall recorded at Irwin Bridge, Sangli

2. LITERATURE REVIEW

- **A comprehensive spatial analysis of social vulnerability to natural hazards in Zimbabwe: Driving Factors and policy implications (2021)**

Author: Emmanuel Mavhura, and Tawanda Manyangadze [International Journal of Disaster Risk Reduction 56 (2021) 102139] (Emmanuel Mavhura, 2021)

The study aims to explore the interplay between natural hazards, socio-economic factors, and ideological beliefs across different population groups in Zimbabwe. It investigates how social attributes and the biophysical environment influence disaster impacts and identifies factors contributing to varying vulnerability levels. The analysis focuses on the differential impact of hazards, assessing the capacity of different groups and the role of development in shaping this capacity. By examining spatial variations in social vulnerability, the study provides insights into the drivers of vulnerability, such as poverty, informal employment, and socio-economic conditions. Using Principal Component Analysis (PCA) and Factor Analysis (FA) within a GIS framework, it reveals that southern districts face high vulnerability, often linked to poor agro-ecological conditions, while northern districts are moderately vulnerable. The study concludes that addressing regional disparities and implementing economic reforms and social safety nets are crucial for reducing vulnerability and improving disaster resilience.

- **Geospatial approach for assessment of vulnerability to flood in local self-governments**

Author: S. Deepak, Gopika Rajan and P.G. Jairaj [Geoenvironmental Disasters (2020) 7:35] (S. Deepak, 2020)

The study aims to assess flood vulnerability in Sangli City by integrating socio-economic and physical-environmental factors through a geospatial approach. Utilizing Multi-Criteria Decision Analysis (MCDA) for socio-economic vulnerabilities and the Random Forest method for physical-environmental risks, it generates comprehensive vulnerability maps. This methodology, applied to Aluva Municipality, Kerala, demonstrates its effectiveness in identifying high-risk areas and populations. Data from satellite imagery, DEM, and various socio-economic and environmental indicators support the analysis. The study concludes that the combined use of Analytical Hierarchy Process (AHP), Weighted Linear Combination (WLC), and Random Forest provides accurate, actionable insights for targeted flood management and mitigation strategies, offering valuable guidance for enhancing resilience to flooding.

- **Are flood events really increasing? A case study of Krishna River Basin, India**

Author: Gaurav Pakhale, Rakesh Khosa, A.K. Gosain [Natural Hazards Research 3 (2023) 374-384] (Gaurav Pakhale, 2023)

This study offers a comprehensive review of flood risk in the Krishna River Basin (KRB), addressing objectives such as historical flood analysis, causal factor identification, and impact assessment. It employs SWAT hydrological modeling, frequency analysis of rainfall and streamflow, and examines spatial-temporal flood patterns using observed and gridded data. Findings indicate a decrease in flood severity in subbasin K7 but no significant trend overall. The study calls for a robust flood risk framework incorporating hazard, exposure, and vulnerability assessments, floodplain zoning, and inundation maps. It also recommends cautious use of sensitive parameters and geotagging events for improved flood risk management.

3. RESEARCH GAP AND OBJECTIVES

In the comprehensive exploration of geospatial approaches to assess flood risk, specifically in understanding the relationship between hazards, vulnerability, and risk. While existing studies provide valuable insights, there is a need for more focused research on how geospatial methods can enhance flood vulnerability assessments. Conducting a detailed flood vulnerability assessment in Sangli City, Maharashtra, is essential to fill this gap. Such an assessment would advance the understanding of flood risk dynamics and contribute significantly to enhancing the city's resilience to flooding, reducing flood risks, and improving the community's capacity to adapt to and recover from flood events.

1. To understand the site's **natural terrain, physical features, and geographical characteristics**, and to investigate the causes and mechanisms of flooding in the area.
2. To prepare a **flood hazard map** using geospatial analysis to show areas prone to flooding.
3. To identify flood-prone areas by analyzing the interplay of physical, and environmental. Social and economic factors to gain a holistic understanding of flood susceptibility.
4. To identify areas and populations at the highest risk of flood impacts, enabling the development of targeted mitigation and adaptation strategies for enhancing overall flood resilience.
5. To develop effective risk management strategies to alleviate the adverse impacts associated with floods.

4. METHODOLOGY

The collection and processing of relevant data, including topographic maps, hydrological data, and land use information. Subsequently, it describes the methodology for flood hazard analysis, which involves the use of geographic information systems (GIS) to map flood-prone areas based on historical flood data and hydrological modeling. The flood vulnerability analysis considers socio-economic factors, infrastructure, and environmental conditions to assess the at-risk population and assets. The chapter discusses the flood risk analysis and combines hazard and vulnerability assessments to identify high-risk areas and prioritize mitigation measures.

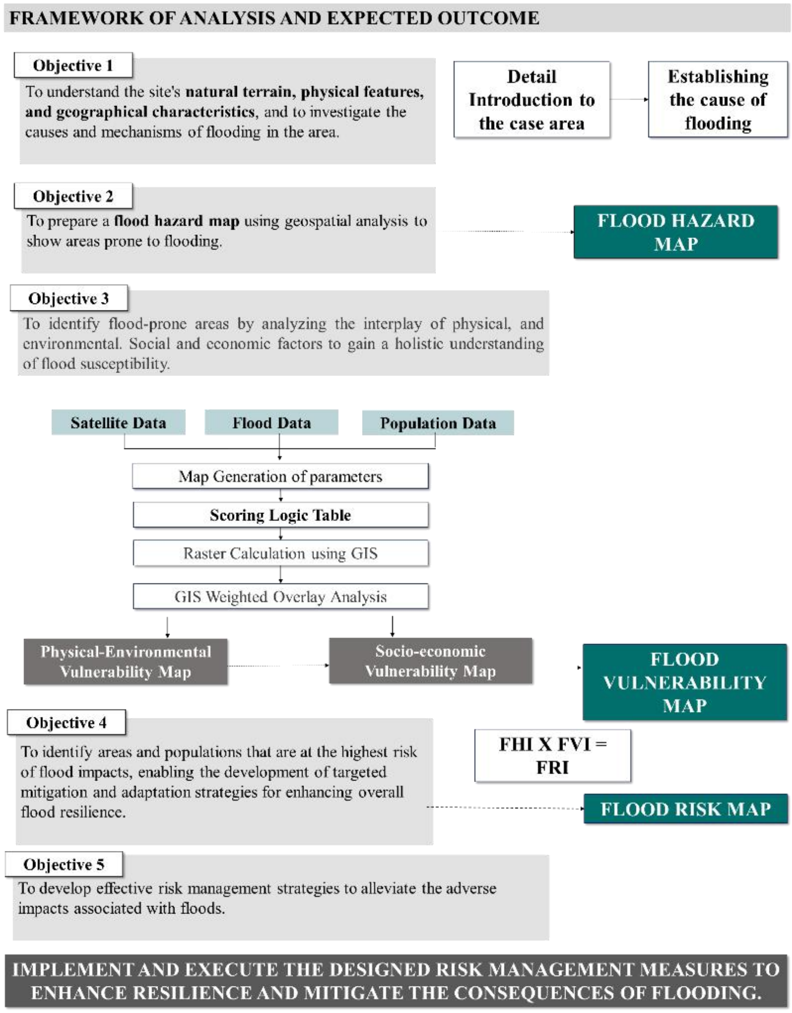

Figure 4: Methodology for the Analysis

4.1 FLOOD HAZARD ANALYSIS

A flood hazard map is a visual representation of areas that are at risk of flooding. These maps are created using data on factors such as elevation, topography, hydrology, rainfall, and land use to assess the likelihood and extent of flooding in different areas. Flood hazard maps typically show various flood zones based on the level of risk, such as high-risk flood zones (areas likely to flood), moderate-risk flood zones (areas with some risk of flooding), and low-risk flood zones (areas less likely to flood). These maps are important for land use planning, emergency preparedness, and risk management, helping communities understand and mitigate the impacts of flooding. (S. Deepak, 2020)

The parameters selected for making a hazard map play a crucial role in determining areas that are vulnerable to flooding. Here's an elaboration on each parameter:

- **Slope:** The slope of the land affects how water flows across the surface. Areas with steep slopes are more prone to rapid runoff and erosion, increasing the risk of flooding, especially during heavy rainfall events.
- **Elevation**: Elevation refers to the height of the land above sea level. Low-lying areas, such as those near rivers or in floodplains, are more susceptible to flooding compared to higher elevations.

- **Watershed:** A watershed is an area of land where all the water drains into a common water body, such as a river or lake. Understanding watersheds helps in identifying areas that are likely to experience increased water flow during heavy rainfall, which can lead to flooding downstream.
- **Rainfall:** Higher rainfall amounts can lead to increased flood vulnerability, especially in urban areas with poor drainage systems, as it can overwhelm the capacity of waterways and infrastructure to handle the excess water.
- **Drainage Density**: Drainage density refers to the network of natural or man-made channels that carry water away from an area. Areas with high drainage density are more likely to experience flooding due to the concentration of water flow.
- **Proximity to River**: Areas close to rivers are at higher risk of flooding, especially during periods of high water levels or when rivers overflow their banks.

Table 1: Scoring logic for Flood Hazard map

Parameter	Slope	Elevation	Rainfall	Drainage density	Distance from watershed	Distance from river
Relationship	Direct	Inverse	Direct	Direct	Inverse	Inverse
Very low	0 - 1.2	150 - 180	0.00001 - 0.2	0-340	>1000	>3000
Low	1.3 - 2.2	120 - 140	0.3 - 0.4	350-680	1000	3000
Moderate	2.3 - 3.7	73 - 110	0.5 - 0.6	690-1000	500	2000
High	3.8 - 6.7	37 - 72	0.7 - 0.8	1100-1400	250	1000
Very high	6.8 - 22	0 - 36	0.9 - 1	1500-1700	100	500

To develop a flood hazard map using ArcGIS, several geospatial analysis steps are undertaken:

- **Slope Map Creation**: A digital elevation model (DEM) is imported into ArcMap. Using the Spatial Analyst Toolbox, the "Slope" tool generates a slope raster, with steepness visually represented through a color ramp. This map is critical in understanding terrain variations, which influence flood risk.
- **Elevation Map Generation**: Another raster map is created by applying the "Elevation" tool to the DEM. The elevation values are symbolized, highlighting terrain heights that affect water flow and flood-prone areas.
- **Watershed Delineation**: The watershed is delineated by first filling DEM sinks to remove imperfections. Flow direction and accumulation tools are applied to establish flow patterns and identify stream channels. The watershed tool, using these channels, delineates watershed boundaries essential for understanding water flow within the area.
- **Rainfall:** Rainfall data was imported as a point feature class. Using the Inverse Distance Weighting (IDW) method from the Spatial Analyst toolbox, rainfall values were interpolated to generate a raster map. The output raster was symbolized with a color ramp to depict varying rainfall intensities, with warmer colors indicating higher rainfall amounts.

- **Drainage Density Map Development**: Using the DEM, flow direction, and accumulation tools, drainage density is calculated and visualized, revealing areas with concentrated drainage networks that affect surface runoff and flood potential.
- **Proximity to Rivers Assessment**: Buffer rings are created around river features to assess proximity, crucial for identifying areas at higher flood risk due to their closeness to water bodies.

The parameter maps generated for Flood Hazard Analysis are given in Appendix I.

4.2 FLOOD VULNERABILITY ANALYSIS

Flood vulnerability analysis is a process used to assess the susceptibility of an area or community to the impacts of flooding. It involves identifying and evaluating various factors that contribute to the vulnerability of a place, such as its exposure to flood hazards, the sensitivity of its population and infrastructure to flooding, and its capacity to cope with and recover from flood events.

Vulnerability analysis is a comprehensive process that is typically divided into two main sub-objectives: socio-economic vulnerability and physical-environmental vulnerability. These sub-objectives help in understanding the complex interactions between social, economic, and environmental factors that contribute to vulnerability.

Socio-economic vulnerability focuses on the susceptibility of communities and populations to the impacts of flooding based on their social and economic conditions. This includes factors such as income levels, access to resources, education, health, and social networks.

Physical-environmental vulnerability, on the other hand, assesses the susceptibility of the physical environment to flooding, including the exposure of infrastructure, buildings, and natural resources to flood hazards.

To further refine the analysis, these sub-objectives are broken down into three key components: susceptibility, exposure, and resilience. Susceptibility refers to the inherent vulnerability of a system or community to flooding, based on its characteristics and location. Exposure quantifies the extent to which elements at risk, such as buildings or infrastructure, are exposed to flood hazards. Resilience measures the ability of a system or community to absorb and recover from the impacts of flooding, including the availability of resources, infrastructure, and response mechanisms.

By breaking down vulnerability into these components, analysts can better understand the complex nature of vulnerability and develop targeted strategies to reduce risk and enhance resilience to flooding.

Physical Environmental Vulnerability Analysis

Physical environmental vulnerability refers to the susceptibility of an area to the physical impacts of natural hazards, such as floods. In the context of Sangli City, Maharashtra, physical environmental vulnerability to floods can be influenced by various factors, including topography, land use, soil type, and drainage patterns.

The topography of an area plays a crucial role in determining its vulnerability to flooding. Low-lying areas and those near rivers or streams are more prone to flooding, as water naturally flows downhill and collects in these areas during heavy rainfall. In Sangli City, low-lying areas along the Krishna River may be particularly vulnerable to flooding. (S. Deepak, 2020)

Land use also affects vulnerability to flooding. Urban areas with extensive pavement and buildings can experience increased runoff, leading to higher flood risk. In contrast, areas with more green spaces, such as parks or wetlands, can absorb water and reduce the risk of flooding. Proper land use planning in Sangli City can help mitigate flood risk by ensuring that vulnerable areas are not overdeveloped.

Soil type is another important factor in determining vulnerability to flooding. Highly permeable soils, such as sandy soils, can absorb water quickly and reduce runoff. In contrast, soils with low permeability, such as clay soils, can lead to increased runoff and higher flood risk. Understanding the soil characteristics in Sangli City can help identify areas that are more susceptible to flooding. (S. Deepak, 2020) . Drainage patterns also play a critical role in determining vulnerability to flooding. Areas with well-maintained drainage systems are better able to manage excess water and reduce flood risk. In Sangli City, ensuring that drainage systems are properly maintained and functioning can help reduce the impact of flooding.

Table 2: Scoring Logic for Physical Environmental Parameters

S.no	Parameter	Unit	Relationship	Weightage	Flood vulnerability index classification				
					Very low	Low	Moderate	High	Very high
1	Slope	Degree	Direct	16.5	0 - 1.2	1.3 - 2.2	2.3 - 3.7	3.8 - 6.7	6.8 - 22
2	Elevation	Meters	Inverse	5.8	150 - 180	120 - 140	73 - 110	37 - 72	0 - 36
3	Rainfall	Range	Direct	39.9	0.00001 - 0.2	0.3 - 0.4	0.5 - 0.6	0.7 - 0.8	0.9 - 1
4	Proximity to river	Meters	Inverse	11.4	5000	3000	2000	1000	500
5	Normalised difference vegetation index (NDVI)	Range	Inverse	12.2	0.29 - 0.44	0.23 - 0.28	0.18 - 0.22	0.13 - 0.17	-0.37 - 0.12
6	NDBI	Range	Direct	7.3	-0.31 - - 0.13	-0.12 - - 0.082	-0.081 - - 0.043	-0.042 - - 0.00068	- 0.00067 - 0.14
7	Distance from roads	Meters	Direct	6.9	4000	2000	1000	500	250

Methodology to prepare Slope, Elevation, Rainfall and Distance from River maps has discussed in the Section 4.1. To develop a flood physical environmental map using ArcGIS, several geospatial analysis steps are undertaken:

- **Normalized Difference Vegetation Index (NDVI) Map**: Using raster datasets of the NIR and red bands, the NDVI was calculated as (NIR−Red)/(NIR+Red). The output map, symbolized with a green-brown color ramp.
- **Normalized Difference Built-Up Index (NDBI) Map:** Two raster datasets, representing the near-infrared (NIR) and short-wave infrared (SWIR) bands, were used. The NDBI was calculated using the formula (NIR−SWIR)/(NIR+SWIR). The resulting map was symbolized to highlight built-up areas, aiding in urban planning and land use management.
- **Proximity to Roads:** A road dataset was used to create multiple ring buffers using the Buffer tool, showing varying distances from the roads. This analysis helped identify areas more vulnerable to flooding due to their proximity to roads, which can

channel runoff and increase flood risk.

Socio-Economic Vulnerability Analysis

In the socio-economic vulnerability analysis for flood-prone areas, several key parameters are considered to assess the vulnerability of communities. These include population density, which indicates the concentration of people in an area and their potential exposure to flood risks. Distance from floodplains is also crucial, as areas closer to flood-prone areas are more susceptible to flooding. Access to healthcare centers, schools, hospitals, and NGOs is important for disaster preparedness and response, as communities with limited access may face challenges in accessing essential services during and after floods. Literacy and employment rates are indicators of a community's ability to cope with and recover from flood impacts. Lastly, the distance from evacuation shelters is critical for identifying areas where residents may have difficulty accessing safe shelter during floods. (S. Deepak, 2020)

Table 3: Scoring Logic for Socio-Economic parameters

S.no	Parameter	Unit	Relationship	Weightage	Flood Vulnerability Index classification				
					Very low	Low	Moderate	High	Very high
1	Population density	Person /sq.km	Direct	27.7	1515.91 - 3430.86	3430.87 - 6003.83	6003.84 - 12345.30	12345.31 - 28721.70	28721.71 - 70416.70
2	Proximity to inundation area	Meters	Inverse	23.3	10000	5000	2000	1000	500
3	Literacy	Person /sq.km	Inverse	8.3	23266.41 - 55852.9	9442.11 - 23266.4	4727.1 - 9442.1	2098.93 - 4727.09	1117.07 - 2098.92
4	Employment	Person /sq.km	Inverse	15.9	9949.92 - 23676.1	4135.5 - 9949.91	2956.29 - 4135.49	1544.96 - 2956.28	565.18 - 1544.95
5	No. of hospitals	Meters	Inverse	5.1	5000	2000	1500	1000	500
6	No. Of schools	Meters	Inverse	2.9	5000	2000	1500	1000	500
7	Evacuation shelters	Meters	Direct	7.4	500	1000	1500	2000	5000
8	Healthcare centres	Meters	Direct	5.3	500	1000	1500	2000	5000
9	Ngo location	Meters	Direct	4	500	1000	1500	2000	5000

To develop parameter maps for socio-economic vulnerability map, following methods were adopted:

- To create a map of population density, data was entered ward-wise into an attribute table. This data likely included the population count or density for each ward. In ArcGIS, this data was used to generate a thematic map, symbolized using five different categories to represent varying levels of population density across the study area. The categories may have been defined based on natural breaks or quantile classification methods to ensure meaningful groupings. Similarly, maps of literacy and working population were created by entering data ward-wise into attribute tables, likely containing literacy rates and the number or percentage of the working-age population. These maps were also symbolized using multiple categories to visually represent the distribution of literacy rates and working population across the study area.

- The distance-based parameters maps, such as those showing the distance from healthcare centers, schools, hospitals, NGOs, and evacuation shelters, were created using buffer analysis in ArcGIS. The buffer analysis involved creating multiple concentric buffer rings around each of these locations, with each ring representing a different distance threshold. For example, the first ring might represent a distance of 100 meters, the second 500 meters, and so on. These buffer rings help visualize areas that are within a certain distance of each location, which is important for understanding accessibility and vulnerability.
- After creating the buffer rings, the maps were clipped to the study area boundary to focus the analysis on the relevant area. Clipping the maps ensures that only the buffer rings within the study area are displayed, providing a clearer and more accurate representation of the distances from the specified locations.

The parameter maps generated for Flood Vulnerability Analysis are given in Appendix I.

4.3 FLOOD RISK ANALYSIS

Flood risk analysis is a method used to assess the potential risks and impacts of flooding on communities and infrastructure. It involves combining information about flood hazards with vulnerability assessments to determine the likelihood and consequences of flooding in a particular area. In this analysis, the flood hazard map identifies areas prone to flooding based on factors such as elevation, slope, and proximity to water bodies. The socio-economic and physical vulnerability map indicates the susceptibility of communities and infrastructure to flood damage based on factors such as population density, building types, and access to services.

To calculate flood risk, the socioeconomic and physical vulnerability map is first added together to create a composite vulnerability map. This composite map represents the overall vulnerability of an area to flooding, taking into account both the physical and social factors that influence vulnerability. Next, the composite vulnerability map is multiplied by the flood hazard map using Raster Calculator in ArcGIS. This multiplication combines the information from both maps to produce a flood risk map, which highlights areas at higher risk of flooding due to both the likelihood of flooding (hazard) and the potential impact of flooding (vulnerability).

4.4 TRADITIONAL INDIAN KNOWLEDGE SYSTEM

Traditional practices are deeply rooted in local knowledge, environmental understanding, and community engagement, making them relevant even in contemporary urban planning and disaster management strategies.

- **Jal Kalp:** Ancient India had sophisticated water management systems, such as step wells (baolis), tanks, and ponds, which were designed to manage water resources efficiently. These structures not only provided water during dry periods but also helped in flood management by storing excess rainwater.
- **Ahars and Pyne Systems**: In Bihar, the Ahar-Pyne system is a traditional floodwater harvesting and management technique. Ahars are reservoirs, and pynes are channels

that distribute water. This system controls flooding and supports agriculture by managing the flow of excess water.

- **Settlements and Floodplains**: Traditional Indian towns and villages were often strategically located on higher ground or away from river floodplains. This was a deliberate planning choice to minimize flood risks while still maintaining access to water resources.
- **Natural Indicators:** Communities historically relied on natural indicators, such as changes in animal behavior or specific weather patterns, to predict floods. This indigenous knowledge often provided early warning signs that allowed for timely evacuation and preparation.
- **Sustainable Urban Planning**: Incorporating principles from IKS into contemporary urban planning can lead to more sustainable and resilient cities. This includes designing cities with natural drainage systems, preserving wetlands, and maintaining green belts that act as flood buffers.

5. RESULTS AND FINDINGS

The hazard map and vulnerability map were created by overlaying all the individual parameter maps as mentioned in Table 1, Table 2, and Table 3. This overlay analysis resulted in classifying the area into five hazard classes: very high, high, moderate, low, and very low. Each class was assigned a specific color for better visualization: very high was represented by red, high by orange, moderate by yellow, low by light green, and very low by dark green.
This color scheme was chosen to clearly differentiate between the different levels of hazard in case of hazard map and level of vulnerability in vulnerability map, with red indicating the highest level of hazard/vulnerability/risk and dark green indicating the lowest.

5.1 FLOOD HAZARD MAP

The hazard map provides a comprehensive overview of the potential risks in the area, aiding in better planning and management of resources to mitigate these hazards.

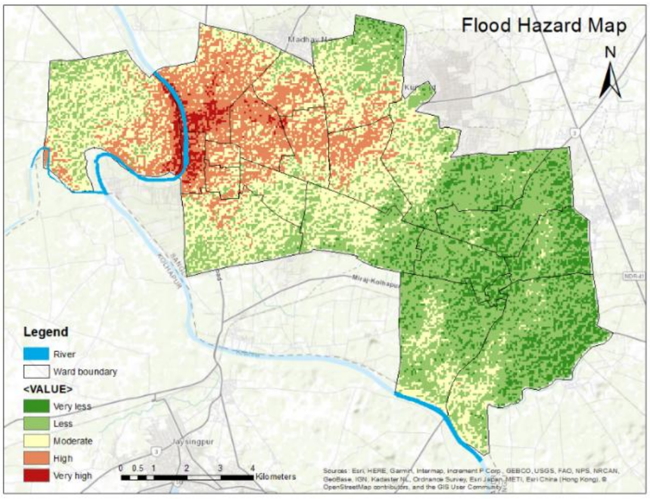

Figure 5: Flood Hazard Map

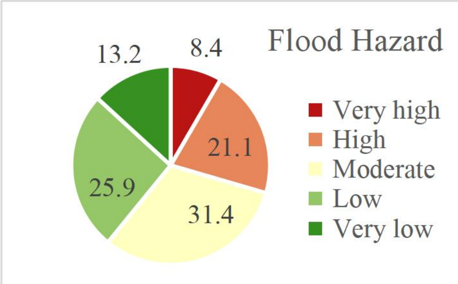

Figure 6: Percentage of an area under Flood Hazard

The flood hazard analysis reveals that 8.4% of the 200.2 sq. km area in Sangli City, amounting to approximately 16.8 sq. km, is classified as being at a very high flood hazard risk, while 21.1%, or around 42.2 sq. km, is at a high flood hazard risk.

5.2 FLOOD VULNERABILITY MAP

The physical and environmental parameters used in flood vulnerability analysis help identify vulnerable areas around water bodies, particularly those with low elevation. Low-lying areas near water bodies are more susceptible to flooding due to their proximity to sources of water and their lower elevation compared to surrounding areas. Settlements located in these vulnerable areas are at higher risk of flood damage, as they are more likely to be inundated during flood events.

Areas with higher population density, lower literacy rates, and limited access to healthcare, education, and employment opportunities are considered more vulnerable. In the context of the city, the core areas with high population density and limited space, such as wards with high-rise buildings or densely populated neighborhoods, are often the most vulnerable. Despite their small area, these wards have a high concentration of people, making them more susceptible to flood impacts.

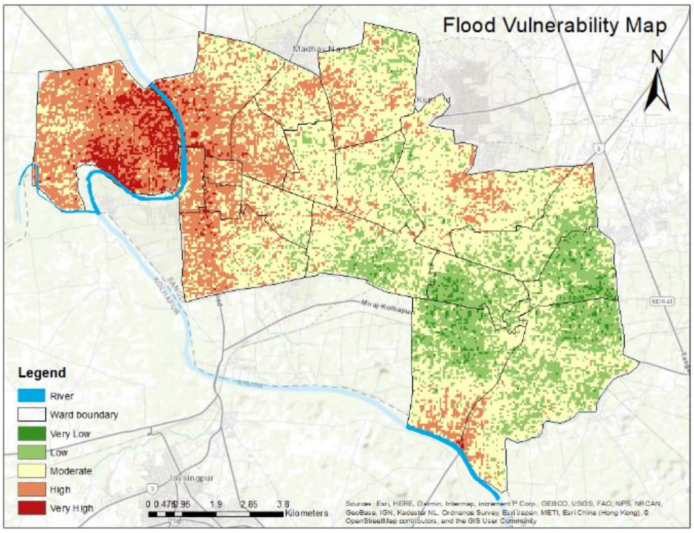

Figure 7: Flood Vulnerability Map

The flood vulnerability map is a crucial tool in understanding and mitigating the risks posed by floods in a specific area. It is created by combining the physical environmental vulnerability map and the socio-economic vulnerability map, using the Raster Calculator in ArcGIS resulting in a comprehensive assessment of the factors contributing to flood vulnerability.

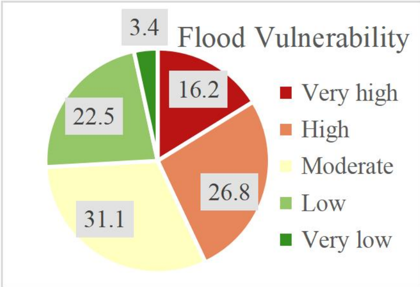

Figure 8: Percentage of an area under Flood Vulnerability

The flood vulnerability analysis indicates that 16.2% of the 200.2 sq. km area in Sangli City, which is approximately 32.4 sq. km, is highly vulnerable to floods, while 26.8%, or about 53.7 sq. km, is at a high vulnerability rate.

5.2 FLOOD RISK MAP

Areas with high population density are at significant flood risk due to the greater exposure of people, infrastructure, and economic activities. The concentration of assets in these areas increases the potential for damage and endangers human safety during floods.

Conversely, areas on the outskirts of the city, often lacking essential resilience facilities like healthcare, emergency services, and evacuation shelters, also face heightened flood risks. The absence of these critical infrastructures can worsen flood impacts, leading to more severe loss of life and property.

Proximity to rivers further amplifies flood risk, as these areas are directly exposed to river overflows during heavy rainfall or snowmelt. The risk is heightened by large watershed areas that contribute more water to rivers, potentially causing overflow. Built-up areas near rivers also increase flood risk by generating higher runoff due to impermeable surfaces like roads and buildings, which prevent water absorption into the ground. The combination of a large watershed and extensive built-up areas near rivers significantly elevates the flood risk in these regions.

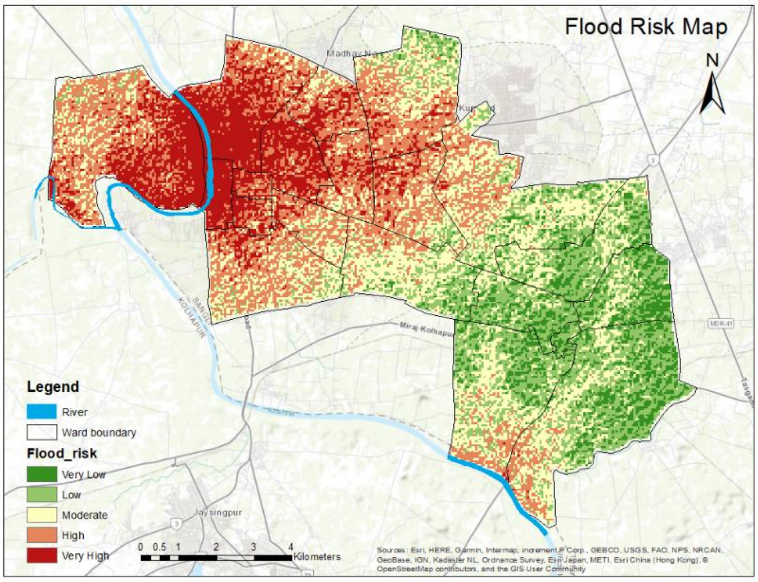

Figure 9: Flood Risk Map

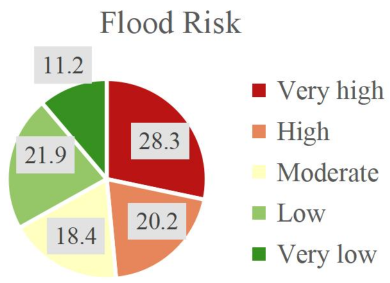

Figure 10: Percentage of an area under Flood Risk

The flood risk analysis reveals that 28.3% of the 200.2 sq. km area in Sangli City, approximately 56.6 sq. km, is at a very high risk of flooding, while 20.2%, or around 40.4 sq. km, is at a high risk.

6. DISCUSSIONS

The vulnerability based on socio-economic dimensions reveals that the core areas of the city are often less vulnerable to floods. This is because these areas are typically well-equipped with infrastructure, such as drainage systems, flood defenses, and emergency services, which can mitigate the impacts of flooding. Additionally, these areas often have better access to resources and facilities, such as healthcare and education, which can help residents cope with and recover from flood events more effectively.
Overall, understanding the vulnerabilities of different areas based on physical, environmental, and socio-economic factors is crucial for developing effective flood mitigation and management strategies. By identifying and prioritizing vulnerable areas, policymakers and planners can implement measures to reduce the impacts of floods and protect vulnerable communities.

Emphasizing a blend of modern engineering and traditional practices, the chapter suggests a holistic approach to mitigating flood risks.

- **Structural Measures:** The chapter advocates for the construction of embankments, flood levees, and flood walls along the most flood-prone sections of the riverbanks. These structures are vital for physically containing floodwaters and preventing inundation of critical infrastructure and residential areas. However, the chapter goes beyond conventional engineering by integrating principles from traditional Indian water management systems. For instance, the proposal includes the development of blue-green infrastructure, such as green roofs, rain gardens, and permeable pavements, which serve dual purposes. Not only do they manage excess rainwater by allowing it to infiltrate the ground, but they also mimic the natural water absorption and retention strategies found in historical practices like the use of step wells (baolis) and natural reservoirs (talabs). These traditional methods effectively managed water resources by capturing, storing, and gradually releasing water, reducing the intensity and impact of floods.

- **Non-Structural Measures:** In the realm of non-structural measures, the chapter emphasizes the importance of an early warning system that blends modern meteorological tools with traditional ecological knowledge. Historically, communities in India relied on natural indicators such as changes in animal behavior, unusual cloud patterns, and the behavior of local flora and fauna to predict impending floods. The proposal suggests the integration of this indigenous knowledge with contemporary technologies like satellite monitoring, remote sensing, and real-time data analytics to create a robust early warning system. This system would not only provide accurate and timely flood alerts but also empower local communities by reconnecting them with their traditional knowledge systems.

- Another critical non-structural measure is the regulation of reservoirs and dams, informed by ancient water management practices. In many parts of India, the controlled release of water from tanks and reservoirs was a key strategy during heavy rains to prevent overflow and downstream flooding. The proposal recommends modernizing this practice with automated systems that can predict the optimal timing and volume of water release, thus minimizing flood risks while ensuring that water is efficiently managed for agricultural and domestic use.

7. CONCLUSIONS AND WAY FORWARD

The study on flood vulnerability assessment in Sangli City, Maharashtra, reveals that the city faces considerable flood risks, particularly during intense rainfall, exacerbated by upstream conditions along the Krishna River and the closure of the Almatti Dam. The geospatial approach employed in the analysis provided critical insights into flood hazard, vulnerability, and risk, pinpointing high-risk areas and populations in need of targeted intervention.

Key recommendations include the construction of embankments, blue-green infrastructures, and improved drainage density to mitigate flood impacts. Additionally, non-structural measures such as development control regulations, an early warning system, reservoir regulation, and flood insurance are crucial for effective flood management.

The study highlights the importance of a comprehensive flood risk management framework that integrates hazard, exposure, vulnerability, and risk assessments. This approach, coupled with strong stakeholder engagement and policy support, is essential for reducing Sangli City's vulnerability to floods and enhancing its overall resilience.

The way forward for enhancing flood resilience in Sangli City involves the diligent implementation of the proposed mitigation measures, including the construction of embankments, blue-green infrastructure, and improved drainage systems. The successful execution of these strategies will significantly reduce flood risks and protect vulnerable populations. Additionally, the geospatial methodology employed in this study can be adapted to assess flood risk in other regions, offering a valuable tool for urban planning and disaster management across various contexts. Further, incorporating dam management and studying the backwater effects of rivers can enhance the comprehensiveness of this work, providing deeper insights into flood dynamics and enabling more effective mitigation strategies.

8. REFERENCES

1. Emmanuel Mavhura, T. M. (2021). A comprehensive spatial analysis of social vulnerability to natural hazards in Zimbabwe: Driving Factors and policy implications . *Disaster Risk Reduction* .
2. Gaurav Pakhale, R. K. (2023). Are flood events really increasing? A case study of Krishna River Basin, India . *Natural Hazards Research 3*.
3. Organisation, W. H. (2024). *World Health Organisation*. Retrieved from Health Topics : https://www.who.int/health-topics/floods#tab=tab_1
4. Prep, B. E. (2024). *Fllods in India* . Retrieved from BYJU's Exam Prep: https://byjus.com/free-ias-prep/flooding-in-india/#:~:text=Floods%20are%20the%20most%20lethal,at%20a%20humongous%20%2458.7%20billion.
5. S. Deepak, G. R. (2020). Geospatial approach for assessment of vulnerability to flood in local self-governments . *Geoenvironmental Disasters* .
6. statista. (2023, June 28). *Number of deaths due to floods in India from 2010 to 2021*. Retrieved from statista: https://www.statista.com/statistics/1007627/india-number-of-deaths-due-to-floods/
7. testbook. (2024). *testbook*. Retrieved from Floods in India: Learn the causes, effects and distribution of floods: https://testbook.com/ias-preparation/floods-in-india-analysis
8. UNESCO-IHE. (n.d.). *Institute for Water Education* . Retrieved from UNESCO-IHE: http://www.unesco-ihe-fvi.org/

Sustainable Management of Natural Resources in a Coastal Ecosystem, a Case of Panjim, Goa

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Abstract

Coastal Ecosystem contains a diversity of habitats including beaches, forests, sand dunes, salt marshes, mangroves, estuaries, wetlands and inter-tidal zones. They maintain a delicate balance between a marine ecosystem and a terrestrial ecosystem. They act as shock absorbers to the natural disasters that occur in these areas. But there has been an increasing concern that these coastal ecosystems receive inputs of excessive nutrients, due of irresponsible handling of solid waste, overexploitation of groundwater, deforestation and reduction in the extent of mangrove cover increases the vulnerability of the coastal ecosystem to the natural disasters.
The study area, Panjim, is a coastal city with 33% of the city constituting natural features which includes mangroves, hill, natural orchards, salt pans, khazan lands, lake and creeks. The aim of the study is to assess the decadal change in the conditions of the natural resources of a coastal ecosystem and suggest practices for the sustainable management and conservation of the same. It comprehends and analyses the existing situation of water resources in terms of rainfall, surface water availability, water quality and the groundwater potential. It also portrays the decadal change in the extent of green cover (Forests and Mangroves) and its carbon sequestration potential.
The study finds that encroachment of water bodies resulted in the floods and unsustainable extraction of groundwater led to salt water intrusion. Degradation of vegetation and mangroves, decreased the carbon sequestration potential and increased the Land Surface Temperature. The study helps the policy makers and spatial planners to understand the extent of degradation of quality and quantity of natural resources as it raises an alarm to estimate the resource utilization & resource availability to arrive at sustainable approaches to minimize the consumption. This makes it significant to follow sustainable practices for the management and conservation of these resources.

Keywords: Sustainable management; Water resources; Groundwater; Mangroves; Carbon sequestration; Eco-sensitive area

1. INTRODUCTION

1.1 Background

The word sustainability is defined as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" according to the United Nations Bruntland Commision. Sustainable Management refers to an approach that integrates environmental, social, and economic considerations into decision-making processes to ensure the long-term viability of resources and systems. This concept emphasizes the importance of balancing the needs of the present generation with those of future generations, aiming to minimize negative impacts on the environment while promoting social equity and economic growth.Sustainable management of natural resources is crucial for maintaining ecological balance, supporting biodiversity, and ensuring the livelihoods of communities dependent on these resources.

Freshwater resources, such as rivers, lakes, and wetlands, are essential for maintaining biodiversity in coastal ecosystems. They serve as critical habitats for many species, including fish, birds, and invertebrates. For instance, estuaries, which are areas where freshwater from rivers meets saltwater from the ocean, serve as nurseries for many commercially important fish species. Wetlands, mangroves, and estuaries act as natural buffers, absorbing wave energy and reducing the impact of flooding. Healthy freshwater systems contribute to the resilience of coastal ecosystems against climate change and extreme weather events, safeguarding both natural habitats and human settlements. Freshwater resources are critical for the livelihoods of coastal communities. They provide water for drinking, agriculture, and aquaculture, supporting food security and economic development. Sustainable management of these resources can enhance community resilience, reduce conflicts over water access, and promote equitable resource distribution. Additionally, healthy freshwater ecosystems can boost tourism and recreational opportunities, further contributing to local economies.

Mangroves are a vital component of coastal ecosystems, providing a range of ecological, economic, and social benefits. Mangroves are salt-tolerant trees and shrubs thrive in the inter-tidal zones of tropical and subtropical regions, forming a unique and diverse habitat. Mangroves act as natural barriers, protecting coastal areas from erosion, help stabilize shorelines and reduce the impact of extreme weather events like tsunamis. They are highly efficient at sequestering and storing carbon, a process known as "blue carbon". They can store up to four times more carbon than other tropical forests, making them valuable in the fight against climate change.Forests play a crucial role in maintaining water quality in coastal ecosystems. Their dense root systems trap sediments, filter pollutants, and prevent contamination of waterways. Despite their importance, mangrove forests are under threat from various human activities, including coastal development, aquaculture expansion, pollution, and climate change.

1.2 Need for the study

Resource depletion in coastal ecosystems is driven by a combination of direct human activities and underlying socio-economic factors. Coastal development, including urbanization, agriculture, and aquaculture, results in the destruction and alteration of critical habitats such as mangroves, coral reefs, and wetlands. These ecosystems are essential for biodiversity, providing nursery grounds for many marine species and serving as natural barriers against storms and erosion. The conversion of land for development not only reduces habitat availability but also leads to increased pollution and sedimentation, further degrading water quality and ecosystem health. (Martens).

Coastal ecosystems are highly susceptible to pollution from various sources, including agricultural runoff, sewage discharge, and industrial effluents. Nutrient loading from fertilizers can cause eutrophication, leading to harmful algal blooms that deplete oxygen in the water, harming marine life. Additionally, plastic waste and other contaminants pose severe threats to marine organisms and ecosystems, contributing to biodiversity loss.

Rapid population growth in coastal areas leads to increased demand for resources such as water, land, and food. Urbanization often results in the expansion of infrastructure and services, which can encroach on natural habitats and increase pollution. The concentration of human activity in coastal zones places immense pressure on local ecosystems, making sustainable management increasingly challenging.

Many natural regions are potentially threatened by uncontrolled conventional tourism. The consumption patterns of both the residents and tourists in the area need to be assessed in order that the unsustainable use of an area's resources could be tackled from various perspectives and at various levels of governance. There are raising concerns on the consumption patterns of the tourists which are leading to the depletion of the national resources such as water resources, local resources and land degradation. Over the years, the city's infrastructure for tourists has come under pressure from the city's growing tourist population and increasing environmental degradation have become crucial elements of concern.

1.3 Objectives

This study aims to focus on the natural resources, particularly, water resources, mangroves and forests in a coastal ecosystem. Emphasis is made to understand the level of depletion and degradation of these resources in the quantitative and the qualitative sense in the possible areas. Following are the objectives of the study:

- To comprehend and analyze the existing situation of water resources in terms of rainfall, surface water availability, water quality and the groundwater potential
- To study the decadal change in the extent of green cover (Forests and Mangroves), and calculate its carbon sequestration potential
- To suggest sustainable practices for the management and conservation of the studied natural resources

1.4 Methodology

Various types of analyses under the heads of water resources, vegetation and mangroves as given in the table 1 has been listed along with the data required and the techniques used. Rainfall analysis has been done entirely on secondary data from IMD. Water quality assessment is done using the data provided by CPCB collected from the water quality monitoring stations. Groundwater recharge potential has been calculated with the help of runoff calculation for years 2002 and 2022 to arrive at the difference in runoff over 2 decades. This gives an understanding on how much area has come under concrete layers which doesn't let the water seep into the ground. Assessment on groundwater extration is done by comparing it with the groundwater recharge potential which helps to understand if the extraction rate is sustainable.

Area under forests, vegetation and mangroves is derived using NDVI of years 2002 and 2022 which showed a drastic difference in the loss of area under the same. Using a study based on number and types of trees present in the conserved parks of the study area, density of trees per sq.m and carbon sequestrated per sq.m of green cover is calculated. Resource depletion and Land degradation would result in the rise in the temperature of the study area over the past 20 years. Hence, Land Surface Temperature is mapping was done to identify the range of its impact on temperature.

Table 1 Methodology and Data required

OBJECTIVE	TYPES OF ANALYSIS	DATA REQUIRED	SOURCE	TECHNIQUES
WATER RESOURCES	Rainfall Analysis	Decadal rainfall data (1901-2011)	IMD	Geospatial tools – Interpolation
	Water Quality	Water quality parameters and values	CPCB	Water Quality Index
	Surface Water	Surface water bodies and water available	WRD	
	Groundwater	Depth of wells and permissible amount of groundwater extractable	WRD	Calculating groundwater recharge potential
VEGETATION	Carbon sequestration potential	Types of trees and number of trees	Glimpses of Biodiversity in Panjim	
	Ratio of green spaces	Area under forests and vegetation	USGS	NDVI
MANGROVES	Loss of Mangroves	Area under Mangroves	USGS	NDVI

1.5 Case Area Description

The municipality of Panaji is situated in the North Goa district's Tiswadi taluk. It serves as both North Goa district's administrative centre and the state capital of Goa. It was the administrative centre during the Portuguese rule and was acquired by India together with the rest of Goa and the former Portuguese territory in the invasion of 1961. It later became a state capital when Goa attained independence in 1987. It is now the only urban area in the state possessing the status of a municipal corporation, along with the state capital of Goa. After Margao and Vasco, Panaji is the third-largest city in the state. Due to its tourism resources, strong accessibility, and availability of good tourist infrastructure facilities, the city has developed as a key tourist destination in the state in recent years. The city's expanding prominence as a tourist destination has enhanced tourism-based economic activity through numerous factors over the years. Various trade and commercial establishments, hotels and restaurants, tours and travels, and tourism-based art and antiquities have all contributed to this. The city is also a key commercial centre for agricultural goods and other commodities originating in nearby smaller cities and rural regions.

Panaji makes for 16% of the urban population in the North Goa district and 2% of the state as a whole. Over the past fifty years, the expansion of the city's population has fluctuated mostly because of changes in the territory under CCP's control. The total population of Panaji, which was 59,066 in the Census of 2001, is now 40,017, according to the 2011 Census. This is because Taigao and Durgawado, which were a part of the Panaji Municipal Council in the Census of 2001, were excluded in the Census of 2011. These regions were excluded from Panaji's authority in 2002 when it was granted municipal corporation status by incorporation of the Corporation of City of Panaji Act 2002, leading to a decrease in Panaji's jurisdiction. The city receives considerable amount of tourist population throughout the year. As per the tourist statistics for 2011, Tiswadi taluka received 1,13,6861 tourists which comprised of 6, 90,926 domestic tourists and 4, 45,935 foreign tourists.

Given that Panaji is one of the most popular tourist sites in the country, it is reasonable to infer that the city welcomes the greatest number of Taluka level visitors throughout the year. The city region has evolved over the past 50 years into a significant commercial and tourism destination in addition to being the administrative capital. Panaji is one of the top tourist sites in the state due to its favourable geographic location, administrative hub, accessibility to other tourist locations, and availability of adequate tourism infrastructure. The city's economy is supported by a variety of industries, particularly the tourist sector. (Corporation of the city of Panaji, 2015)

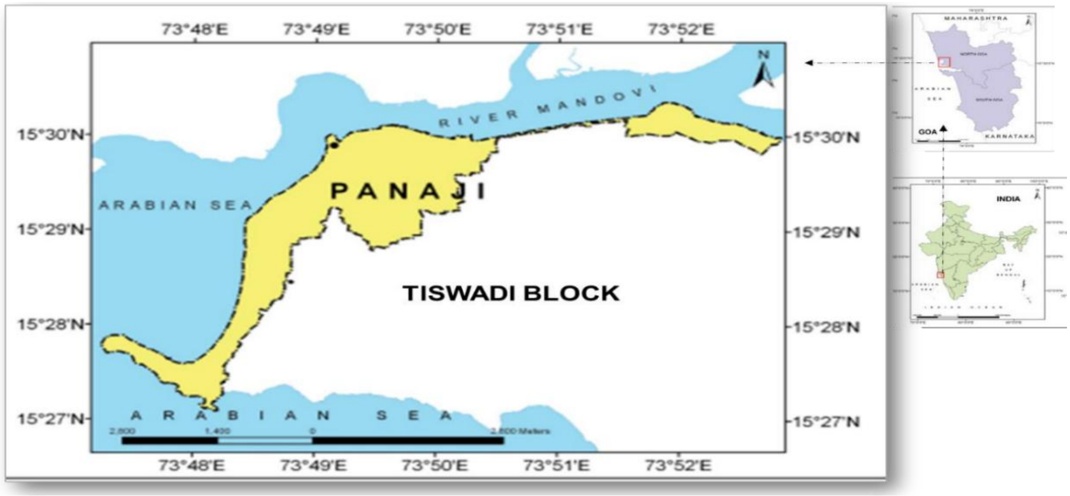

Figure -1 Study Area - Panjim, Goa

Panjim lies on the bank of the River Mandovi and is also bounded by two creeks. Around 33% of the Panjim city constitutes of the area under natural features. It covers an area of 8.12 sq.km and has a population of 40,017 (as per 2011 census). It has a population density of 4928 persons per sq.km. Annual tourist influx into the city is 2.35 lakhs which accounts to 5380 tourists per day.Water Bodies: The major water bodies located in and around the city are River Mandovi, Zuari estuarine, Mala Lake, Qurem creek and St Inez drain.Urban Green: Natural resources is about 2.09%. The natural features mainly includes marshy lands and mangroves along the water front which act as barrier from the flooding caused during the monsoons. It also includes mangroves, hill, natural orchards, salt pans, khazan lands, lake and creeks.

1.6 Discussion

Water resources

Water resource assessment (WRA) is a critical process that involves evaluating the quantity and quality of water resources available within a specific area. Assessment includes Rainfall analysis, Surface water analysis, groundwater analysis and calculation of water quality index.Water resource assessment is an essential tool for effective water management, enabling stakeholders to understand the dynamics of water availability and usage. By integrating data collection, stakeholder engagement, and policy recommendations, WRA supports sustainable water management practices that are crucial for addressing current and future water challenges.

Rainfall analysis:

Rainfall Analysis is crucial in understanding the extreme hydrological events, such as droughts or floods, and helps in evaluating the surface and subsurface water resources and their quality. Understanding rainfall processes is crucial in addressing several hydrological challenges that have both positive and negative impacts on agriculture, climate change, and natural hazards. Panjim receives rainfalI from South-West monsoon between the months of June to September (Corporation of the city of Panaji, 2015).

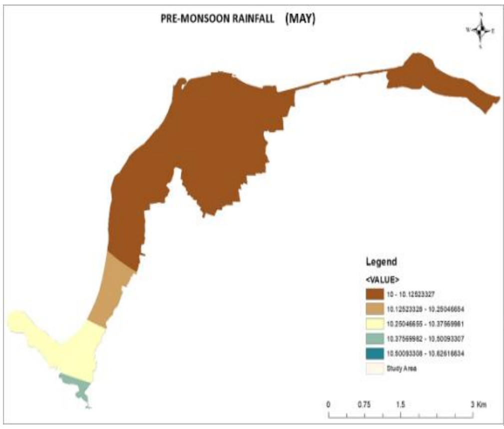

Figure 2 Post-Monsoon Rainfall (May

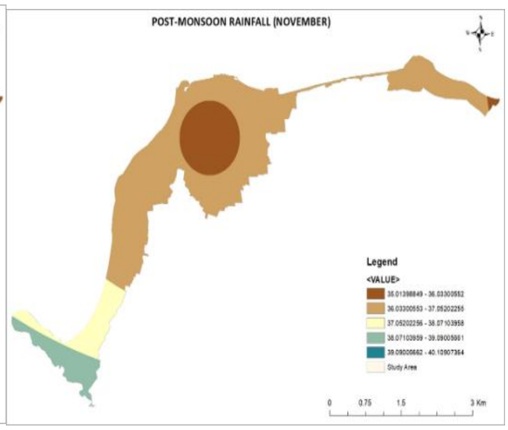

Figure 3 Post-Monsoon Rainfall (November)

For the Past 30 Years (1991–2022):

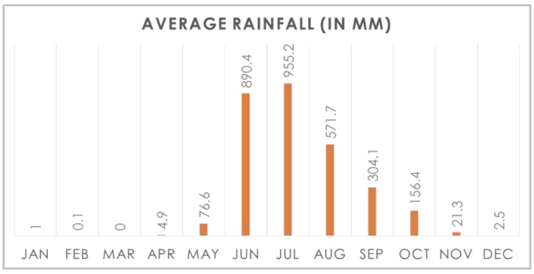

Figure 4 Average Rainfal

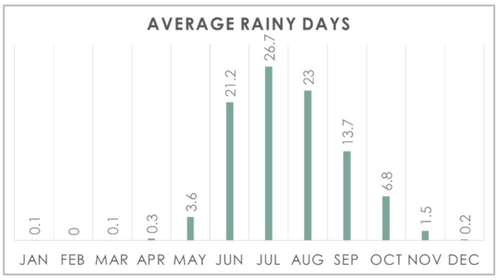

Figure 5 Average number of Rainy days

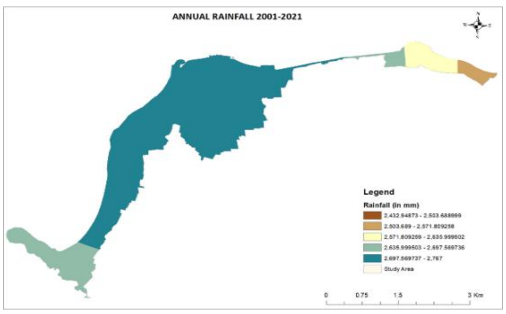

Figure 6 Annual Rainfall 2001-2021

Over 90% of annual rainfall occurs during monsoon months of June to September of which about 32% of the annual rainfall is received during July. The annual average rainfall is 2,932 mm.

Surface Water Availability:
Surface water availability refers to the amount of water present in visible bodies of water on the Earth's surface, such as rivers, lakes, reservoirs, and wetlands. Surface water availability is crucial for various human needs and ecosystem functions, but its monitoring and management face challenges due to data limitations and the impact of human activities and climate change on the water cycle

Table 2 Surface water bodies

ER BODY TYPE	CONSTRUCTION	STORAGE CAPACITY (L)	EXTRACTABLE – 25%
Spring	Man Made	31	7.75
Lake	Natural	44505	11,126.25
Spring	Man Made	21	5.25
Lake	Man Made	28909	7227.25
Total		**73907**	**18,476.75**

All the water that is required by the city is provided from Opa Water Works. The gross water supply considering the population of CCP and its surrounding areas as per Census 2011 and daily supply of
24.2 MID the supply rate works out to be 198 lpcd which is considered as substantially high when compared with the service level benchmark of 135 lpcd as per by the CPHEEO (Corporation of the city of Panaji, 2015)

Table 3 Water Storage Reservoirs in Panjim

RESERVOIR TYPE	CAPACITY (IN M3)	WATER SUPPLIED (MLD)
Storage Tank no.8	5000	15
(GLSR) 1	800	
GLSR 2	800	
GLSR 3	800	
GLSR 4	800	
GLSR 5	800	
Overhead Tank no.6	450	
OHT no.7	650	
Ribandar (GLSR)	150	1.2
Ribandar (GLSR)	300	
Nagali (sump and OHT)	200	8
Taleigo (2 OHT)	1600	
Taleigo (OHT)	650	
TOTAL	**13000**	**24.2**

Water Quality:
Water quality assessment is a systematic approach to evaluating the condition of water bodies, including rivers, lakes, and groundwater, to determine their suitability for various uses and to monitor the health of aquatic ecosystems. Water quality assessment is essential for managing and protecting

water resources. It provides valuable information for decision-makers, helps identify pollution sources, and supports the sustainable use of water bodies. By employing various assessment methods and engaging stakeholders, effective water quality management can be achieved, ensuring the health of aquatic ecosystems and the safety of water for human use. Water pollution data has been collected from CPCB, Goa and the streams which are highly polluted are identified. For all the identified highly polluted streams water quality index has been calculated to arrive at the possible condition of the water body with respect to the standards.

Water Quality Index (WQI) is a widely used tool for assessing and communicating the quality of water bodies. It provides a single numeric value that represents the overall water quality based on multiple parameters. WQI can be calculated by using the following equation: (Paun1, 2016)

$$WQI= \sum \qquad \sum$$

The quality rating scale (Qi) for each parameter is calculated by using this expression:

$$Qi=100[(Vi-V0/Si-V0)]$$

Where,

Vi is estimated concentration of i^{th} parameter in the analyzed water

V0 is the ideal value of this parameter in pure water

V0 = 0 (except pH =7.0 and Dissolved Oxygen = 14.6 mg/l)

Si is recommended standard value of i^{th} parameter.

The unit weight (Wi) for each water quality parameter is calculated by using the following formula:

$$Wi=K/Si$$

Where K= proportionality constant and can also be calculated by using the following equation:

$$K= 1 /\sum (1/ \quad)$$

Sample calculation: WQI at Mandovi Bridge, River Mandovi:

Table 4 Calculation of WQI at Mandovi Bridge, Mandovi River (2017-18)

Parameter	Si (Standard value)	1/Si	Wn=K/Si	Vi	Qn	WQI
DO	8	0.125	0.301447	5.91	73.875	22.26939
BOD	30	0.033333	0.080386	1.6	5.333333	0.428725
pH value	7.5	0.133333	0.321543	7.6	101.3333	32.58307
Turbidity (NTU)	10	0.1	0.241158	20	200	48.23151
Total Suspended solids (mg/lt)	500	0.002	0.004823	198	39.6	0.190997
Total dissolved solids (mg/l)	500	0.002	0.004823	25377	5075.4	24.47942
Sulphate	200	0.005	0.012058	2430.8	1215.4	14.65514
Chloride content (mg/lt)	250	0.004	0.009646	15905	6362	61.36977
Total alkalinity(mg/lt as CaC03)	200	0.005	0.012058	106	53	0.639068
Total hardness (mg/lt as CaC03)	200	0.005	0.012058	5360	2680	32.31511
		0.414667	1		WQI	237.1622
	k	2.411576				

Table 5 Calculation of WQI at Mandovi Bridge, Mandovi River (2020-21)

Parameter	Si (Standard value)	1/Si	Wn=K/Si	Vi	Qn	WQI
DO	8	0.125	0.301447	6.3	78.75	23.73895
BOD	30	0.033333	0.080386	2	6.666667	0.535906
pH value	7.5	0.133333	0.321543	7.58	101.0667	32.49732
Turbidity (NTU)	10	0.1	0.241158	2.8	28	6.752412
Total Suspended solids (mg/lt)	500	0.002	0.004823	40	8	0.038585
Total dissolved solids (mg/l)	500	0.002	0.004823	31722	6344.4	30.6
Sulphate	200	0.005	0.012058	2046	1023	12.33521
Chloride content (mg/lt)	250	0.004	0.009646	17220	6888	66.44373
Total alkalinity(mg/lt as CaC03)	200	0.005	0.012058	108	54	0.651125
Total hardness (mg/lt as CaC03)	200	0.005	0.012058	6400	3200	38.58521
		0.414667	1		WQI	212.1784
	k	2.411576				

Likewise, the calculation is also done for the other site at Ribandar Water quality monitoring station both of which were notified as polluted stretches due to activities like jetty movement, residential encroachments have been done. The consolidated table is discussed. The range of WQI and its corresponding inference and the parameters considered to calculate WQI has been given below.

Table 6 Colour coding of Water Quality Index

WQI	STATUS
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very Poor
>100	Unsuitable for drinking

There are incredibly higher amounts of TDS, Total alkalinity, total hardness, sulphates and chloride contents in all the samples.

Table 7 Comparing WQI of the years 2017 and 2021

S.NO	SITE LOCATION OF SAMPLE	WQI (in 2017)	INFERENCE	WQI (in 2021)	INFERENCE
1	River Mandovi, Mandovi Bridge	237.162		212.17	
2	Ribandar Ferry Point	195.5823		230.8508	

These 2 sites were identified as highly polluted as it has excess amounts of chemicals that is discharged from the households and small industries due to the improper solid waste management. Operation of ferries and cruise ships for transport and tourism activities also contribute to the water pollution significantly.

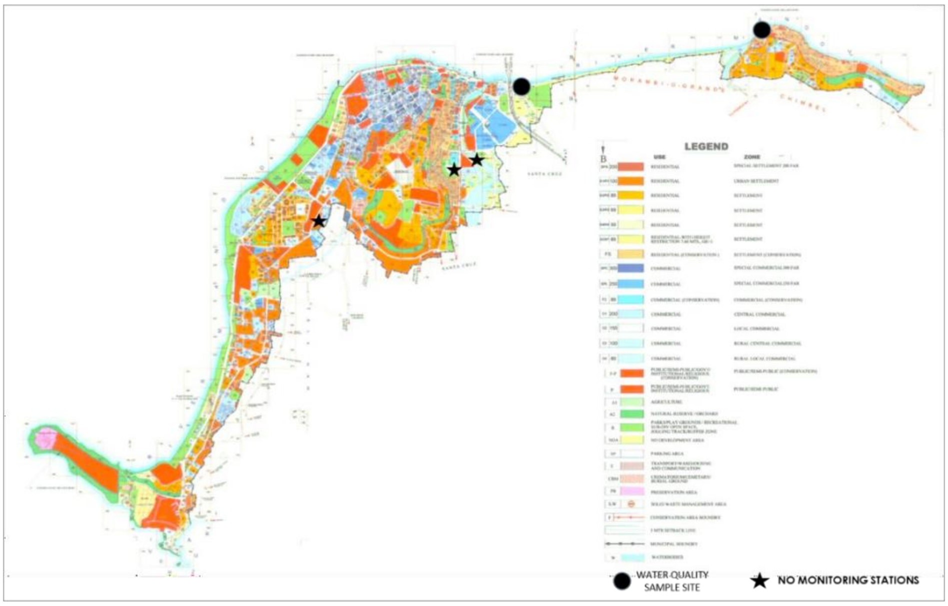

Figure 7 Water Quality Monitoring Stations

It is also to be noted that there are no monitoring systems or mechanism to monitor the water quality of city level water bodies viz. Mala Lake, St. Inez creek and Qurem creek on regular intervals which are prone to maximum pollution in the city.

Table 8 Condition of water bodies:

S.NO	NAME	CONDITION	REMARKS
1	Mala Lake	Poor	Receiving solid waste from clogged drains during backflow in monsoons.
2	Qurem Creek	Visibly Clean	Apart from incidental black spots along the banks, the water body appears to be clean
3	St.Inex Creek	Severely degraded	Receiving solid wastes from direct dumping clogged drains and sewage from hutments on the banks

NDWI 2002 Vs 2022 Comparison:

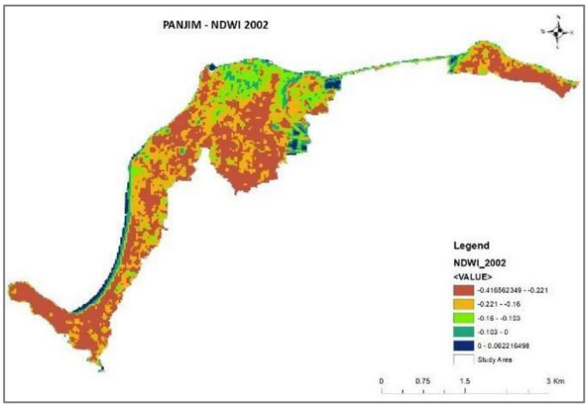

Figure 8 NDWI 2002

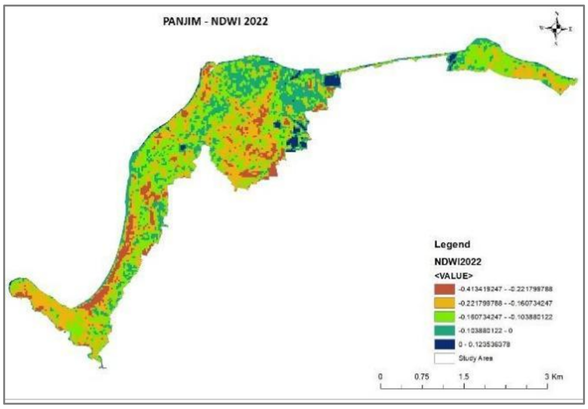

Figure 9 NDWI 2022

Due to encroachment along the lakeside its area reduced from 70,000 m2 to 15,000 m2 and is still prone to encroachments. As a result, with reduction in balancing capacity to retain water from the surplus flows of Altinho is causing floods in the Mala Lake area.

Groundwater:

Groundwater availability has been reported at 1 to 1.5m below ground level during the monsoon but Salt water intrusion has impacted the quality of available groundwater (Corporation of the city of Panaji, 2015)

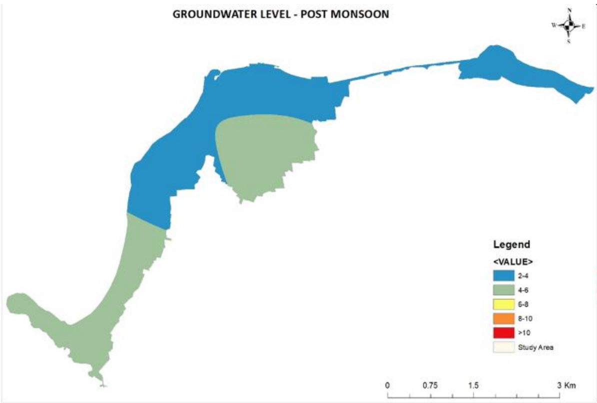

Figure 10 Groundwater level – Pre monsoon

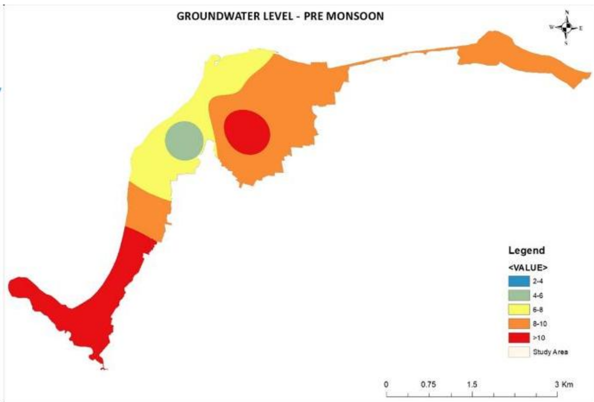

Figure 11 Groundwater level – Post monsoon

Table 9 Area under different depths of Groundwater

Groundwater depth	Post-monsoon (November)	Post-monsoon (March)
2-4	4.72105	-
4-6	3.94688	0.37191
6-8	-	1.85304
8-10	-	4.26532
>10	-	2.17768

In the post monsoon season, during the months of November and March, there is huge decrease in the availability of groundwater because of which the depth of the same has increased in most of the areas.

Table 10 Purpose - Groundwater extraction

PURPOSE	NO. OF WELLS	% of wells	AMOUNT OF WATER DRAWN PER DAY (IN LT)	AMOUNT OF WATER DRAWN ANNUALLY (Mn L)
Agriculture	14	9.52	52005	18.98
Commercial	31	21.09	3,66,000	133.59
Construction	5	3.4	53500	19.52
Domestic	73	49.66	39150	14.28
Horticulture	7	4.76	16903	6.16
Hotels	10	6.8	48000	17.52
Industry	1	0.68	6000	2.19
Irrigation	1	0.68	1000	0.36
Others	5	3.4	7000	2.55
TOTAL	**147**		**589,558**	**215.18**

It can be observed that 49.66% of the wells are used for domestic purpose but only consumes about 6.64% of GW. Hotels uses only 6.8% wells but consumes about 8.14% of GW. The highest amount of GW i.e., 62.08%, is used for the commercial purpose. A small area of around 8 sq.km is booming with huge number of construction activities which are majorly driven by tourism industry. The Real estate activities and development in the city are using pumps to extract large volumes of groundwater for construction purposes resulting in salt water intrusion (Corporation of the city of Panaji, 2015)

Calculation of Groundwater Recharge Potential:

To calculate groundwater potential, Mean temperature of the study area, elevation, annual precipitation, needs to be calculated. Thereby, calculate the area covered under the buildings and roads using the run-off coefficients.

The table below shows the calculation of evapo-transpiration, where the terms mean,

R is the mean daily range of temperature
R_{ann} is the difference between the mean temperatures of the hottest and coldest months

Table 11 Evapo-transpiration - calculation

Study area	T-Mean Temperature	h- elevation	Tm= T+0.006h	A- latitude in degrees	R	R ann	Td= 0.0023h+0.37T+0.53R+ 0.35Ran-10.9degC	Eo= (700Tm/(100-A)+15(T-Td))	Eo= (700Tm/(100-A)+15(T-Td))/(80-T) mm/day
Panjim	26.95	7	26.99	15.29	26.5	3.7	14.42	410.88	7.75

Percolation

$P = Ra - R_u - A_e$

Where,

- P = Percolation (mm)
- R_a= Annual Rainfall (mm)

- Ru = AnnuaI Runoff (mm)
- Ae = AnnuaI Evapotranspiration (mm)

Run Off Coefficient

- Building = 0.90
- Roads = 0.95
- Forest = 0.15
- Open Spaces = 0.60
- Agriculture Land = 0.40

Peak Rate of Runoff Q = 1/360*C*I*A Where,

- Q= Peak rate of runoff, m3/sec
- C= Runoff Coefficient
- I= Intensity of rainfall, mm/hr
- A= Area of catchment, Ha

GROUND WATER RECHARGE CALCULATION																
Year	Area (m2)	No. of Rainy days	Maximum Daily Precipitation (mm) Pa	Annual Precipitation (L) Pa	Area under each category (m2) (A)			Annual Rainfall Intensity (mm/hr) (I)	Peak Rate of runoff (in m3/sec)			Annual Runoff (L) R	Annual ETR (L) ET	Ground water recharge= Pa-R-ET (L/yr)	Ground water recharge= Pa-R-ET (ML/yr)	40% Extraction (ML)
					Built up	Vegetation	Open Spaces		Built up	Vegetation	Open Spaces					
2002	8120000	97.3	89.29	264637702	4932250	2181080	348046	3.72	17430571.5	1217042.64	776838.7	19,424,452.81	2.82	245,213,246.4	245.2	98.09
2022	8120000	97.3	89.29	264637702	5938010	927370	164396	3.72	20984927.34	517472.46	366931.9	21,869,331.67	2.82	242,768,367.5	242.8	97.11

Table 12 Groundwater recharge potential calculation

Panjim typically receives about 89.29 millimeters (3.52 inches) of precipitation and has 97.3 rainy days annually. (As an average for the past 30 year rainfall data). From the Table 12 it can be inferred that the area under built up has increased significantly by 12.38% which led to an increase of 6.2% in the peak rate runoff. Here, there's a need for huge emphasis on the runoff due to the area covered by concrete layers has led to around 89.7% peak run off in the year 2002 and 95.9% runoff in the year 2022. This has led to flooding in the low-lying areas.

There's an increase in the runoff from 19.4 ML to 21.87 ML due to the increase in the built-up area which led to the decrease in pervious layers of the land. It is evident that the groundwater resources and its recharge potential has been depleting as there is an increase in built-up area and decrease in the Green Open Spaces and Vegetation.

Sustainable Groundwater extraction

It is evident that the groundwater resources and its recharge potential has been depleting as there is an increase in built-up area and decrease in the Green Open Spaces and Vegetation. Maximum Limit on Groundwater extraction is 70%. Coastal areas, generally go up to 60% of the extraction

Extraction of Groundwater – Scenarios (in ML)				
Year	40% (Sustainable Yield)	50% (Safe Yield)	60% (Coastal areas)	70% (Max. limit)
2002	98.1	122.6	147.1	171.6
2022	97.1	121.4	145.7	169.9

The amount of Ground water that is extracted is way more than the permissible amount of ground water that can be extracted for the area to be sustainable. Permissible Daily extraction limit is more than the GW available for the annual extraction. Groundwater extraction is 1.2 times more than the Maximum Extractable amount of groundwater and it is 1.6 times more than the safe limits for the coastal areas. This has led to salt water intrusion into the groundwater resources.

Parks vs. Water Consumption:

Table 13 Water consumed for watering parks

S.NO	PARK	AREA (IN M2)	TOTAL TREES	GREEN COVER	SOURCE OF WATER	DAILY WATER USED (IN L)
1	Kala Academy	10630	300	2675	Borewell	10000
2	North Goa Range Forest Park	5000	390	2250	Borewell	4800
3	South Goa Range Forest Park	6500	200	1625	Borewell	8400
4	Mahavir Park	18312	3130	6410	Borewell	15000
5	Garcia da Orta Garden	4000	180	1500	Corporation water +Borewell	4000
6	Ambedkar Park	10000	400	6500	Treated Wastewater	16000
7	Joggers Park	11500	400	6900	Borewell	36000
	Total	**65942**	**5000**	**27860**		**94200**

A study made on parks of Panjim states that the source of water for watering the trees and plants in these parks are given in the above Table 14. It can inferred that around 83% of the water used to water the parks are from bore wells which is groundwater which is quite significant. Alternate sources of water need to be used for such purposes to save groundwater from depletion.

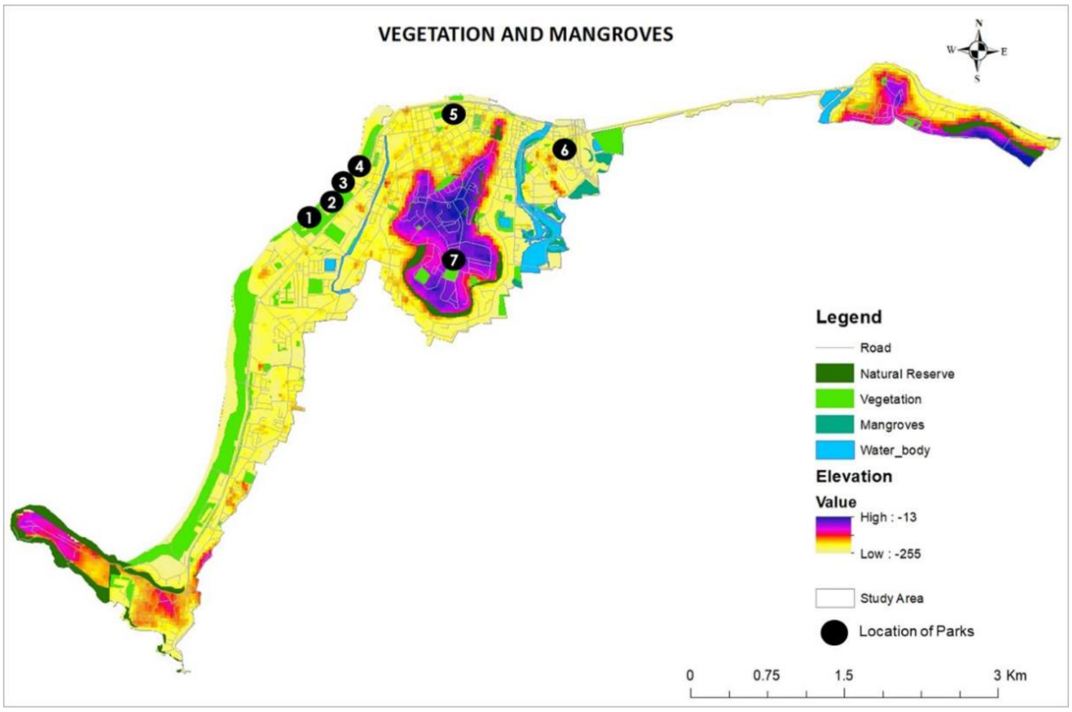

Figure 12 Location of Parks and Mangroves

MANGROVES:

Figure 13 Role of Mangroves

There are a large number of cases where coastal stretches have been subjected to the forces of erosion due to cutting down of mangroves for land reclamation. The Qurem creek is dominated by mangroves on both its banks and near Patto Bridge.


Ourem creek


Mangroves near Pattobridge

In the year 2002, the area under Mangroves is 28.92Ha but over 2 decades the area has declined to about 16.44 Ha which is a loss of around 12.4ha of coverage under the mangroves.

VEGETATION:

NDVI 2002 vs 2022:

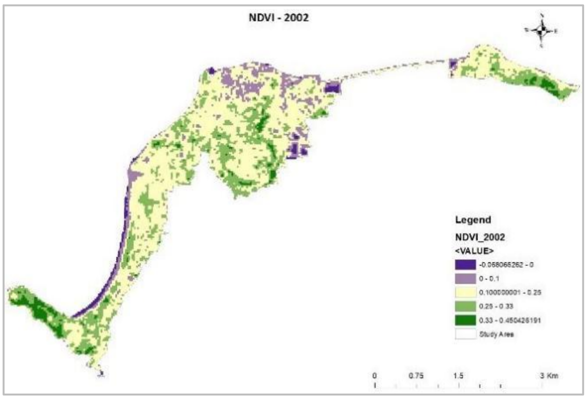

Figure 14 NDVI 2002

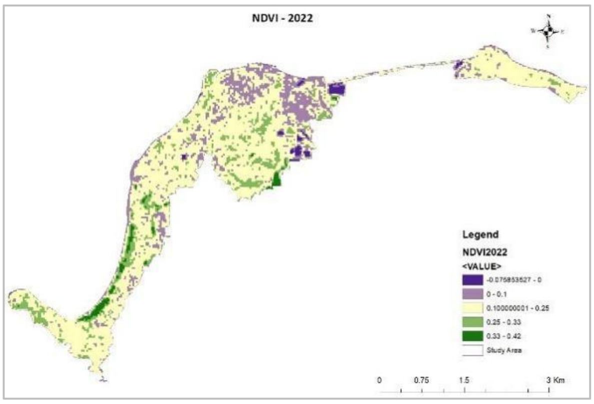

Figure 15 NDVI 2022

The area under vegetation and forests is 26.86% in 2002. It has drastically declined to 11.4% due to rapid urbanisation and increase in the construction activities. Over 2 decades there has been a decrease of more than 15% of the areal extent that was under green cover.

Table 14 Comparing Vegetation to URDPFI guidelines

Category of Park	No. of Parks required	Unit in area	Existing facilities (no.)	Total req. (as in 2021)	Required area (in ha)- 2021	Gap (in Ha)	Total req. (as in 2041)	Required area (in ha) - 2041	Meet the Benchmark
Housing Area Park	1 for 5000 pop	0.5		20	10		35	17.3	
Neighbourhood Park	1 for 15000 pop	1		7	7		12	11.6	
Community Park	1 for 1 lakh pop	5	16	1	5	212	1	8.7	NO
TOTAL			**80**	**28**	**292**		**48**	**292**	

Out of the total city area of 8.30 km2 around 33% of Panjim constitutes of the area under natural features which includes marshy lands and mangroves along the water front which act as barrier from the flooding (Corporation of the city of Panaji, 2015). The city, in 2022, has 11.4% of the land use under open spaces and parks which is inadequate as per the norms. As Panjim is a coastal city, it must have 18-20% of its land use under Green and Open spaces, according to URDPFI guidelines.

LST 2002 vs 2022:

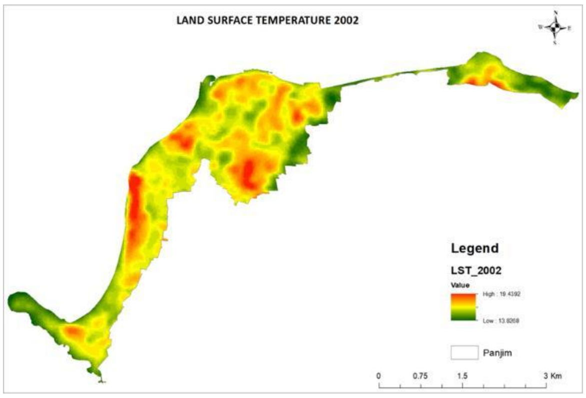

Figure 16 LST 2002

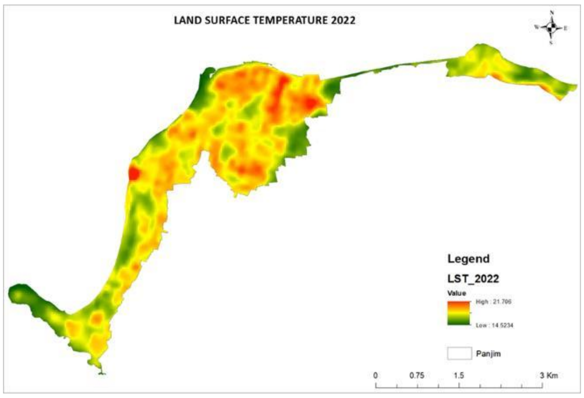

Figure 17 LST 2022

The maps in the Figures 14 and 15 shows the increase in Land Surface Temperature. The minimum temperature of area has an increase of around 1°C and the maximum temperatures has gone high by around 2°C. This increase in the land surface temperatures shows a direct relation with the huge decline in the extent of green cover of the city.

Carbon Sequestration Potential:

The analysis carried out was aimed at obtaining the total amount of CO_2 that have sequestrated from the atmosphere by each of the forest parcels. Various factors such as the age of the tree, the type of the vegetation, tree density etc were also considered while carrying out the analysis.

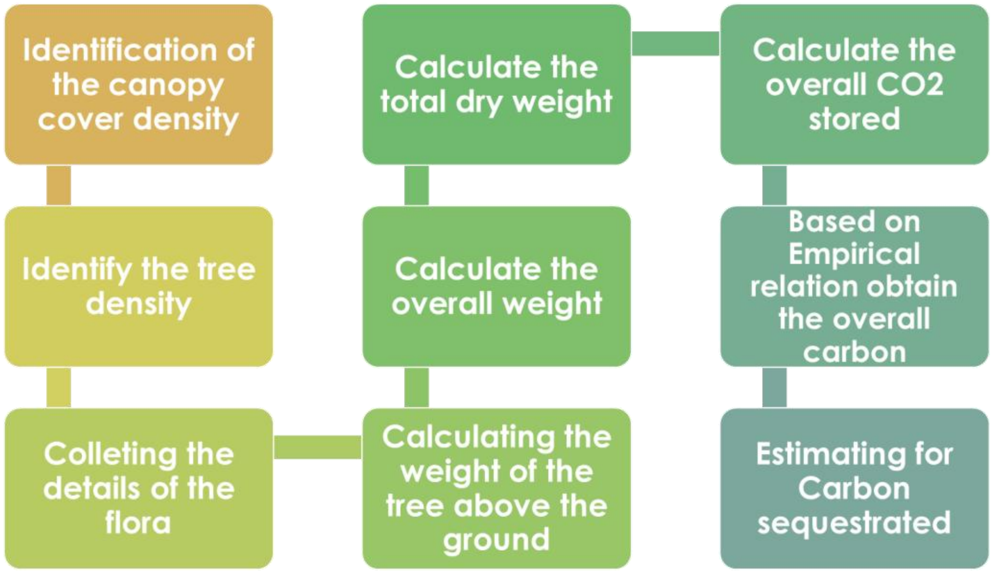

Figure 18 Methodology for calculation of Carbon sequestration potential

Table 15 Carbon sequestrated in the parks

Name of the trees	Common name	No. of trees	Height	Diameter	Age	Carbon Sequestrated
Alstonia scholaris	Blackboard Tree	300	15	20	40	9124.054384
Lannea Coromandelica	Indian Ash Tree	590	15	45	25	145346.1863
Bombax ceiba	Red Cotton Tree	2100	25	60	30	1277367.614
Grewia tiliifolia	Dhaman	1200	8	60	15	467151.5845
Careya Arborea	Wild Guava	410	20	15	15	24939.08198
Canarium Strictum	Black dammar	400	40	100	40	811027.0564
TOTAL		5000				2734955.577 tonnes of CO2

Area under the parks is 27,860 sq.m in which it has around 5000 trees. Using this, we can find the density of the trees per sq.m in the most of the areas with the green cover (vegetation and forests which include the conserved parks).

- Density of trees per sq.m = 5000/27860 = 0.179.
- Carbon sequestrated for 5000 trees = 2734955.577 tonnes of CO2
- Using this, carbon sequestrated per 1 sq.m of green cover is calculated.
- Carbon sequestrated per 1 sq.m of green cover = 0.179* 2734955.577 = **4, 89,557.05 tonnes of CO2**

Table 16 Total carbon sequestrated by Green Cover (2002 vs 2022)

NDVI	Area (IN ha)	Land Area	RATIO OF GREEN SPACES	Area (IN ha)	Land Area	RATIO OF GREEN SPACES
	2002			2022		
VEGETATION	259.8	812	31.96	224.7	812	27.67
CARBON SEQUESTRATED	**1271869.22** Mega tonnes of CO_2			**1100034.69** Mega tonnes CO_2		

From the above table it can be inferred that there is 4.29% decline in the vegetation which led to decline in the carbon sequestrated by 13.5%.

1.7 Findings

Core issues identified are

- Groundwater Extraction limits are higher than the recharge potential
- Green Open spaces are being watered using groundwater resources
- Surface water available is Lakes are being polluted with the solid waste discharge
- Recreational spaces doesn't comply with the URDPFI standards
- Loss of natural features – Water bodies, Vegetation and Mangroves
- High urbanization affecting the natural drainage pattern, the ecologically sensitive areas around the city

1.8 Way Forward

Watering Parks Using Treated Waste Water Treating and reusing city-generated wastewater for maintaining urban green spaces (UGS) helps in reducing/preventing groundwater extraction, ensuring sufficient supply of potable water, and bringing down. The benefits of reusing treated wastewater in UGS for enhancing regulatory ecosystem services (RES) and ushering in a circular economy are yet to be realized (Manish Ramaiah, 2022)

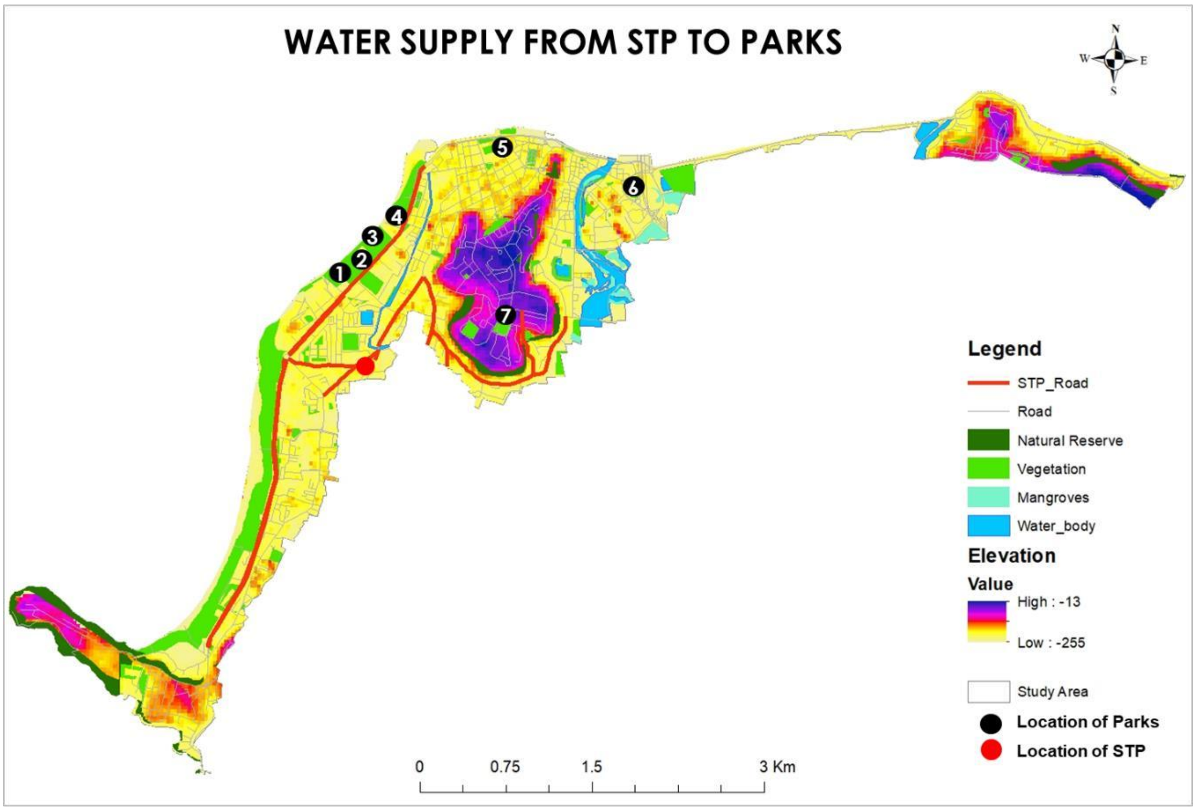

Figure 19 Water supply from STP to Parks

Regulatory Ecosystem Services Aided By Treated Wastewater – Reuse

Urban heat (IST) balancing through watering tree regularly. Enhanced thermal comfort, shading (added tourist attraction. Reduced to null extraction of already depleted groundwater. Partial to full compensation of evapotranspiration losses. Close to stress-free plant growth due to water availability

throughout the year. Enhanced carbon sequestration and long term carbon storage.
This also helps to meet the Sustainable Development Goals such as SDG-6 which deals with the waste water treatment and reuse; SDG-8 that deals with the inclusive growth and SDG-11 that aims for liveable cities.

Water Quality Monitoring:

Water quality monitoring helps in evaluating the nature and extent of pollution control required, and effectiveness of pollution control measures already in existence.

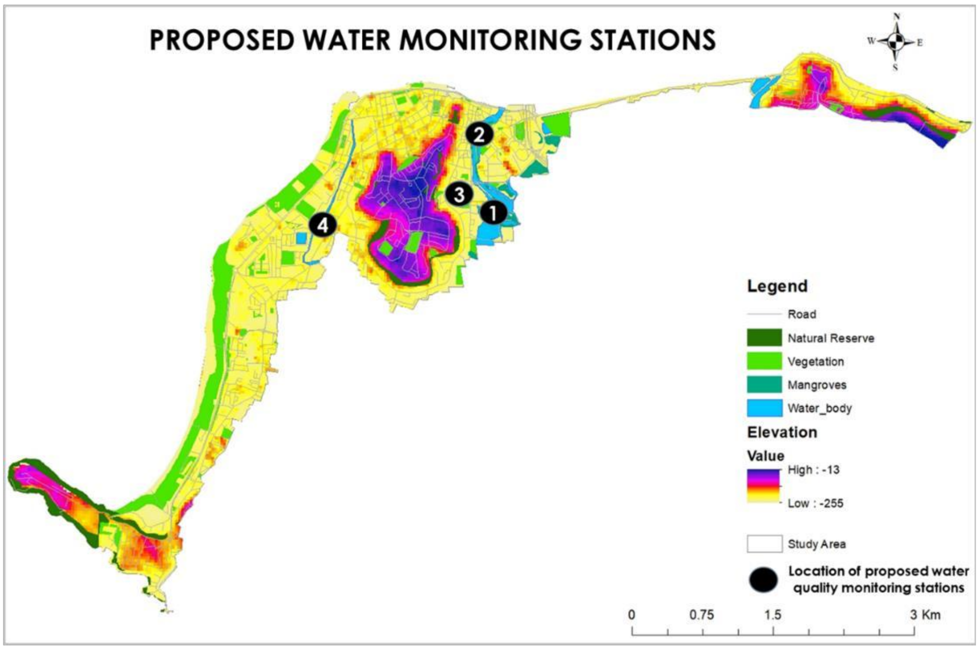

Figure 20 Proposed Water Quality Monitoring Stations

Water quality monitoring stations are proposed at MaIa Iake, Qurem creek, St. Inez creek to identify the water quality and analyze the type of pollutants and pollutant load.

Activities in and around Eco-sensitive areas

Eco-Sensitive Areas are characterized by the area's vulnerability to environmental damage and are called ecologically fragile. areas earmarked as Protective and Eco-sensitive Areas shall be termed as 'E Zone'

E-1: Water Bodies

E-2: Special recreation zone/protective areas such as sanctuaries, reserve forests

E-3: Forest Zone

E-4: Coastal Zone

E-5: Undevelopable use zone shall be identified as Earthquake/landslide prone, cliffs and environmentally hazardous area (URDPFI Guidellines, 2014)

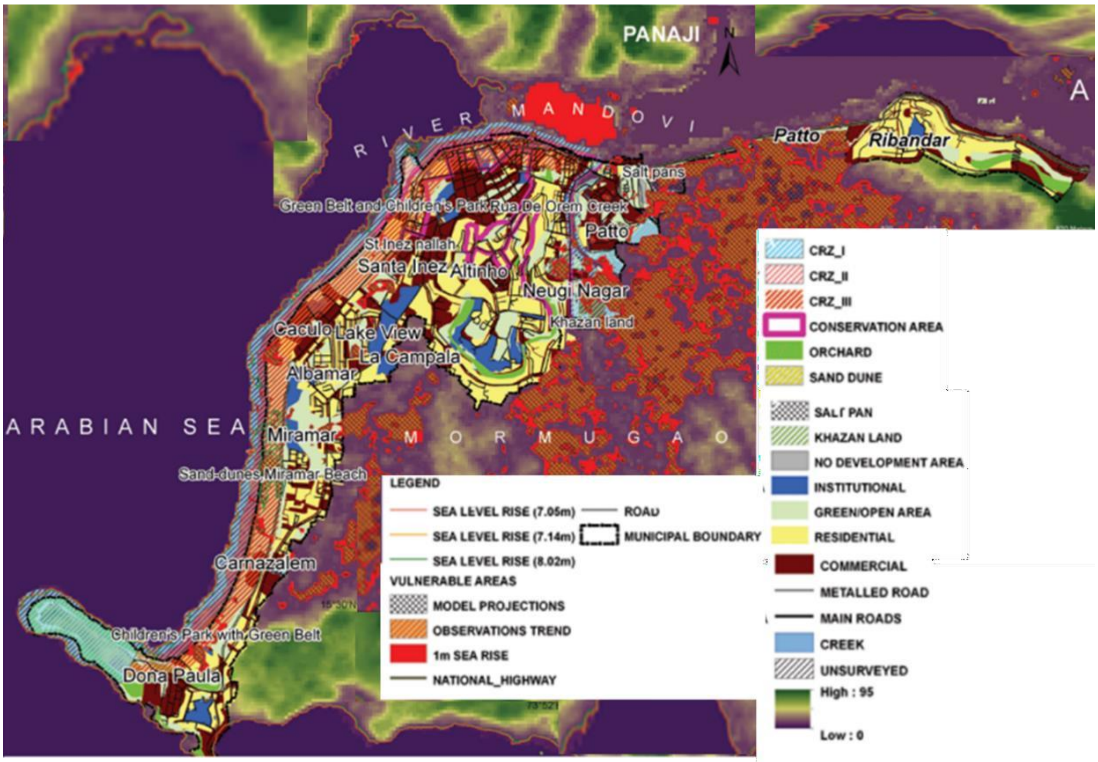

Figure 21 Eco-sensitive areas of Panjim

Ecologically sensitive areas in Panjim are Khazan lands, salt pans, creeks, and estuaries in the northern part of the city, tidal influenced water bodies like the St. Inez creek, Rua de Qurém. Sand dunes and beaches in Miramar, Dona Paula, and Caranzalem (Corporation of the city of Panaji, 2015).

Table 17 Activities Permitted, Regulated and Restricted

ACTIVITIES		
PERMITTED	REGULATED	PROHIBITED
Ongoing agricultural or horticultural practices	Felling of trees	commercial mining, saw mills
rainwater harvesting, organic farming	the establishment of hotels and resorts	industries causing pollution
use of renewable energy sources	commercial use of natural water	discharge of effluents or any solid waste or hazardous substances.
adoption of green technology for all activities	erection of electrical cables	commercial use of wood

Lake Conservation:

The Mala Lake is an ecosystem that, among its other services, provides the city of Panjim with flood protection. There is a need to identify and demarcate the catchment area of Mala lake and identification of sensitive zones in the area is required (Corporation of the city of Panaji, 2015).

Rejuvenation of Water Bodies – Mala Lake:

Development of Mala Lake with proper cleaning, construction of bund wall, landscaped garden area with recreational facilities, fencing, parking etc. A proposed project aimed at Development and beautification of Mala Lake as city level recreational area with an estimated investment of 3 Crores. Mala Lake needs restoration as it is encroached (Corporation of the city of Panaji, 2015).

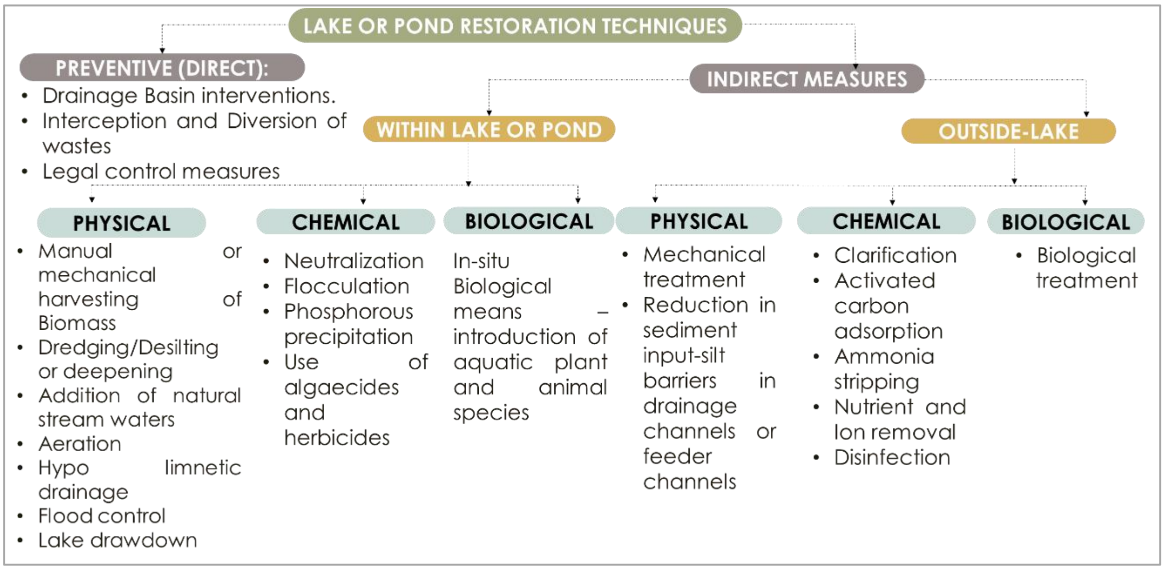

Figure 21 Lake Restoration Techniques

Protection and Conservation of Mangroves:

Fishbone Channel Plantation Method

By the use of fishbone-shaped channels, water from streams is redirected to mangrove gaps, making the formerly barren, salty area productive again for the planting of mangrove species. Because of its form, the water can reach every crack and opening in the space.

Figure 22 Fishbone Channel Plantation Method

References

1. Retrieved from www.studyiq.com
2. (2015). Retrieved from Corporation of the city of Panaji: www.ccpgoa.com (2017).

   Centre for Science and Environment.
3. John Davenport, J. L. (2005). The impact of tourism and personal leisure transport on coastal environments: A review. Elsevier Ltd.
4. Manish Ramaiah, ,. R. (2022). Treated Wastewater Use for Maintenance of Urban Green Spaces for Enhancing Regulatory Ecosystem Services and Securing Groundwater. Hydrology.

5. Martens, E. Causes of Biodiversity loss in Coastal Ecosystem. Centre for Biodiversity, National Museums of Kenya.
6. Suresh Kumar Rohilla, M. M. (2017). Water sensitive Urban Design and Planning - a practitioner's guide. Centre for Science and Environment.
7. (2014). URDPFI Guidellines.

Integrating Renewable Energy for Sustainable Coastal Urban Development: Case Area-Visakhapatnam

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Abstract

In the context of coastal urban planning, this research-based study explores the dynamic convergence of cutting - edge renewable energy technology and conventional ecological knowledge, focusing on environmentally conscious resource management. This study clarifies the intricate potential and constraints typical in coastal Indian city like Visakhapatnam by closely investigating the integration of renewable energy sources, including wind, solar, and biomass. Including a thorough computational framework, the study combines policy analysis, technology developments, and assessments of social and economic issues to offer an extensive perspective on the distribution of renewable energy. Empirical evidence and case studies demonstrate Integrated Smart Grids ' significance in maximizing energy efficiency and boosting the reliability of coastal urban infrastructure. The study also emphasizes the importance of involving the community and incorporating traditional ecological knowledge to promote resilience and long-term sustainability. In addition to identifying possible remedies, the study outlines critical roadblocks such as regulatory challenges, budgetary limitations, and infrastructure deficiencies. The results highlight how combining state-of-the-art technology with traditional knowledge systems can promote sustained urban coastal environments. Through comprehensive strategic suggestions, this research advocates for an integrated approach to urban coastal planning incorporating renewable energy for sustainable development, providing invaluable insights for policymakers, urban planners, and industry stakeholders. The study finds that, in order to address ecological issues and meet long-term sustainability goals, renewable energy solutions must be integrated into metropolitan coastal areas.

Keywords: Coastal Cities; Coastal Urban Planning; Energy-Efficiency; Integrated Smart Grids; Policy Analysis; Renewable Energy Integration; Resource Management; Socio-Economic Evaluation; Sustainable Urban Development; Technological Advancements

1. BACKGROUND AND CONTEXT OF THE RESEARCH

Coastal cities across the globe are facing unprecedented challenges due to climate change, urbanization, and environmental degradation. In India, cities like Visakhapatnam are particularly vulnerable due to their geographical location and rapid urban development. The city is witnessing increasing pressure on its natural resources, rising sea levels, and frequent extreme weather events, threatening its infrastructure and population. Against this backdrop, there is an urgent need to explore sustainable urban planning strategies that can mitigate these risks while promoting economic growth and social well-being.

Integrating renewable energy sources into the urban infrastructure is critical to sustainable development in coastal areas. Renewable energy, such as wind, solar, and biomass, offers a cleaner, more sustainable alternative to fossil fuels. However, the challenge lies in effectively integrating these technologies into the existing urban framework. This research focuses on the potential for combining cutting-edge renewable energy technologies with traditional ecological knowledge (TEK) to create resilient, sustainable urban coastal environments. By examining the case of Visakhapatnam, this study aims to provide insights into how these approaches can be effectively implemented in similar coastal cities.

2. LITERATURE REVIEW

2.1 Coastal Urban Planning and Sustainability

Previous studies have highlighted the importance of sustainable urban planning in coastal areas, emphasizing the need for strategies that balance development with environmental conservation. Coastal cities are particularly vulnerable to climate change, making resilience and sustainability critical in urban planning. Literature has explored various approaches to enhancing the sustainability of coastal urban areas, including green infrastructure, climate-resilient architecture, and sustainable transportation systems. The capacity of a landscape to maintain multifunctionality through ongoing pressures relates to its sustainability and is affected by land use policy and environmental changes. In coastal zones, limited empirical evidence exists regarding the impact of macro-level policy changes on local landscapes and their resulting temporal and spatial responses. (Wang, Liao, Ye, O'Byrne, & Scown, 2024)

2.2 Renewable Energy Integration

The global energy environment is experiencing a fundamental shift driven by the urgent need to address climate change, reduce greenhouse gas emissions, and assure energy security (Hassan et al., 2024). Fossil fuels, the primary energy source for ages, have caused environmental deterioration, air pollution, and geopolitical problems (Okoh & Okoh, 2021). In response, there is a growing understanding among politicians, corporations, and civil society organizations that a transition toward renewable energy sources is vital (Lucas et al., 2021).
Renewable energy, obtained from natural processes that replenish in a human timeframe, is a cleaner and more sustainable alternative to fossil fuels (Jain, 2020). Solar, wind, hydropower, biomass, geothermal, and ocean energy are some of the most important renewable resources that can help satisfy the world's energy demands (Agrawal & Soni, 2021). These sources are readily available, widely spread, and produce little or no greenhouse emissions during operation, making them ideal options for replacing traditional fossil fuels (Rahman et al., 2022).
However, the intermittent nature of renewable energy sources such as solar and wind complicates their extensive integration into the existing electricity grid (Basit et al., 2020). Weather-related variations in generation levels can cause grid instability, reliability concerns, and supply and demand imbalances (Altamimi, 2020). As a result, there is a rising realization of the need for novel techniques to improve the dependability and robustness of renewable energy systems (McTigue et al., 2018). Integrating renewable energy sources into urban infrastructure has been widely studied, focusing on the technical, economic, and policy challenges. Research has shown that coastal areas have significant potential for renewable energy generation, particularly from wind and solar sources. However, the literature also highlights the barriers to widespread adoption, including regulatory hurdles, high initial costs, and infrastructure limitations.

2.3 Traditional Ecological Knowledge

Traditional ecological knowledge (TEK) has gained increasing recognition in environmental management and sustainable development. TEK encompasses the insights and practices developed by indigenous and local communities over generations, often in harmony with the natural environment. Literature has demonstrated that TEK can provide valuable contributions to resource management, biodiversity conservation, and climate change adaptation, particularly in regions with limited modern scientific knowledge.

TEK provides a thorough understanding of ecosystem dynamics and how they relate to societal norms, practices, and resource use patterns. The integrity of TEK is often in jeopardy due to changes in belief systems, regional languages, traditional ways of subsistence, and disruption of traditional socialecological systems. Landscape restoration can promote self-determination while safeguarding indigenous peoples' livelihoods, beliefs, culture, and biodiversity. However, a substantial knowledge gap exists on how TEK might aid ecosystem restoration, particularly in elephant corridors.(Haq, Pieroni, Bussmann, Abd-ElGawad, & El-Ansary, 2023)

2.4 Integration of Modern Technology with TEK

The literature explores the potential for integrating modern technologies, such as renewable energy, with TEK. Studies have shown that this integration can lead to more sustainable and culturally appropriate solutions, particularly in contexts where local communities are central to resource management. However, the literature also points to challenges bridging the gap between traditional knowledge systems and modern technological approaches. Traditional Ecological Knowledge contributes to rural communities' resilience and adaptability to alterations in socioecological systems. Based on observations of the continuously changing environment, rural societies rely on TEK to innovate and adapt (Athayde et al., 2017; Folke, 2004; Ianni et al., 2015; Zent, 2013). Several international organizations and conventions called for the preservation of TEK and referred to it as cultural heritage (Argueta, 2016; Hosen et al., 2020; Ianni et al., 2015; Zent, 2013). Strategies to revitalize and strengthen TEK are gaining momentum and are now part of community-based projects worldwide (Fausto & de Vienne, 2014; Pilgrim et al., 2010). Countering the prevailing assumption of TEK being static (Berkes et al., 2000), there is a growing interest in studying how TEK originates, is transmitted, transforms, hybridizes, diffuses, erodes, and extinguishes (Zent, 2013).\

3. RESEARCH GAP AND OBJECTIVES

Despite the extensive research on renewable energy and traditional ecological knowledge, there is a lack of studies that specifically explore their integration in the context of coastal urban planning. Most studies focus either on the technical aspects of renewable energy or the cultural and ecological aspects of TEK, with limited attention to how these two areas can be combined in practical, urban contexts.

This research aims to fill this gap by investigating the potential for integrating renewable energy technologies with TEK in the coastal city of Visakhapatnam. The objectives of the study are as follows:

i. To assess the potential of renewable energy sources in Visakhapatnam. ii. To explore how TEK can complement modern renewable energy technologies in urban coastal planning.

iii. To identify the challenges and opportunities associated with integrating renewable energy and TEK in coastal urban areas.
iv. To develop strategic recommendations for policymakers, urban planners, and industry stakeholders.

4. METHODOLOGY

4.1 Research Design and Approach

The research adopts a mixed-methods approach, combining qualitative and quantitative data collection and analysis techniques. This approach is chosen to provide a comprehensive understanding of the complex interactions between renewable energy technologies, traditional ecological knowledge, and coastal urban planning.

4.2 Data Collection & Analysis

Data was collected through a combination of field surveys, interviews, and secondary data analysis. The field surveys focused on assessing the potential for renewable energy generation in Visakhapatnam, including wind and solar energy potential mapping. Interviews were conducted with local community members, urban planners, and energy experts to gather insights on TEK and its relevance to urban planning. Secondary data analysis involved reviewing existing literature, policy documents, and case studies related to renewable energy and TEK. Data was collected through interviews and case studies involving stakeholders, community members, and experts in both renewable energy and TEK. Interviews provided in-depth perspectives on personal experiences, beliefs, and practices, while case studies offered contextual examples of successful integrations and challenges faced.

5. CITY PROFILE

Visakhapatnam, often hailed as the "City of Destiny," epitomizes the philosophical idea that "The journey of a thousand miles begins with a single step" (Lao Tzu). This sentiment reflects Vizag's evolution from a modest fishing village to a thriving industrial metropolis driven by visionary planning and relentless progress.
It is a pivotal industrial hub on India's southeastern coast, characterized by its strategic geographical positioning and advanced infrastructural development. Historically evolving from a small fishing village into a bustling urban center, The transformation was catalyzed by British colonial interests seeking a secure seaport to connect the mineral-rich central provinces to the East Coast. Today, Vizag boasts Asia's most secure natural harbor, underpinning its rise as a significant maritime gateway. The city's industrial trajectory accelerated in the 1980s with establishing the Vizag Steel Plant and other heavy industries, laying the foundation for its modern economic framework. The economic liberalization of the 1990s further spurred growth, positioning Vizag as a crucial node in India's industrial and commercial networks. Leveraging its natural advantages, Vizag integrates cutting-edge technologies in logistics, renewable energy, and intelligent urban planning, driving sustainable development while enhancing its role as a key player in global trade and regional economic stability.

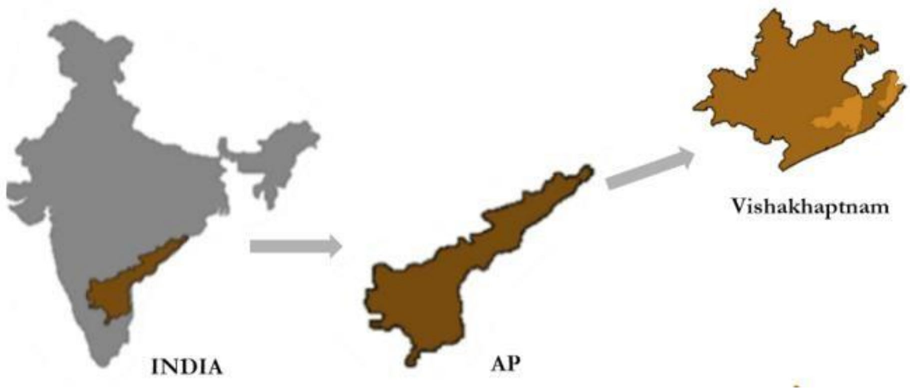

Figure 1 : Visakhapatnam, Andhra Pradesh

5.1 Geographical Setting

Visakhapatnam is positioned at approximately 17.7° N latitude and 83.3° E longitude. The city spans an area of about 681.96 square kilometers, featuring a coastline that extends roughly 72 kilometers along the Bay of Bengal. The geographical layout includes a blend of coastal plains, rolling hills, and rivers, with notable topographical features such as the Eastern Ghats running parallel to the coast. This strategic coastal location contributes significantly to the city's maritime and economic activities.

5.2 Climate and Environmental Factors

The city experiences a tropical wet and dry climate characterized by high temperatures and humidity throughout the year. Summers are notably hot, with temperatures often exceeding 35°C (95°F), while winters are relatively mild, with temperatures ranging between 20°C and 25°C (68°F to 77°F). The monsoon season, from June to September, brings substantial rainfall, averaging around 1,100 mm annually. The city's climate is influenced by its coastal position, which moderates temperature extremes and contributes to its distinctive weather patterns.

5.3 Historical Context

Visakhapatnam has a rich historical and cultural heritage. Initially known for its maritime significance, the city has been a critical trade and naval hub since ancient times. It was an important port during the British colonial era, facilitating trade and commerce between India and various international markets. The city's historical landmarks include the Visakha Museum, the ancient Buddhist sites at Thotlakonda and Bojjana Konda, and the historic Ross Hill Church. This historical backdrop has shaped city’s identity as a prominent coastal city with a diverse cultural tapestry

Table 1: City Profile- Visakhapatnam

City Profile- Visakhapatnam	
Location	Southeastern coast of India, Andhra Pradesh

Geographical Area	681.96 square kilometers
Population	Approximately 2.1 million (as of the 2021 Census)
Climate	Tropical wet and dry climate; hot summers, mild winters, and heavy monsoon rains
Major Industries	Shipbuilding, steel production, petrochemicals, textiles, information technology
Major Port	Visakhapatnam Port, one of the largest ports on the east coast of India
Educational Institutions	Indian Institute of Management Visakhapatnam (IIM-V), Andhra University, GITAM University
Economic Development	Major development in the 1980s with the establishment of the Visakhapatnam Steel Plant; liberalization in the 1990s
Environmental Challenges	Coastal erosion, pollution, impact of cyclones and flooding
Energy Sources	Predominantly coal-based power, emerging renewable energy projects (solar, wind)
Cultural Heritage	Rich cultural history with a blend of modern and traditional influences, famous for its beaches, temples, and local festivals
Infrastructure	Well-developed port facilities, industrial areas, transportation networks, and urban amenities
Tourism Attractions	Kailasagiri Hill Park, Rishikonda Beach, Submarine Museum, Araku Valley

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5.4 Economic Dynamics

Visakhapatnam plays a vital role in India's economy, particularly in the industrial and maritime sectors. The city has several major industries, including steel production, shipbuilding, petrochemicals, and information technology. Critical industrial facilities such as the Visakhapatnam Steel Plant, Hindustan Shipyard, and the Visakhapatnam Port are crucial to the city's economic base. The port, one of the largest and busiest in India, handles a significant portion of the country's maritime trade, including cargoes of coal, iron ore, and petroleum products. The city's economic landscape is further bolstered by its growing IT sector, with numerous IT parks and technology companies establishing a presence in the region.

5.5 Demographic Trends

Visakhapatnam is one of the most populous cities in Andhra Pradesh, with an estimated population of over 2 million. The city's demographic profile reflects a diverse population of various ethnic, linguistic, and cultural groups. The primary languages spoken include Telugu, the official language of Andhra Pradesh, and English, which is widely used in business and education. Urban migration, economic opportunities, and infrastructural development have influenced the population growth.

5.6 Infrastructural Development

The city's infrastructure continually evolves to support its growing population and economic activities. Key infrastructure elements include an extensive road network, a major international airport, and a modernized port facility. The road network connects city with other major cities and regions, facilitating transportation and logistics. The Visakhapatnam International Airport is a crucial gateway for domestic and international travel, further enhancing the city's connectivity. Additionally, the port infrastructure supports commercial and passenger shipping, contributing to the city's economic vitality.

5.7 Educational and Cultural Institutions

Visakhapatnam is home to several prominent educational institutions, including the Andhra University, which offers various undergraduate and postgraduate programs. The city also boasts a rich cultural scene, with numerous festivals, cultural events, and art exhibitions contributing to its vibrant social life. Institutions such as the Kalabharathi Auditorium and the Visakhapatnam Art Gallery are vital in promoting the city's cultural heritage.

5.8 Urban Challenges and Opportunities

As Visakhapatnam grows, it faces various urban challenges, including traffic congestion, waste management, and environmental sustainability. The city's rapid urbanization has increased demand for infrastructure and services, necessitating strategic planning and development. Opportunities for improvement include investing in sustainable urban development practices, enhancing public transportation systems, and promoting green spaces and environmental conservation.

It is a dynamic and multifaceted city with a significant economic, cultural, and historical presence. Its strategic coastal location, diverse economic activities, and rich cultural heritage make it a key player in India's urban and industrial landscape. Understanding the city's profile provides valuable context for addressing its energy needs, development challenges, and opportunities for integrating renewable energy sources into its growth strategy.

6. INTEGRATION OF RENEWABLE ENERGY WITH TRADITIONAL ECOLOGICAL KNOWLEDGE IN VISAKHAPATNAM

Traditional Ecological Knowledge (TEK) offers valuable insights into the sustainable management of coastal resources, particularly in cities like Visakhapatnam where local communities have long interacted with their environment. By integrating TEK with modern technologies such as smart grids and renewable energy systems, Visakhapatnam can create a more resilient and environmentally attuned urban infrastructure.

6.1 Role of Traditional Ecological Knowledge (TEK) in Visakhapatnam

Traditional Ecological Knowledge (TEK) is particularly relevant in a coastal city like Visakhapatnam, where local communities have long interacted with the unique coastal environment. For centuries, the indigenous and fishing communities in Visakhapatnam have developed a deep understanding of the local ecosystems, including knowledge about the seasonal patterns of the Bay of Bengal, coastal vegetation, marine life, and the monsoon's impact on the coast (Haq et al., 2023). This knowledge is crucial for sustainable resource management, as it offers practical insights into the best times for fishing, the optimal use of coastal resources, and strategies to mitigate the impacts of natural disasters like cyclones (Wang et al., 2024).

6.2 Complementing Modern Technology with TEK in Visakhapatnam

Integrating TEK with modern renewable energy technologies in Visakhapatnam can enhance the sustainability and effectiveness of coastal urban planning (Haq et al., 2023). For example, understanding local wind patterns, as informed by TEK, can be invaluable in optimizing the placement of wind turbines (Smith et al., 2023). Similarly, knowledge of seasonal variations can guide the deployment of solar panels to maximize energy capture throughout the year (Wang et al., 2024). TEK can also inform the management of biomass resources, ensuring that energy generation from these resources is sustainable and does not deplete critical ecological functions (Haq et al., 2023). By complementing scientific knowledge with TEK, Visakhapatnam can develop energy systems that are both technologically advanced and culturally and environmentally sensitive (Smith et al., 2023).

6.3 Practical Applications and Examples in Visakhapatnam

In Visakhapatnam, there have been efforts to incorporate TEK into renewable energy projects, though these are still nascent (Haq et al., 2023). One potential application is in the development of solar energy projects that respect traditional land-use practices (Wang et al., 2024). For instance, solar farms can be designed not to disrupt traditional fishing grounds or sacred sites (Smith et al., 2023). Additionally, local communities can manage these projects, drawing on their TEK to monitor environmental impacts and adapt the technology to local conditions (Haq et al., 2023). These projects could serve as models for how renewable energy initiatives can be aligned with cultural values and traditional practices, fostering greater community ownership and long-term sustainability (Wang et al., 2024).

6.4 Technological Innovations and Smart Grids

In the context of Visakhapatnam, Integrated Smart Grids could play a transformative role in managing the city's energy needs (Smith et al., 2023). Smart Grids in Visakhapatnam would involve integrating digital technology to monitor and control energy distribution, ensuring that energy is used efficiently and reliably (Haq et al., 2023). Given Visakhapatnam's status as a rapidly growing urban area with a significant industrial base, the electricity demand is high. It fluctuates, particularly with the influence of seasonal tourism and extreme weather events (Wang et al., 2024). Smart Grids could help manage these fluctuations by optimizing the flow of electricity, integrating renewable energy sources like solar and wind, and reducing the reliance on fossil fuels (Smith et al., 2023).

Implementing Smart Grids in Visakhapatnam offers numerous benefits. These systems can significantly reduce energy waste by adjusting the energy supply in real time to meet demand, thus lowering operational costs (Haq et al., 2023). Smart Grids would also improve the integration of renewable energy sources, making it easier for the city to harness its solar and wind potential (Wang et al., 2024). This is particularly important in Visakhapatnam, where frequent cyclones and flooding threaten energy infrastructure (Smith et al., 2023). Smart Grids could enhance the resilience of the city's energy system by enabling more adaptive and responsive energy management, reducing the risk of outages, and ensuring a more stable energy supply during extreme weather events (Haq et al., 2023).

6.5 Lessons from Other Cities Abroad

While empirical evidence from cities like San Francisco and Singapore has demonstrated the effectiveness of Smart Grids (Smith et al., 2023), Visakhapatnam can draw on these examples to implement its own Smart Grid initiatives. For instance, Singapore's success in reducing energy consumption through Smart Grids highlights the potential for Visakhapatnam to achieve similar results, especially in managing the energy needs of its industrial sector and reducing its carbon footprint (Wang et al., 2024). Additionally, the deployment of Smart Grids in other coastal cities has shown improvements in disaster resilience, which is crucial for Visakhapatnam, given its vulnerability to cyclones (Haq et al., 2023). By studying these case studies and adapting their strategies to local conditions, Visakhapatnam can develop a robust and sustainable energy infrastructure that meets the city's growing needs while protecting its unique coastal environment (Smith et al., 2023).

7. RESULTS AND FINDINGS

Policy approaches like marine spatial planning (MSP) or a blue economy (BE) try to provide answers to the question of how to achieve a *better* future for marine and coastal ecosystems and people alike. Despite being shaped and promoted by international and supra-regional institutions, they are locally realized and differ in their practical implementation (Douvere & Ehler, 2009; Jones et al., 2016). What they have in common is the aim to tackle increasing risks, conflicts, and change by transforming ways of interacting, doing business, and living with the sea—so reassembling the human and morethan-human, foremost in coastal spaces (Winder & Le Heron, 2017). The study's results highlight the significant potential for renewable energy generation in Visakhapatnam, particularly from wind and solar sources. The city's coastal location and climatic conditions make it an ideal candidate for largescale renewable energy projects. However, the study also identified several challenges, including regulatory barriers, high initial costs, and infrastructure limitations, which must be addressed to realize this potential.

The findings also underscore the importance of traditional ecological knowledge in coastal urban planning. TEK provides valuable insights into local environmental conditions, resource management practices, and resilience-building strategies that can complement modern renewable energy technologies. For instance, traditional knowledge about local wind patterns and seasonal changes can inform the optimal placement of wind turbines, while understanding indigenous agricultural practices can enhance biomass energy production.

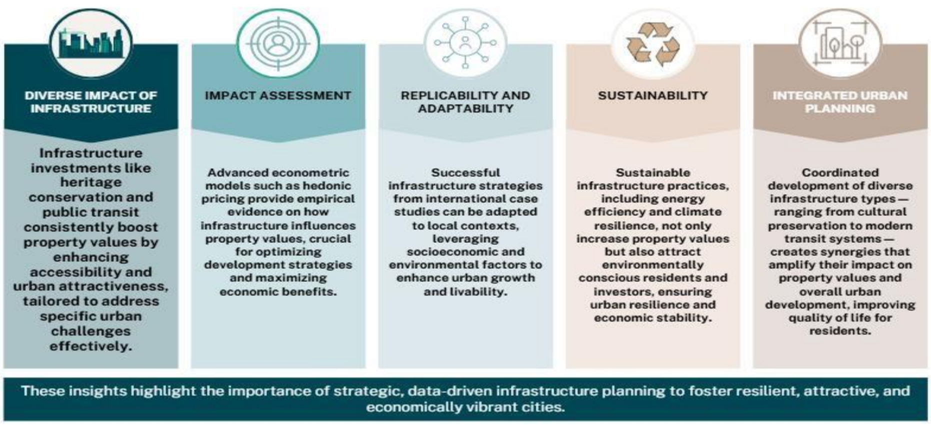

Figure 2: Key Findings of the Study

8. DISCUSSIONS

The integration of renewable energy with traditional ecological knowledge presents a promising approach to sustainable coastal urban planning. The study's findings suggest that this integration can lead to more resilient, adaptive, and culturally appropriate urban environments. However, several challenges must be addressed to realize this potential.

Table 2: Proposed Remedies to Challenges

Regulatory Challenge	Description	Proposed Solutions for Visakhapatnam
Outdated Regulations	Existing regulations may not address the needs of modern renewable energy technologies and TEK integration.	Update local and state regulations to accommodate advancements in renewable energy and TEK. Develop flexible frameworks that can adapt to new technologies.
Lack of Supportive Policies	Absence of policies that promote the integration of renewable energy with TEK, hindering progress.	Create and implement policies that specifically support the integration of renewable energy and TEK in coastal urban planning. Promote incentives for projects that blend traditional knowledge with modern technology.
Bureaucratic Red Tape	Lengthy and complex approval processes that delay the implementation of renewable energy projects.	Streamline approval processes and reduce bureaucratic hurdles for renewable energy projects. Establish a dedicated task force to expedite permits and approvals.
Limited Awareness and Training	Insufficient awareness among policymakers and planners about the benefits of integrating TEK with renewable energy.	Conduct training programs and workshops for policymakers and urban planners on the benefits of TEK and renewable energy integration. Include TEK in educational curricula

		for urban planning professionals.
Inadequate Stakeholder Engagement	Lack of effective mechanisms for engaging local communities and integrating their knowledge into planning processes.	Develop community engagement strategies that involve local stakeholders in the planning and decision-making processes. Create platforms for continuous dialogue between policymakers and local communities.

Regulatory challenges are a significant barrier to the integration of renewable energy and TEK in coastal urban areas. Outdated regulations, lack of supportive policies, and bureaucratic red tape can slow down the adoption of new technologies and approaches. Policymakers must prioritize the creation of an enabling environment that supports innovation and sustainability in urban planning.Infrastructure deficiencies, such as outdated energy grids and inadequate storage systems, pose significant challenges to the integration of renewable energy in coastal cities. Upgrading infrastructure is essential to ensure that renewable energy can be effectively integrated into the urban energy system. This requires significant investment and collaboration between public and private sectors.Community involvement is crucial for the successful integration of renewable energy and TEK in coastal urban planning. Local communities possess valuable knowledge and insights that can inform planning processes, and their active participation ensures that solutions are culturally appropriate and socially acceptable. Engaging the community in the planning and implementation process also enhances resilience and promotes long-term sustainability.

The study concludes that integrating renewable energy technologies with traditional ecological knowledge offers a viable path to sustainable urban coastal development. Coastal cities like Visakhapatnam, which face significant environmental and social challenges, can benefit from this integrated approach by developing resilient, adaptive, and sustainable urban environments.

9. STRATEGIC RECOMMENDATIONS

The study provides several strategic recommendations for policymakers, urban planners, and industry stakeholders:

Table 3: Recommendations with Policy Directives

Aspect	Description	Context	Relevant Policies/Acts	Implementation Strategies

Policy Development	Update and streamline regulations to support renewable energy and TEK integration.	Existing regulations may be outdated and not fully supportive of renewable energy and TEK.	- **National Renewable Energy Act (2015)**	- Review and revise local and state regulations in line with these policies.
			- **Andhra Pradesh Solar Power Policy (2015)**	- Develop specific guidelines for integrating TEK with renewable energy.
Infrastructure Investment	Prioritize investment in modernizing energy infrastructure to support renewable energy sources.	Outdated energy grids and infrastructure may not accommodate new renewable technologies.	- **National Electricity Policy (2005)**	- Invest in upgrading energy grids and storage systems.
			- **National Tariff Policy (2016)**	- Develop infrastructure that supports solar, wind, and biomass energy.
			- **Andhra Pradesh Transmission and Distribution System Act (2014)**	- Enhance resilience of infrastructure to handle extreme weather conditions.
Community Engagement	Actively involve local communities in the planning and implementation of renewable energy projects, leveraging their traditional knowledge and insights.	Local communities hold valuable TEK that can improve project outcomes and ensure cultural appropriateness.	-**Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act (2006)**	- Establish community advisory panels for energy projects.
			- **National Environmental Policy (2006)**	- Conduct workshops and consultations with local stakeholders.
				- Incorporate community feedback into project designs and implementation.

Capacity Building	Invest in capacity building for local governments and communities to enhance their ability to manage and sustain renewable energy projects.	Local governments and communities may need additional skills and knowledge to effectively manage renewable energy projects.	- **Capacity Building for Industrial Pollution Management (2003)**	- Provide training programs for local officials and community leaders.
			- **Andhra Pradesh State Skill Development Policy (2014)**	- Develop educational programs on renewable energy technologies and TEK.
				- Support ongoing technical assistance and knowledge sharing.
Computational Framework	Combine policy analysis, technology developments, and social/economic assessments to provide a comprehensive view on renewable energy distribution.	A detailed framework can help in understanding the interplay of policies, technology, and community needs in Visakhapatnam.	- **Integrated Energy Policy (2006)**	
			- **National Action Plan on Climate Change (200**	

Several strategic recommendations are essential for policymakers, urban planners, and industry stakeholders to address the challenges and opportunities in integrating renewable energy and Traditional Ecological Knowledge (TEK) in Visakhapatnam. Firstly, **policy development** should focus on updating and streamlining regulations to support renewable energy and TEK integration better. Existing regulations may not fully align with the latest advancements; therefore, revising local and state policies in line with the National Renewable Energy Act (2015) and the Andhra Pradesh Solar Power Policy (2015) is crucial (National et al. Act, 2015 Andhra et al. Power Policy, 2015). Specific guidelines should be developed to ensure that TEK is effectively integrated with renewable energy projects (Andhra Pradesh Solar Power Policy, 2015).

Regarding **infrastructure investment**, there is a need to prioritize modernizing energy infrastructure to accommodate renewable technologies. Current energy grids and infrastructure may need to be improved for new technologies. Investments should be made in upgrading grids and storage systems, guided by the National Electricity Policy (2005) and the National Tariff Policy (2016) (National Electricity Policy, 2005; National Tariff Policy, 2016). Additionally, infrastructure development should focus on supporting solar, wind, and biomass energy and enhancing resilience to extreme weather conditions, as outlined in the Andhra Pradesh Transmission and Distribution System Act (2014) (Andhra Pradesh Transmission and Distribution System Act, 2014).

Community engagement is also critical. Actively involving local communities in planning and implementing renewable energy projects leverages their TEK and ensures cultural appropriateness. This can be facilitated by establishing community advisory panels, conducting workshops and consultations, and incorporating community feedback into project designs (Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006; National Environmental Policy, 2006). Relevant policies such as the Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act (2006) and the National Environmental Policy (2006) support this approach (Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006; National Environmental Policy, 2006).

Lastly, **capacity building** must be a priority to enhance local governments' and communities' skills and knowledge in managing and sustaining renewable energy projects. Training programs for officials and community leaders, educational programs on renewable technologies and TEK, and ongoing technical assistance should be implemented. Policies like the Capacity Building for Industrial Pollution Management (2003) and the Andhra Pradesh State Skill Development Policy (2014) provide a framework for these initiatives (Capacity Building for Industrial Pollution Management, 2003; Andhra Pradesh State Skill Development Policy, 2014). By addressing these strategic areas, Visakhapatnam can develop a robust and sustainable approach to integrating renewable energy and TEK.

10. CONCLUSION

An integrated approach to renewable energy is imperative for achieving sustainable urban development in Visakhapatnam. The city's potential for harnessing wind, solar, and biomass energy presents a unique opportunity to enhance its energy sustainability and reduce environmental impacts. However, realizing this potential requires addressing several key challenges, including regulatory barriers, infrastructure limitations, and the need for community engagement.

Combining advanced technologies with traditional ecological knowledge can significantly enhance the city's resilience and long-term sustainability. Using lessons from other coastal cities, Visakhapatnam can develop and implement strategies that effectively integrate renewable energy into its energy landscape. This integrated approach should encompass supportive policies, infrastructure investments, and active community involvement.

Collaborative efforts among policymakers, industry stakeholders, and community leaders are crucial for creating a favorable environment for renewable energy projects. It can achieve its renewable energy goals and ensure a sustainable and resilient future by fostering partnerships and addressing the identified challenges.

The insights from this study provide a solid foundation for strategic planning and informed decisionmaking. As the city moves forward, it is essential to continue exploring and implementing innovative solutions that align with its energy needs and sustainability objectives. This proactive approach will enable the city to meet its future energy demands in an environmentally responsible manner, supporting sustainable urban development and contributing to broader climate goals.

In conclusion, integrating renewable energy with Traditional Ecological Knowledge (TEK) presents a transformative opportunity for enhancing sustainability and resilience in coastal urban areas. The analysis underscores the necessity of updating regulatory frameworks, investing in modern infrastructure, engaging local communities, and building capacity to effectively integrate these elements. By aligning policies with modern needs and leveraging the unique insights of TEK, Visakhapatnam can not only address its current environmental and energy challenges but set a precedent for other coastal cities. This approach promises to foster more adaptable, culturally sensitive, and sustainable urban development, paving the way for a resilient and eco-friendly future.

11. FUTURE RESEARCH DIRECTIONS

Future research should explore the long-term impacts of integrating renewable energy and TEK in coastal urban planning. Longitudinal studies could provide valuable insights into the sustainability and resilience of these integrated approaches over time. Additionally, research could explore the potential for scaling up successful models to other coastal cities in India and beyond.

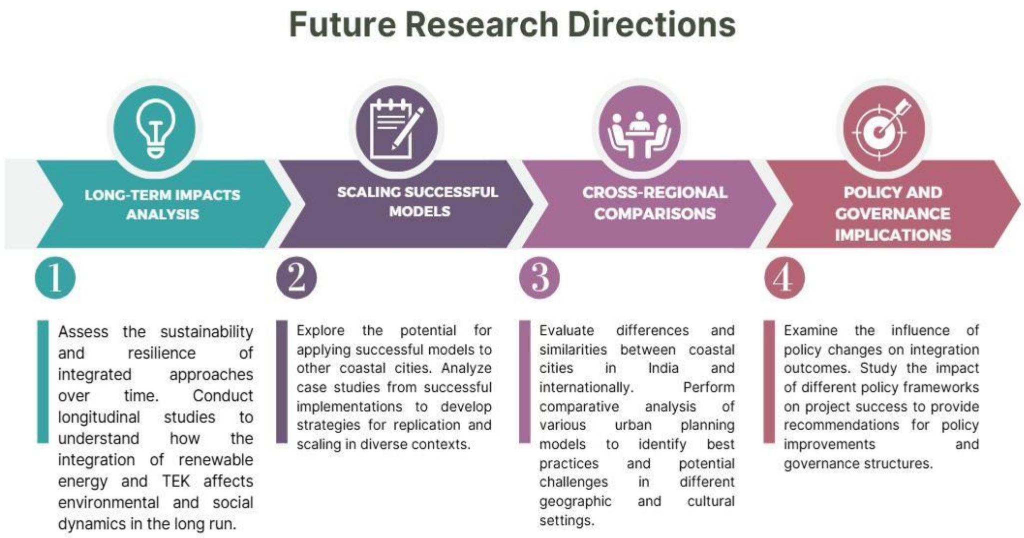

Figure 3: Key Future Research Directives

12. **REFERENCES**

1. Wang, Y., Liao, J., Ye, X., O'Byrne, D., & Scown, M. W. (2024). Implications of policy changes for coastal landscape patterns and sustainability in Eastern China. *Landscape Ecology, 39*(4). https://doi.org/10.1007/s10980-024-01456-7
2. Hassan, M., Sidiropoulos, J., Amri, K., & Hsueh, C. (2024). Global energy transitions: A review of current trends and future prospects. *Renewable and Sustainable Energy Reviews, 174*, 112749.
3. https://doi.org/10.1016/j.rser.2024.112749
4. Okoh, O. S., & Okoh, E. (2021). The environmental impact of fossil fuel usage and the drive towards renewable energy sources. *Environmental Science and Pollution Research, 28*(1), 107119. https://doi.org/10.1007/s11356-020-10353-4
5. Lucas, A., Belward, A., & Seddon, N. (2021). Policy measures and innovation pathways for transitioning to renewable energy systems. *Energy Policy, 149*, 112014.
6. https://doi.org/10.1016/j.enpol.2021.112014
7. Jain, S. (2020). Renewable energy technologies: An overview. *Journal of Cleaner Production,*
8. *264*, 121273. https://doi.org/10.1016/j.jclepro.2020.121273

9. Agrawal, A., & Soni, P. (2021). Renewable energy sources: Current status and future prospects. *Renewable Energy, 164*, 1687-1702. https://doi.org/10.1016/j.renene.2020.11.061
10. Rahman, M. M., Chowdhury, M. H., & Choudhury, T. (2022). Advances in renewable energy technologies: An overview. *Renewable Energy Reviews, 143*, 1031-1051.
11. https://doi.org/10.1016/j.rser.2021.110927
12. Basit, A., Kumar, S., & Singh, P. (2020). Integration challenges of renewable energy into the existing grid systems. *Energy Reports, 6*, 453-461. https://doi.org/10.1016/j.egyr.2020.11.048
13. Altamimi, H. (2020). Addressing the variability of renewable energy sources and its impact on grid stability. *Energy Storage Materials, 30*, 240-255.
14. https://doi.org/10.1016/j.ensm.2020.08.008
15. McTigue, N., Hargrove, R., & Mitchell, D. (2018). Novel techniques to enhance the reliability of renewable energy systems. *Energy, 159*, 744-754. https://doi.org/10.1016/j.energy.2018.06.069 ➢ Haq, S. M., Pieroni, A., Bussmann, R. W., Abd-ElGawad, A. M., & El-Ansary, H. O. (2023). Integrating traditional ecological knowledge into habitat restoration: Implications for meeting forest restoration challenges. *Journal of Ethnobiology and Ethnomedicine, 19*(33). https://doi.org/10.1186/s13002-023-00599-8
16. Athayde, S., Morsello, C., & Arima, E. (2017). Traditional Ecological Knowledge and resilience: The case of the Amazon rainforest. *Ecology and Society, 22*(2). https://doi.org/10.5751/ES09187-220216
17. Folke, C. (2004). Traditional ecological knowledge in environmental management. *Ecological Applications, 14*(3), 899-911. https://doi.org/10.1890/03-5083
18. Ianni, A., Espinosa, P., & Foster, K. (2015). Bridging traditional and scientific knowledge:
19. Contributions to sustainable resource management. *Sustainability Science, 10*(1), 85-100. https://doi.org/10.1007/s11625-014-0287-0
20. Zent, S. (2013). Traditional Ecological Knowledge and its role in modern environmental management. *Journal of Ethnobiology, 33*(1), 1-14. https://doi.org/10.2993/0278-0771-33.1.1 ➢ Argueta, J. (2016). The role of traditional knowledge in contemporary environmental policy. *Global Environmental Change, 39*, 229-237. https://doi.org/10.1016/j.gloenvcha.2016.05.001
21. Hosen, M., Rahman, M., & Shahid, S. (2020). Preservation of traditional knowledge and its integration into contemporary practices. *Cultural Heritage, 13*(2), 321-335.
22. https://doi.org/10.1016/j.culher.2020.01.005
23. Fausto, C., & de Vienne, D. (2014). Revitalizing traditional knowledge: A global perspective.
24. *Journal of Environmental Management, 142*, 335-343.
25. https://doi.org/10.1016/j.jenvman.2014.04.014
26. Pilgrim, S., Pretty, J., & Smith, R. (2010). Strategies for strengthening traditional knowledge systems. *Environmental Science & Policy, 13*(4), 315-323.
27. https://doi.org/10.1016/j.envsci.2010.01.002
28. Berkes, F., Colding, J., & Folke, C. (2000). Rediscovery of traditional ecological knowledge as adaptive management. *Ecological Applications,*

10(5), 1251-1262. https://doi.org/10.1890/1051-0761(2000)010[1251:ROTKEA]2.0.CO;2
29. Andhra Pradesh Solar Power Policy. (2015). *Andhra Pradesh Transmission Corporation Limited*. Retrieved from https://aptransco.gov.in
30. Andhra Pradesh State Skill Development Policy. (2014). *Andhra Pradesh State Skill Development Corporation*. Retrieved from https://apssdc.in
31. Andhra Pradesh Transmission and Distribution System Act. (2014). *Andhra Pradesh Transmission Corporation Limited*. Retrieved from https://aptransco.gov.in
32. National Electricity Policy. (2005). *Ministry of Power, Government of India*. Retrieved from https://powermin.gov.in
33. National Renewable Energy Act. (2015). *Government of India*. Retrieved from https://mnre.gov.in
34. National Tariff Policy. (2016). *Ministry of Power, Government of India*. Retrieved from https://powermin.gov.in
35. Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act. (2006). *Government of India*. Retrieved from https://tribal.nic.in
36. Capacity Building for Industrial Pollution Management. (2003). *Government of India*. Retrieved from https://cpcb.gov.in

Traditional Indian Knowledge Systems: Case study of systems Addressing Functional, Spatial, Economic and Social Needs in Different Coastal Areas

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Abstract

India's diverse coastal regions are home to numerous communities with deep rooted traditional knowledge systems. The traditional Indian knowledge systems are a rich repository of indigenous wisdom, practices and technologies that have evolved over centuries. They encompass practices related to fishing, agriculture, and resource management, shaped by centuries of interaction with the local environment. The region's indigenous knowledge also includes the construction of traditional houses using locally available materials that are resilient to the humid climate and seasonal monsoons. It is a part of the cultural heritage and ecological sustainability. They offer sustainable solutions for various needs such as functional, spatial, economic and social needs. This paper explores the diverse applications like agriculture, environment conservation, sustainable fishing practices, water management as well as cultural and social practices of Traditional Indian Knowledge Systems in different coastal regions of India, highlighting their relevance and efficacy in contemporary times. By documenting and analysing these traditional practices, we can learn valuable lessons in sustainability and resilience that are crucial for addressing contemporary challenges in the coastal areas.

Keywords: Coastal communities, Traditional knowledge, Indigenous, Fishing, Environment

1 . Introduction

India's coastal regions, with their rich cultural and ecological diversity, have nurtured a wealth of traditional knowledge systems over centuries. Ingrained in coastal communities' everyday routine, these systems are a evidence of the traditional knowledge that has been handed down from generation to generation. This knowledge, encompassing various domains such as agriculture, fishing, resource management, and construction, is intricately linked to the natural environment and has evolved through continuous interaction with it. Traditional Indian knowledge systems are not merely historical artifacts but are living traditions that continue to offer practical solutions to contemporary challenges.

The practices such as sustainable fishing methods, water management techniques etc. have been refined to satisfy the functional, spatial, economic and social needs of these communities. There are many lessons to be learned from these tried-and-true systems as the globe struggles with sustainability and resilience concerns. This research investigates the diverse applications of traditional knowledge in India's coastal regions, scrutinizing the manner in which these customs have shaped and sustained communities over an extended period. The goal of the study is to show these systems' ongoing relevance and the valuable lessons they can impart on how to address contemporary social and environmental concerns through a critical analysis of them. Through this exploration, the enduring significance of traditional Indian knowledge systems in fostering ecological balance and cultural continuity becomes evident, providing a blueprint for sustainable living in coastal areas and beyond.

1. Traditional Knowledge Systems of Indian Coastal Settlements

Indian coastal community have developed a rich tapestry of custom, beliefs and abilities throughout the generations which are embodied in their traditional knowledge systems. These systems are made of complex generation to generation passed knowledge about regional maritime habitats, fishing methods and navigational abilities. The various traditional knowledge systems include:

2.1 Coastal Agriculture

The coastal agriculture system is an unique blend of agriculture with the environmental conditions of the coastal regions, where saline soils, irregular water tables and seawater exists. These conditions make it difficult for the conventional farming to take place. Local communities have specialized practices that are well adapted to these conditions ensuring sustainable production and resilience against the changes. Examples include the Mangrove based agriculture in Sundarbans, West Bengal. The farming takes place on the higher grounds while mangroves grow along the edges of the fields and low-lying areas protecting the soil from erosion and act as natural barriers against the storms. Pokkali farming is an ancient system of cultivation of rice known as Pokkali, which is a salt resistant variety and thrives in these conditions. Khazans also include such salt resistant rice variety such as Korgut, Muno, Sheid and Damgo. The system here works with a series of Bunds, sluice gates and dykes. In this region, aquaculture is practiced throughout the dry season whereas agriculture is practiced during the monsoon. It is discussed further in the paper.

Figure 1: Aquaculture in Sundarbans

Figure 2: Agriculture in Sundarbans.

Figure 3: Labours engaged in Pokkali rice cultivation

2.1.1 Coastal Agriculture: The Khazans of Goa

In the coastal fabric of Goa, lies the hidden gem of environmental brilliance and cultural richness – the Khazans. The Khazans of Goa are a remarkable blend of ancient agricultural ingenuity and ecological adaptation, a testament to the region's rich cultural heritage and environmental resilience. The estimated extent of Khazans across Goa is 18,500 hectares (185 sq.km). Half of this is within Tiswadi, the smallest taluka of north Goa. The coastal talukas of Tiswadi, Bardez and Salcete comprise of the majority of the Khazan land along the Goa coast. The bund records available in the notifications of the Government of Goa shows approximately 500 bunds across Goa, 300 of which are within these three vulnerable talukas. Over 3500 years ago, Goa's coastal wetlands were reclaimed from mangroves and transformed into a network of bunds, sluice gates and canals, protecting the land from Arabian Sea tides. This system reflects centuries of wisdom, balancing human needs with nature.

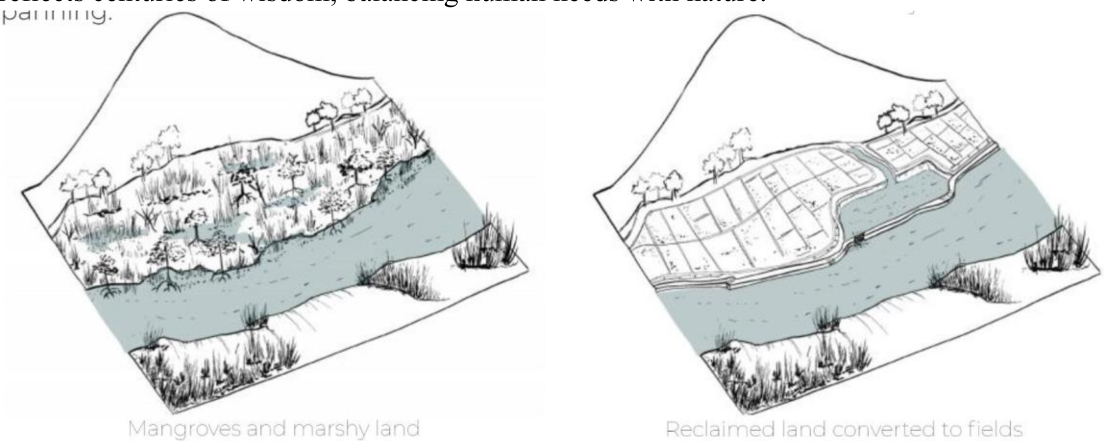

Figure 4: Transformation of mangrove marshy land to reclaimed agriculture lands

These reclaimed wetlands, saltpans and paddy fields demonstrate sophisticated water management and agricultural techniques that have sustained Goan communities for generations. Khazan soil is lateritic in origin, it is saline, acidic, silty clay or silty clay loam and poorly oxygenated. Despite its salinity, acidic nature and poor oxygenation, primitive coastal communities had put these soils to very productive use. Konkan's Gavda community transformed coastal marshes into productive farmlands by regulating tidal water with sluice gates and embankments. This system controls salinity, enabling rice cultivation. The most fertile lands near rivers reclaimed using bunds and dykes. Wooden sluice gates controlled tidal water, while inner dykes retained water and outer dykes protected against river incursion. Shallow pits (poiem) and channels managed water circulation, preventing floods and droughts. In summer, brackish water circulation was introduced to control pests. Bunds, made from local stone, mud, and clay. Withstand tidal waves, with mangroves acting as natural wave breakers. Inner bunds of straw, mud and stones prevent nutrient loss.

Figure 5: Sluice Gates of Khazan

Figure 6: A khazan sluice gate keeper's hut seen with the fishing nets and Poiem (shallow pit) in the background in Goa

Figure 7: Bunds of Khazan

There were four categories of land: morod, kher, khazan and potkharab. Morod was the higher ground where houses were built and potkharab is the uncultivable land. During the monsoon season, the land was used for agriculture where they produced a diverse range of crops, including rice, pulses and vegetables. The various rice varieties include Muno, Shied, Korgut and Damgo which possess greater genetic diversity that equips them with a range of adaptive traits such as tolerance to salinity, drought and water logging making it more resilient to climate variability and extreme weather events compared to high yielding varieties. Rice paddies were stored in bamboo structures called koddo. Traditional practices like mudflat plowing, shellfish farming, and organic manure-maintained soil health. Khazan's irrigation system optimised water use, reducing dependence on freshwater. In dry seasons, aquaculture of fish, prawns and mud crab thrived in brackish waters, managing soil salinity and ensuring sustainability. Low lying areas were used as salt pans, evaporating seawater to produce salt. This diverse system balanced agriculture, aquaculture and salt production, mitigating economic risks from seasonal changes and climate fluctuations.

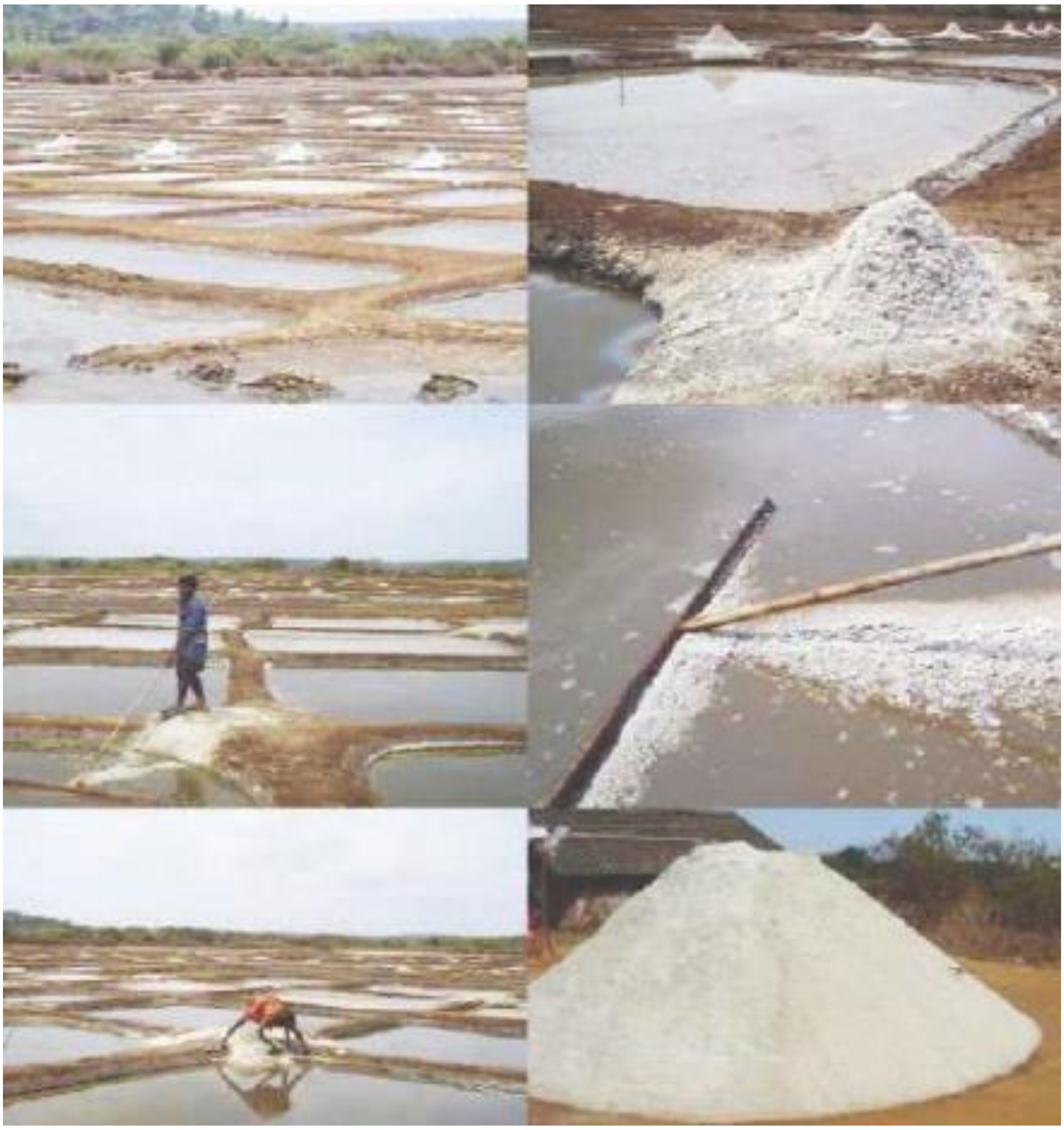

Figure 8: Salt making process

The Khazans, a fragile yet vital ecosystem, have long been central to Goa's rice production, especially in South Goa's Rais-Maina-Curtorim region. Historically managed through communal efforts focused on sustainability, these fertile saline lands supported rice farming. However, modern challenges like bureaucratic inefficiencies and shifting land ownership threaten their survival. As the last of these Khazans face extinction, they remind us of the delicate balance between human ingenuity and nature, urging renewed appreciation for these ancient practices.

2.1.1.a. The decline of Khazan

In contemporary times, the Khazans stand as a living example of resilience and sustainability. As climate change poses new challenges with rising sea levels and extreme weather events, the Khazans offer a blueprint for integrating traditional knowledge with modern conservation practices. They underscore the enduring wisdom embedded in local practices, which continue to inspire innovative approaches to environmental stewardship and cultural preservation.
The following are the reasons of Khazans declining gradually:

a. The workforce required for labour has diminished as people are migrating for better education and job opportunities like cruise-ship jobs.
b. The younger generation has less inclination towards the traditional farming with more appealing job prospects elsewhere.
c. With the increase in the family size, the lands have been subdivided making the mechanized farming difficult which leads to reduced productivity.
d. The embankments are at risk from raising sea levels due to global warming and climate change. As these embankments are crucial for protecting Khazan lands, failure to strengthen them compromises entire Khazan system.
e. As the embankment's breaks, salt water and fish enter the lands, leading to the proliferation of mangroves and disruption of ecosystem.
f. Dykes were traditionally built with chanoy (clayey mud), which are being replaced with concrete structures which adversely impact the environment and biodiversity.
g. The market for prawn and fish is lucrative when compared to rice, thus the profitability of aquaculture is higher compared to paddy driving farmers shift to aquaculture disrupting the traditional seasonal cultivation and decline of Khazan agriculture.
h. Large scale deforestation and filling for construction has driven wildlife into agricultural areas, causing damage to crops and complicating farming.
i. The availability of cheap ration rice has made traditional paddy farming less profitable leading to reduced interest in farmers.
j. The Khazan lands are sold to developers for construction of resorts and other tourism development leading to loss of precious biodiversity and increased flood risks due to absence of natural tidal barriers.
k. With the ban of non-iodised salts, the production of salts reduced

2.1.1.b. Mitigation Strategies taken:

1. Directorate of Agriculture is trying to provide some incentives for the people who take up the Khazan farming.
2. An initiative is taken up to set up a biodiversity committee which would map all the natural features of villages and policies or projects to safeguard them would be created.
3. A Khazan Action Committee has been formed comprising of local residents who want to revive Khazan farming. This is very positive since a lot of villages are coming together.

2.2 Fisheries and Marine Resource Management:

These are the intricate systems which are guided by the deep understanding of the local ecosystems. These promote sustainability that ensures livelihoods of local populations, viability of fisheries as well as maintenance of biodiversity. The examples are Pole and Line fishing which can be seen in the Lakshadweep Islands. It involves the use of a long fishing rod called as the pole and a line with a baited hook or a lure to catch fish, mostly tuna. Poles are basically short bamboo poles with short, heavy-duty lines attached to the tip. Kayar Nombu (coir fasting) in Kerala where the fishing is paused to align with the breeding season of fishes which allows the fish population to recover. There are traditional ways of fish preservation which includes sun drying and smoking which can be seen in many coastal areas. This system avoids the use of refrigeration and preserves their catch for extended periods ensuring food security.

Figure 9: Smoke Drying Fish

Figure 10: Sun drying sting ray fish

2.2.1 Pole and Line Fishing in Lakshadweep

Lakshadweep, a tropical paradise in the Eastern Arabian Sea, is known for its pristine coral reefs and eco-friendly pole and line fishing, a centuries-old practice central to the local economy. With fishing being a main contributor of economy, Pole and line fishing is the mainstay of the tuna fishery. Lakshadweep is the only place where pole and line fishing is still practiced in India. It is a century old, ecofriendly practice that plays a major role in economy and marine conservation efforts.

The lines have a barbless hook, which allows for easy release and reduced damage to the fish. Small fishes like sardines and squids are used to attract the fish which are sourced from nearby freshwaters, keeping the entire fishing process environmentally sound. The primary target is the skipjack tuna and other species like yellowfin tuna, mackerel and trevallies are also caught. Fisherman actively catch matured fishes sparing the younger ones. This system minimized bycatch and reduces the impact on marine ecosystem. This method requires teamwork. Pole and Line fishing supports a large portion of the population and provides income source and food for local communities. The prime fishing season in Lakshadweep is from October to May, aligning with favourable sea conditions and tuna migration patterns. The fisherman operates in the waters around the atolls and reefs of Lakshadweep, which are rich in marine life and provide ideal conditions for tuna fishing. These tunas are highly valued in international markets, particularly in Europe and Japan, where sustainable seafood is in demand.

2.2.1.a. Challenges and Threats faced by the community

Rising sea temperatures and changing ocean currents impact th fish populations and migration patterns, posing a threat to the traditional fishing grounds.

Global competition and fluctuating market prices can make it difficult for fisherman to sustain their livelihoods.

With the greed of earning extra money, overfishing can be seen very often which could affect Lakshadweep’s fish stocks and population.

2.2.1.b. Mitigation Strategies taken up

Efforts are underway to establish Marine Protected Areas in the region to protect marine biodiversity and ensure sustainable fishing practices continue.

The Indian government and various NGOs are involved in promoting sustainable fishing in Lakshadweep, providing training, and supporting infrastructure development.

Figure 11: Pole and Line Fishing

2.3. Spatial planning and Housing

The spatial planning at the village levels is well planned in such a way that it maximizes the use of available land reducing the environmental risks. In many areas the layout includes drainage channels to direct rainwater away from home and into nearby ponds or rivers. It also includes designated areas for cultural and religious practices. Communities also maintain sacred grooves and buffer zones of vegetation along the coastline. These act as natural barriers protecting from tsunami, coastal erosion and preserving biodiversity. The traditional housing structures were designed using techniques that were resilient to harsh weather conditions. They not only adapt to the local environment but also reflect the social and cultural fabric of the communities. The thatch houses in Tamil Nadu, known as Kattumaram are built using palm leaves, bamboo and timber which are locally available materials. They are well suited to the hot and humid climate. They have spaces allocated for storing fishing gears and processing catches as well as storage spaces. The coral stone houses in Lakshadweep are also unique and built to sustain the hot and humid climate. The stones are naturally porous which allows air to circulate through the walls which helps in cooling the interiors. They are also corrosion resistance which is a requirement as the salty coastal air can corrode the building materials. The houses in Sundarbans are built on stilts to protect them from waterlogging during high tides and monsoon rains.

Figure 12 : Kattumaram Houses

Figure 13: Stilt Houses of Sundarbans, West Bengal

2.3.1. The Stilt Houses of Sundarbans

The architecture of the stilt houses in the coastal areas of the Sundarbans, particularly in West Bengal, is a remarkable adaptation to the region's unique environmental challenges, including frequent cyclones and flooding. These structures are constructed using the locally sourced materials, exemplify traditional building techniques that have evolved to withstand the harsh climatic conditions of the delta. These houses reflect the ingenuity of the local communities in adapting to their challenging environment.

The following are the design and techniques used in building stilt houses:

1. Elevated Foundations:

- The houses are built on wooden or bamboo stilts, elevating the living space above the ground level. This helps in protection against the flooding during the monsoon seasons as well as cyclone events. It also helps in reducing the impact of storm by allowing the winds to pass through reducing the pressure.

2. Layouts:

- They have open layout which promotes airflow, which is essential for the humid climate of the Sundarbans. This design not only enhances comfort but also reduce the need for artificial cooling methods. They have single room layout, which serves as a multipurpose living space for cooking, sleeping and storage. In some houses, there are additional raised platforms withing the room used for sleeping or storage, keeping belongings and beds away from potential water and pests.
- A smaller stilt structure is also built adjacent to the house for keeping the cattle or chickens protecting them from extreme environment conditions. In some houses, a separate stilted storage huts might be seen.

- On a coastal area level, these stilt houses are often built in clusters, which are connected by smaller pathways. These are also elevated or made of wooden planks to allow movement during the floods.

Figure 14: Construction of Stilt houses with bamboo structure on top in Sundarbans.

3. Materials:

- Walls: The walls are generally made of Bamboo, woven into mats called as the Chatai, which are lightweight and provide adequate ventilation. There are often coated with a layer of mud mixed with cow dung. This coating helps in insulation of the house and acts as a cooling factor during the hot and humid summers providing a degree of protection against rain and pests.
- Roof: The roof is typically made of thatch, constructed from locally available materials like palm leaves, wild grasses or paddy straw. Keeping the rains and monsoon season in mind, the roofs are sloped to allow rainwater to run off easily, preventing water from accumulating and seeping into the house. Overhanging is provided for additional shade and protection.
- Flooring: The flooring is generally made of wooden planks or woven bamboo planks.

They are left with small gaps between the planks or mats for air circulation keeping the interior cool. In some cases, the bamboo flooring is plastered with mud and cow dung to create smooth and solid surface keeping the pests and insects away.

Since, these locally available materials are used, constructing these houses are easily replaceable, allowing communities to rebuild quickly after storms or flooding. Also, thatch roofs need to be replaced periodically, and the stilts checked for stability.

In the recent years, some stilt houses have also incorporated concrete stilts or reinforced bamboo with concrete to enhance durability, though it is less common due to its cost.

2.3.1.a. Challenges faced:

a. Despite their design, stilt houses are vulnerable to severe cyclones, which can cause significant damage. Cyclones and high winds weaken and damage the structural integrity of the houses, especially if the materials used are not adequately maintained. The chances of thatch roofs flying away or bamboo walls getting damaged are high. However, their lightweight construction reduces the risk of fatalities, as the debris is less likely to cause injury compared to more solid structures.

b. Coastal erosion due to rising sea levels and tidal activity threatens the foundations of stilt houses.

c. The intrusion of saltwater into the land due to rising sea levels and tidal movements leads to increased salinity in the soil, affecting the durability of wooden and bamboo structures.

d. The Sundarbans are home to dangerous wildlife, including Bengal tigers and crocodiles. Wildlife poses a risk particularly at night despite of having stilt houses.

e. With the economic constraints, they do not maintain and reinforce their houses and go for less durable options.

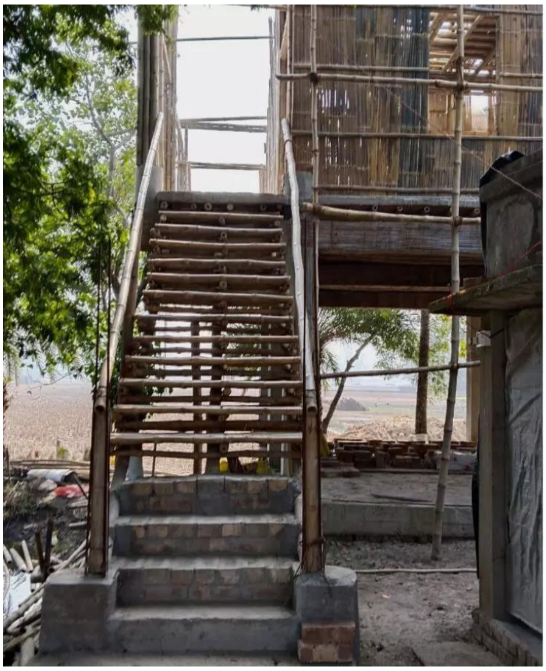

Figure 15: Bamboo combined with concrete

2.3.1.b. Mitigation strategies

a. Organizations like the Dighir Ganguly Foundation Trust focus on training local communities in building resilient structures which empowers the residents and also creates employment opportunities. Bamboos are integrated with concrete to create stronger, more durable buildings that can withstand cyclonic winds and flooring.

b. Locals are engaging the populations in disaster preparedness and response planning which helps in enhancing resilience. Evacuation routes are prepared and multipurpose cyclone shelters that provide safe space for communities are constructed.

c. Water management systems are being incorporated to avoid the salinization of water ensuring that communities have access to clean water.

Figure 16: Construction of stilt house with concrete columns and foundation for better stability continued with the bamboo structure on top in Sundarbans

2.4. Water Management Systems

The coastal areas have seawater which contains a lot of salt content thus a supply of freshwater is critical. Coastal communities developed traditional water management techniques that are both sustainable and innovative. The tank irrigation systems known as Cheruvus in Andhra Pradesh are proof of such a system. These are large shallow reservoir that collect and store rainwater which were used during dry periods. In Karnataka, Surangams were built to access ground water. These are horizontal wells which are dug to tap underground springs. The water flows out naturally due to the pressure of the underground spring and is collected in a reservoir or tank at the mouth of tunnel. These Surangams can also be seen in Kerala which are known as Thurangams, Thorapu or mala in different part of Kasaragod. Coastal wells can also be seen in many areas. These were well designed water storage system which provided drinking water, irrigation water and supported daily household needs. They required deep understanding of the local hydrology and geology.

2.4.1 Surangams of Kasargod

A Surangams also known as Thurangams, thorapu, mala etc. are basically a tunnel dug through a laterite hillock through which water seeps out and into the tunnel. Water is then collected at the end of the tunnel in a storage pit. These are similar to the qanats which once existed in Mesopotamia and Babylon. Generally, it was about 1.5 feet to 2 feet wide, and about 6 feet in height. The length of the tunnel would vary from 3 meters to 300 meters and long tunnels had air shafts which were provided to ensure atmospheric pressure. Surangams are dug in places where hydrogeological profile consists of lateritic and weathered rocks. It was done by the local workmen who were familiar with geology, soil, slope etc. The cost incurred was only the initial cost of digging. These provide water for drinking, domestic use and even for irrigation. There are about 2000 Surangams in Bayar village and Sheni village has 90year-old, 250 m long Surangams with 7 air vents.

Even in Karnataka, manila village in Dakshin Kannada district, a family dug nearly 20 Surangams, out of which 14 are still functional. Apart from this there are about 300 Surangams in the village. It is a water harnessing technology in which groundwater is brought to the surface by a tunnel without the use of mechanical pump or lift. The Surangams can be single tunnel or branched, where the main tunnel has several branches to tap more water. The yield of a Surangams depends on the monsoon rains and the subsequent percolation of water into the laterite hills. A well-functioning Surangams can yield up to 10,000 liters of water per day. Surangams are environmentally sustainable as they do not involve large scale land disruption or deforestation, they work with the natural landscape to capture and store water. By providing a reliable water source, they help in preserving the local ecosystems and reduce the need for deep borewells which deplete the groundwater levels.

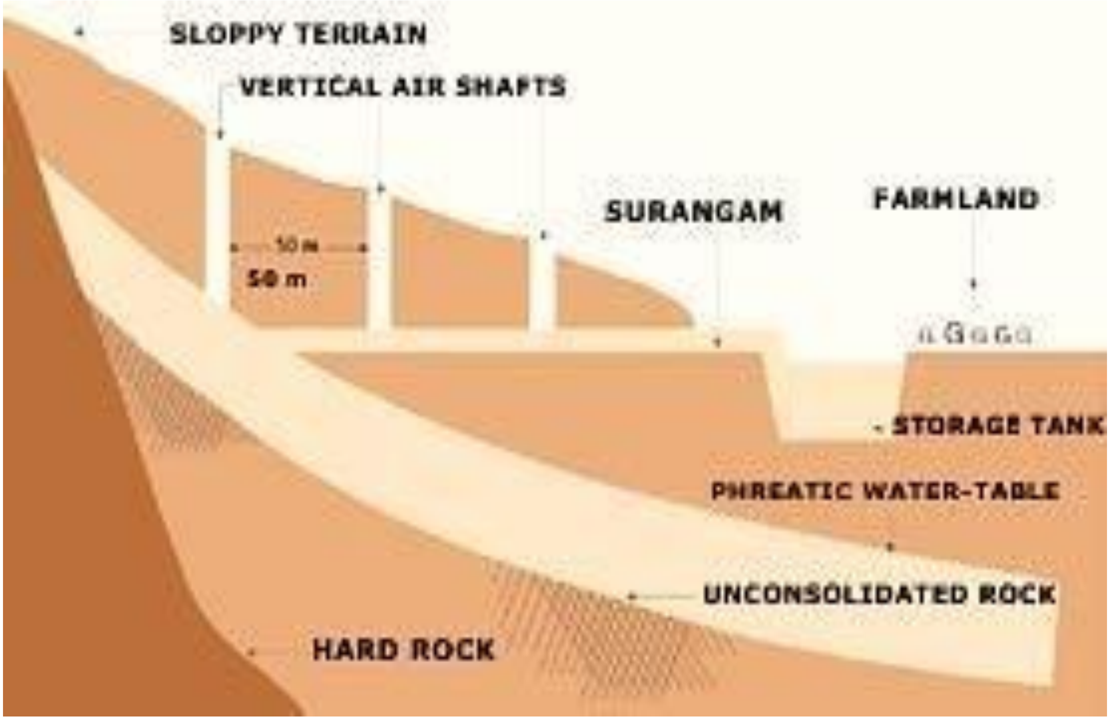

Figure 17: Working of Surangams System

2.4.1.a. Challenges faced:

a. With the advent use of modern water supply systems like borewells and piped water, the usage of Surangams are declines.
b. Many are abandoned or neglected. The younger generations are less inclined to learn the traditional knowledge required to construct and maintain these Surangams.
c. Deforestations and changes in land use patterns have also affected the natural recharge of Surangams reducing their effectiveness.
d. Changes in rainfall patterns due to climate change like reduced rainfall, unpredictable weather, impact the recharge of Surangams making it less reliable.

e. Overtime, Surangams can suffer from structural issues such as collapse of tunnels, siltation or blockage of water channels due to debris and overgrowth which makes it difficult for water to flow freely, reducing the effectiveness or the Surangams.

2.4.1.b. Mitigations Adopted:

a. NGOs and government bodies are putting efforts to revive and conserve Surangams. Thy are often focused on community participation and reintroduction of traditional knowledge.
b. Documentation of the Surangams raise awareness and encourage their preservation. Different studies have also highlighted their importance as a sustainable water management system.

Figure 18: Surangams of Kerala

2.5 Social Structures and traditional trade networks

Social needs in coastal areas contains a range of aspects that are crucial for the well-being and resilience of communities. The different rituals and festivals like Kayar Nombu, seasonal fishing bans in Tamil Nadu ensures the long-term sustainability of marine source and reinforces the social bonds within the communities by bringing them together for fasting, prayers and gathering. It also strengthens social ties and shared values.

Meenava sangams in tamil nadu are traditional cooperative that manage the fishing rights, resolve disputes and provide social security to their members. The play a major role in maintaining the social fabric of coastal community. Panchayats and councils are pivotal in managing the communal resources ensuring that all members of the community benefit from shared resources. In Gujarat’s coastal communities, traditional salt farming called as agar is practiced for centuries. The salt produced through these methods is traded within and beyond the region forming an essential part of the local economy. Salt farming also contributes to the local economy and water management as they use the tidal movements to flood salt pans and extract salt. The trade system supported the livelihoods of salt workers and contributed to the regions' economic stability. It is accompanied by the traditional rituals and festivals.

3. Conclusion

The paper highlights the significance of Traditional Knowledge Systems (TKS) in India's coastal regions, which are rooted in centuries of sustainable practices and ecological wisdom. These systems, encompassing agriculture, aquaculture, and water management, have supported coastal communities while preserving biodiversity and maintaining ecological balance. TKS also provide resilience against environmental challenges like rising sea levels and storms, fostering adaptation in vulnerable regions. Additionally, they promote social cohesion by intertwining with the cultural heritage and identity of coastal communities, while also playing a crucial role in conserving biodiversity by protecting vital species and habitats.

However, the rapid spread of globalization and modernization has marginalized these traditional systems, with modern practices often prioritizing short-term economic gains over sustainability. Younger generations are increasingly drawn to urban lifestyles, leading to a breakdown in the transmission of traditional knowledge. Furthermore, the lack of government recognition and supportive policies has contributed to the erosion of these systems.

To revitalize TKS, systematic documentation is essential, using digital technologies and communityled initiatives to create accessible archives. Integrating traditional knowledge with modern scientific practices can enhance the resilience and sustainability of these systems. Governments must create policies that protect TKS by safeguarding indigenous intellectual property, supporting natural resource management, and incorporating these systems into development plans. Empowering communities to manage and protect their traditional knowledge, along with raising awareness about its value, is critical. Education programs that bridge generational gaps and teach younger generations the importance of traditional practices will also help ensure the survival and revitalization of TKS. By adopting these strategies, TKS can continue to contribute to the sustainable management of coastal areas.

4. References

1. Figure 1 - https://indianexpress.com/article/cities/ko lkata/sundarbans-outskirtsshrimp-farms-turning-mangroves-organic-9040304/
2. Figure 2: https://scroll.in/article/1019382/in-the-cyclone-battered-sundarbanscommercial-aquaculture-is-preying-on-poverty-for-profits
3. Figure 3: https://india.mongabay.com/2022/10/commentary-pokkali-a-gi-tagged-ricevariety-could-be-on-the-verge-of-extinction/
4. Figure 4: https://www.teriin.org/article/goa-village-strives-protect-fast-vanishingkhazans
5. Figure 5: https://neenabhandari.com/can-preserving-goas-khazans-address-climatethreats/
6. Figure 6: https://groundreport.in/khazan-farming-system-an-engineering-marvel-ingoa-explained/
7. Figure 7: https://www.linkedin.com/pulse/ smoke-drying-technology-fishpreservation-hiba-haneefa-smqyc/
8. Figure 8: https://link.springer.com/chapter/10.1007/978-94-007-7202-1_3
9. Figure 9: https://morningchores.com/drying-fish/
10. Figure 10: https://sourcingtransparencyplatform.org/fisheries/lakshadweep-pole-andline-skipjack-tuna

11. Figure 11: https://www.alamy.com/traditional-village-home-with-a-palm-leafthatched-roof-in-palani-pazhani-tamil-nadu-india-photo-by-creative-touch-imagingltdnurphoto-image489605363.html?%20imageid=D6312349-AAA2-43D9B36BF33E50313969&p=1975781&pn=1&searchId=d9b024e6691b9%20ae692f42da 11d2eeee9&searchtype=0
12. Figure 12: https://commons.wikimedia.org/wiki/File:Chandpai_Village_Sundarban_
13. Figure 13, 14,15,16: https://www.gaonconnection.com/english/sundarbans-bamboomunda-community-cyclones-storms-health-cum-storm-shelter-climate-resilient53235/
14. Figure 17: http://www.rainwaterharvesting.org/Rural/west_ghat_tradi.htm
15. Figure 18: https://civilsocietyonline.com/agriculture/nothing-beats-a-suranga/
16. https://www.sahapedia.org/conversation-xavier-rodrigues-khazans-goa
17. https://www.globalissues.org/news/2024/04/04/36391
18. https://www.heraldgoa.in/m/details.php?n_id=126750
19. https://www.outlookindia.com/national/the-green-corridors-can-goa-s-khazansmitigate-the-effects-of-climate-change--magazine-201149
20. https://makeithappen.co.in/the-dying-salt-pans-of-goa/
21. https://issuu.com/snehampandey/docs/thesisbook-final
22. https://www.goya.in/blog/goas-last-living-khazans
23. https://jnanafoundation.org/khazan-project
24. https://www.indiawaterportal.org/articles/lost-khazans-goa
25. https://www.insightsonindia.co m/ 2023/07/08/khazan-land-goa/
26. https://eprints.cmfri.org.in/3692/1/Article_03.pdf
27. https://www.telegraphindia.com/west-bengal/revamped-sunderbans-bungalow-ofmemories/cid/1831064
28. https://archive.nytimes.com/india.blogs.nytimes.com/2012/08/17/in-the-sundarbansfolk-homes-for-modern-living/
29. https://www.travelchhutichhuti.com/blog/sundarbans-mysterious-and-plot-behind-sirhamiltons-bungalow/
30. https://thebetterindia.com/232943/west-bengal-couple-sustainable-home-how-tohouse-build-architecture-mud-bamboo-straw-cyclone-say143/#google_vignette
31. https://amitavghosh.com/a-house-in-the-sundarbans/
32. https://www.cseindia.org/qanats-surangams-3874#:~:text=A%20Surangam%20is%20basically%20a,in%20different%20parts%20 of%20Kasaragod.
33. https://www.cseindia.org/qanats-surangams-3874#:~:text=A%20Surangam%20is%20basically%20a,in%20different%20parts%20 of%20Kasaragod.
34. https://www.drishtiias.com/daily-news-analysis/surangam-system

Scope of Land Pooling in the hilly State of Himachal Pradesh, India

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ABSTRACT:

Demand for land and related resources are increasing day by day driven by various investors and infrastructure projects. This also results into various conflicts among stakeholders involved as, in most cases, the land is procured through the process of compulsory acquisition. To overcome such situations, the concept of 'Land pooling' can be introduced which is the consolidation of scattered land parcels for a unified design and infrastructure provision. Afterwards, the remaining plot is returned to the original owners proportionately. In the current era land is one of the major commodities being bought and sold in the state of Himachal Pradesh mainly for the purpose of housing & other infrastructural developments. But the present geographical conditions make it a comparatively difficult to access the area properly. Presently when the country is moving towards sustainable development, a little part can be played by considering land as a resource in spite of a commodity. Proper management and consolidation of land can lead us to a much better infrastructural development. Cadastral parcels can be transformed to appropriate land-parcels for using in more economical way leading to an equitable, efficient, and sustainable land development. Proper land pooling and reconstitution can lead towards optimizing the land utilization pattern and the betterment of community facilities. It can also be used for development of Greenfield and Brownfield areas along with redevelopment / revitalization of old unplanned towns. The present study highlights the scope of land pooling scheme in Himachal Pradesh, India based on feedback from the local public leading to a possibility for better accessible, planned, fair and equitable urban development.

Keywords: Himachal Pradesh; Hilly region; Land pooling technique; Demonstration and field survey; Land management

1. INTRODUCTION

Land is an important physical as well as economic resource, but at the same time, it is non-renewable and its supply is inherently fixed. So, it should be utilized very carefully. With the increasing global population, the need of land for infrastructure development and other utilities is increasing minute by minute. Some form of land-assembly is required to carry out crucial development projects both in urban and rural areas.

Among many other techniques, which can be used to acquire land for infrastructure development and promote equitable and sustainable land development in urban and rural areas, land pooling or readjustment is one such important measure. The concept of land readjustment has been used in various countries of the world for at least two hundred years. Urban land pooling is a technique for carrying out the unified servicing and subdivision of separate landholdings for planned urban development. It is also known as urban land consolidation, land readjustment, land replotting, and land redistribution in particular countries because it involves these processes (URDPFI, 2014; MIT, 2010). It is widely used in Japan, South Korea and Taiwan and in some cities in Australia and Canada. A somewhat similar technique known as plot reconstitution is used in some cities in India (Ashwin Mahalingam, 2011).

Land pooling leads to equitable and efficient land development and is actually a means of readjusting uneven land distribution by bringing fragmented land holdings together to constitute a larger land parcel. Consequently, infrastructure is developed on the land, and it is then returned to the original owner/s after a nominal deduction from the actual contributed share based on a formula. This formula compensates the developing authority for the infrastructure and provided services by allowing them to sell or retain a part of the original land which later can be used for revenue generation.

Though the process appears complex, this approach can promote social justice along with some effective development. Land pooling involves participation of the national and state governments for policy formulation, notifications, approvals and creation of operational norms. The local agency will receive blanket assistance from various government departments, and is responsible for creating a proper land valuation mechanism to encourage the participation of land owners.

India faces a truly formidable challenge in managing the rapid process of urbanization and the growth of its cities. It is the second-most-populous country in the world, with a population of 1.028 billion and of this, 285 million (27.8 percent) live in its 5,161 cities and towns (CIA, 2014; Census of India, 2011)**.** It has over 17% of world's population living on 2.4% of the world's geographical area. It is expected that by 2050 half of its population will be living in its cities and towns. This will mean that the existing cities will continue to grow larger and many new cities and towns will be added. India Ranks 7th in order of its land area amongst the countries of the world but Due to growing population in India, the per capita availability of land has reduced from 0.89 Ha in 1995 to 0.27 Ha in 2007/08 (US Intelligence agency, 2008). It is estimated that by 2030, India will become the most populated country on earth with 17.9% of world's total population. With this, the per capita land availability will further reduce (Department of Land Resources, 2013). Also othe population density of India varies from district to district depending on the resources available. The highly dense areas require more infrastructure therefore undergo a worse situation in terms on land scaricity.

Himachal Pradesh (HP) is a small hill state with a total area of 55,670 km^2 with total population 6.856 million, situated in the northern part of India (Census of HP, 2011). The urbanisation levels are less as compared to the rest of the country but so is the land record. A large chunk of land is not under the cadastral record because of the inaccessibility and snow-clad terrain as shown in Table 1 (GoHP, 2015).

Table 1: Land Statistics for Himachal Pradesh (Source: Department of Land Revenue, GOI 2016)

Items	Area in sq.km.	Remarks
Total Land Area	55,670	100%
Land under record (cadastral land)	45,431	80.1%
Forest	10,994.30	24.2% of cadastral land
Aimed area for forests	22,715.5	50% of cadastral land
Other Usage	22,715.5	50% of cadastral land
Per capita land	0.003	

Thus, the land available for infrastructure development exclusive of the forest cover and other natural entities is further decreased. In the current scenario the state is also witnessing a considerable amount of industrialisation thus leading to migration and a change in the prior agrarian land use of the area. This decrease in the land share of every individual adds to the need of a better understanding of land use management along with its different policies both at national and local levels and to manage the transformation of India's cities and towns' effective urban planning protocols, processes, and institutions underpinned by effective legislation are required.

Hence, the main aim of the study is to understand land as a resource, particularly in a hill state and analyse the methodologies of proper land use management looking into the concept of land pooling technique along with the scope of its application in the state of Himachal Pradesh through demonstration and primary feedback from the people of the area.

2. METHODOLOGY

2.1 Approach of Study

The approach adopted is based on public surveys and literature analysis from various authors (Patel, 2015; URDPFI, 2014; Department of Land Revenue, 2015; Sunil Tyagi, 2015; Satashia, 2014; Venkatasubramanian, 2014; Mishra, 2013; MoRD, 2013; MoUD, 2013; WGEA, 2013; Beltrao, 2013; Ballaney, 2012; Ashwin Mahalingam, 2011; MAPC, 2011; Quium, 2011; A. Damodaran, 2010; IDFC, 2010; MIT, 2010; SPAV, 2010; Jain, 2009; Gurumukhi, 2003) along with the case examples of different land use management techniques being followed in India. Land use management scenario was studied on national level and based on the same projections were made for regional levels after analysing the local statistics of the area. Discussions with the concerned officials and the local folk were conducted to know the present and the future of land use management especially land pooling scheme in the area with the preparation and demonstration of hypothetical land pooling model.

2.2 Scope and Limitation of Study

The scope of this study involves: (i) analysing the current status of land pooling in the state of Himachal Pradesh with the help of primary survey; (ii) preparation of a demonstrational land pooling model based on the methodologies used in the other parts of the country for the same for a proper understanding of land pooling amongst the common folk; (iii) the acceptance of land pooling in the further land use management for the area will be analysed based on a secondary survey conducted after the demonstration of the model. The present study is constrained by the following limitations: (i) base maps and other statistical data was not available for the study area on a number of parameters; (ii) the study is limited up to analysing of the scope of land pooling scheme in the state of Himachal Pradesh and formulation of detailed guidelines are beyond the scope of the authors; (iii) the demonstration model was prepared for the better understanding of land reconstitution amongst the general folk and analysis is done regarding the increase in monetary value of the land parcels based on market survey by the author.

2.3 Description of Study Area

The study area is located at Baddi-Barotiwala-Nalagarh (BBN) industrial area in Himachal Pradesh (Fig. 1), which is an industrial corridor stretching from Barotiwala to Nalagarh. The area falls under an authority namely 'Baddi Barotiwala Nalagarh Development Authority' (BBNDA), created in 2006 for comprehensive and regulated development of the Baddi, Barotiwala and Nalagarh area (BBNDA, 2010), and lies in Nalagarh tehsil of Solan district and falls under Dharampur Development Block. By virtue of peculiar setting NH-21A passes through the centre of BBN Special area from south to north direction leading to good connectivity with the neighbouring states. This region leaves a prominent mark on the map of South Asia as a pharmaceutical hub for manufacturing of drugs. The BBNDA has very vast Planning area consisting of 41 nos. panchayats having 229 revenue villages measuring 31,814 hectares, including 5000 industrial units, four 'growth centres' i.e. Baddi, Barotiwala, Nalagarh and Panjhera and two Urban Local Bodies. The population of BBN area is numerated 172,270 persons consisting of 95,631 males and 76,659 females. Of this urban population is 40,619 as per the Census 2011 report (Census, 2011). The demographic profile of the BBNDA is shown in table 2.

Figure 1: Location of study area in Baddi (HP). (Source: Google images)

Table 2: Demographic profile of BBNDA. (Source: GoHP, 2015)

Sl.No.	Parameters	Urban standards and norms	Existing village Range	Existing village Average
1.	Population	5000	8 to 2792	498
2.	Growth Rate	20%	-17.46 to 500	48.7
3.	Density	400persons/ sq. km	0.0018-0.37	3.5
4.	Literacy rate	70%	16.35-85.71	57%
5.	Non-Agri. Workers	90%	3.57% to 99.1%	40.6%

2.3.1 Existing land use in BBNDA

The special area comprises of two main segments namely Barotiwala and Nalagarh planning areas with an initial land area of around 7305 hectares, out of which 89.86 percent of area was taken under Barotiwala Planning area and 10.13 percent under Nalagarh Planning area (Development Plan, Baddi Barotiwala Nalagarh Development Area, TCP-HP Department, 2010). The detailed land use structure (Fig. 2) for initial panning was as per table 3.

Table 3: Land use in BBNDA. (Source: GoHP, 2015)

Sl.No.	Land use	Area in Hectares	%age of total area
1.	Residential	86.75	1.19
2.	Commercial	26.1	0.36
3.	Industrial	175.36	2.40
4.	Facilities& Services	14.78	0.20
5.	Parks & open Spaces	0.31	0.00
6.	Govt. & Semi Govt. Offices	2.99	0.04
7.	Traffic & Transportation	65.69	0.90
8.	Total Area	371.98	-
9.	Agriculture & Greens	6763.09	92.58
10.	River/Nallah/Water bodies	169.93	2.33
11.	Grand Total	7305	100.00

2.3.2 Proposed land use for BBNDA

Spreads of existing Industries in the region are considered for proposed industrial area, accordingly space has been allocated in proposed ‘Land Use Map -2025’ for BBNDA. This required some major changes in terms of land use and require proper land use management and planning techniques. The proposed land use is as shown in table 4 and figure 3.

Table 4: Proposed land use of BBNDA for 2025. (Source: GoHP, 2015)

Components	Area in Hectares	%age of total area
Total BBN Area	31874	100
Non-Developable Area	8143.88	26
Total Developed area (Existing land use)	4406	14
Industrial	1043	3.3
Commercial	132	0.4
P& SP	15	0.0
Residential	2896	9.1
Transportation	320	1.0
Net Developable Area (2025 master plan)	19324	60
Industrial	5072	15.91
Commercial	134	0.42
P& SP	881.61	2.81

Residential	7048.69	22.11
Transportation	1593.07	5.00
Park & Open Spaces	546.96	1.72
Vacant	4047.83	12.69

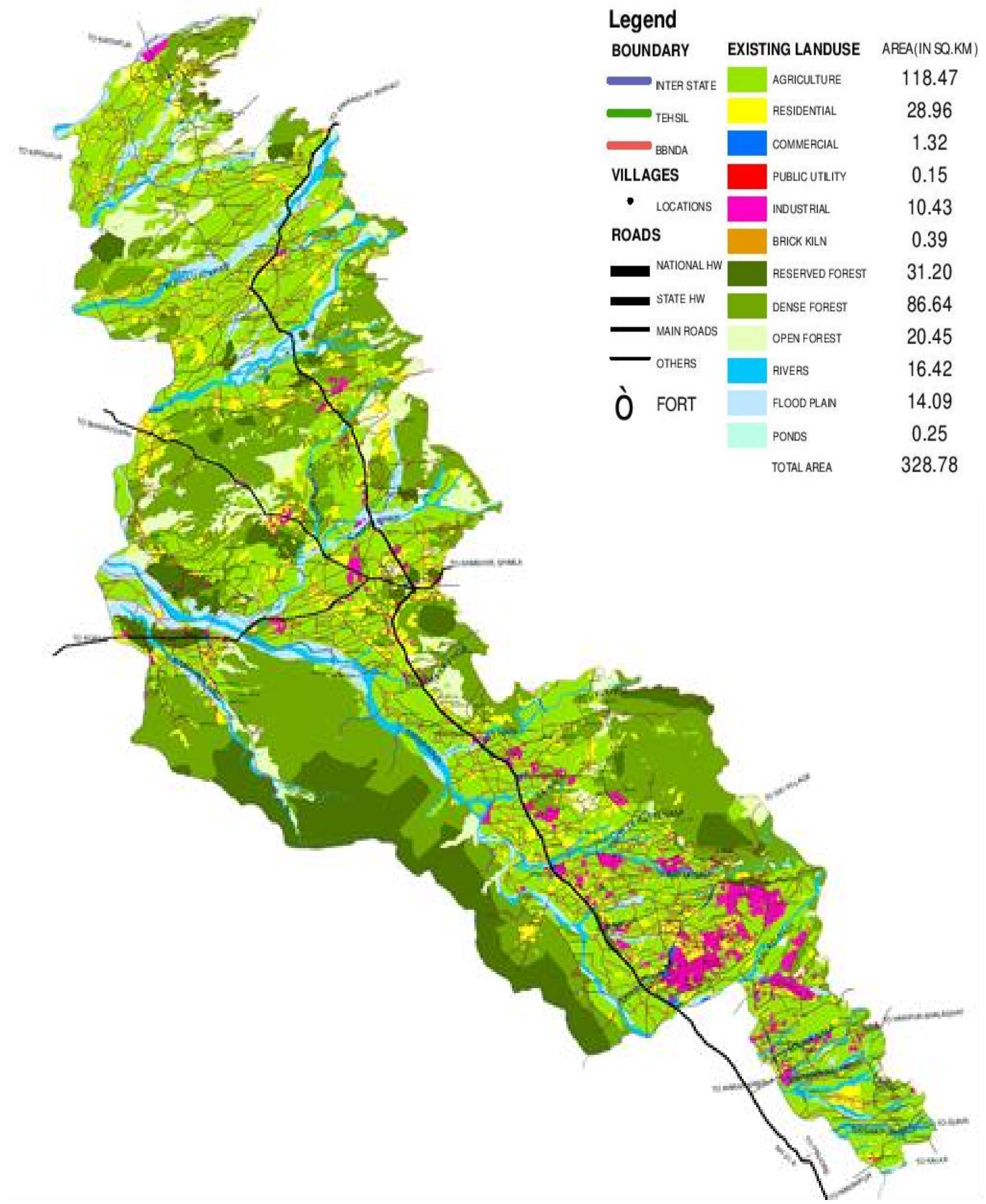

Figure 2: Existing land use plan of 2007. (Source: Office of BBNDA)

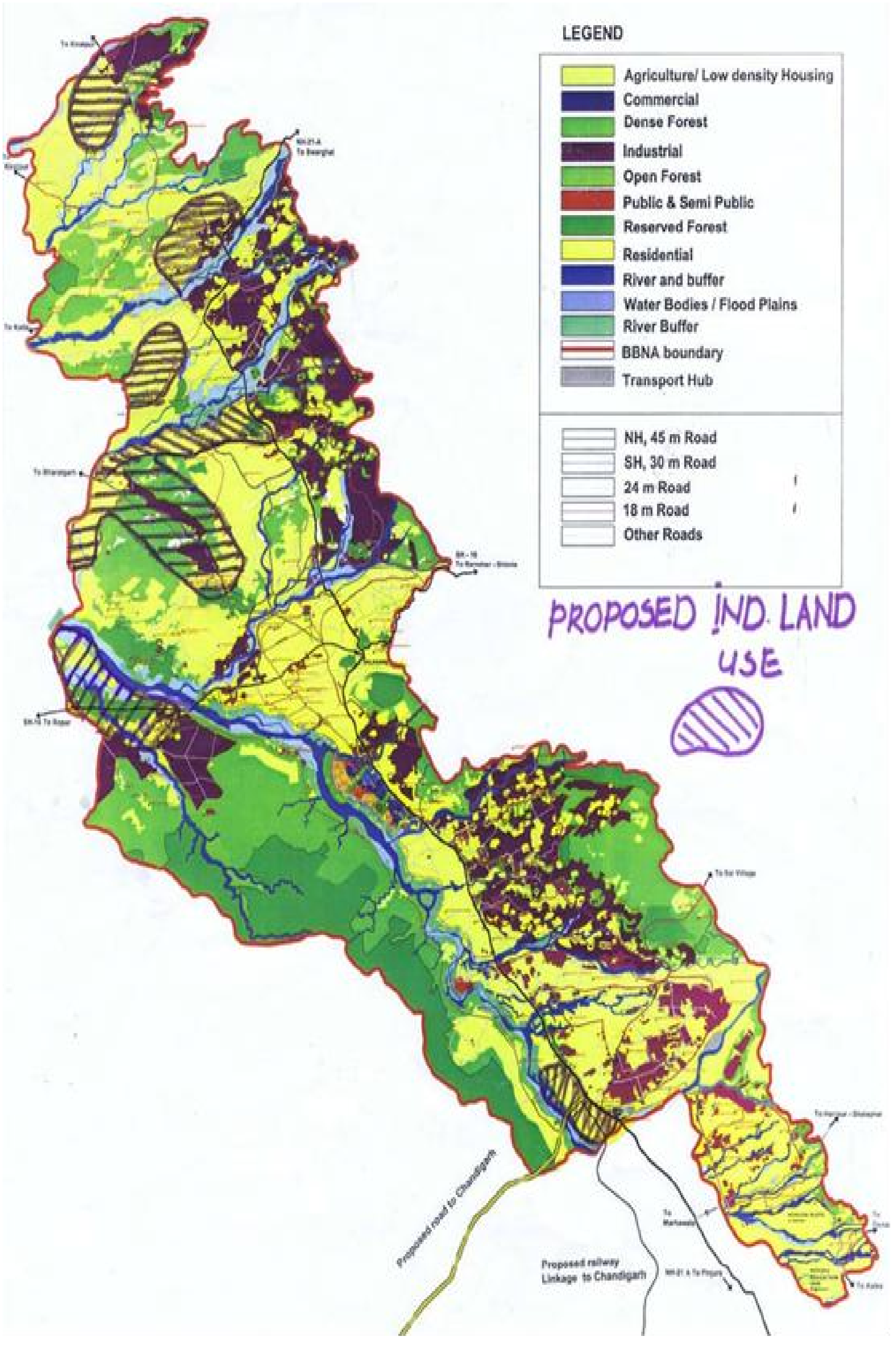

Figure 3: Proposed land use plan for BBNDA for 2025. (Source: Office of BBNDA)

3 RESULTS AND DISCUSSIONS

3.1 Primary Survey

A primary survey with a sample size of 50 people was conducted, on the basis of a questionnaire, to analyse the existing understanding of land use management amongst the local people of BBN special area. The main focus was to study the awareness of the common folk about land use management and planning and to get their views on the concept of land pooling. The sample size of 50 individuals which was considered for the primary survey can be classifies in different groups as shown in figure 4. The results of some of the main questions of the survey are represented by charts as seen in figure 5.1, 5.2 and 5.3.

It can be seen that people are not satisfied with the living standards and are not much aware of land use management and its techniques. They want a better facility but are afraid to take a risk and try new concepts.

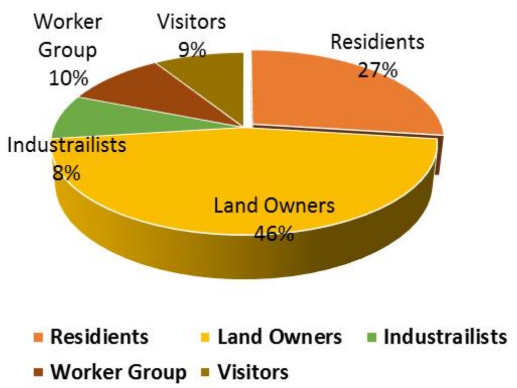

Figure 4: Sample size distribution for primary survey. (Source: Author)

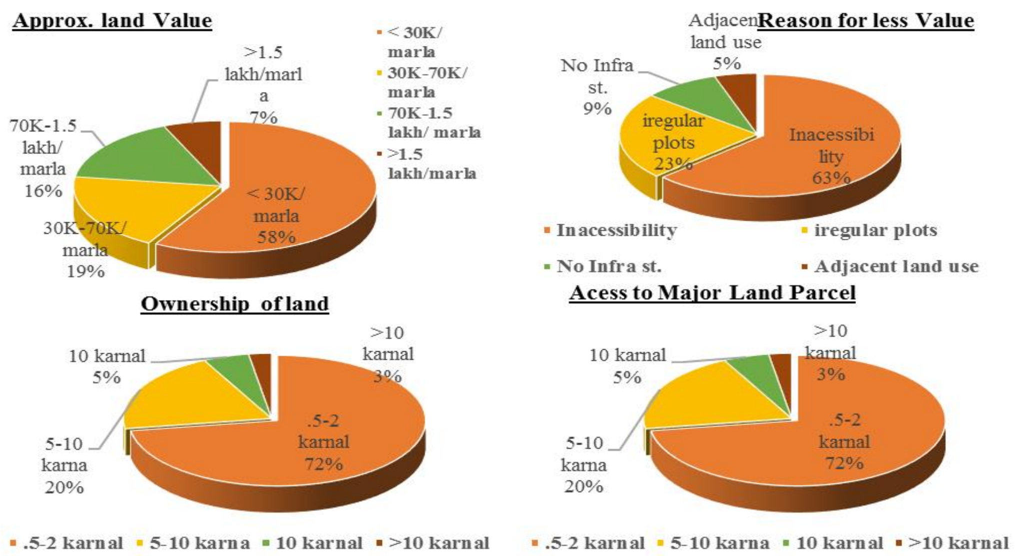

Figure 5.1: Major results of primary survey (Part 1). Source: Analysed by the Author

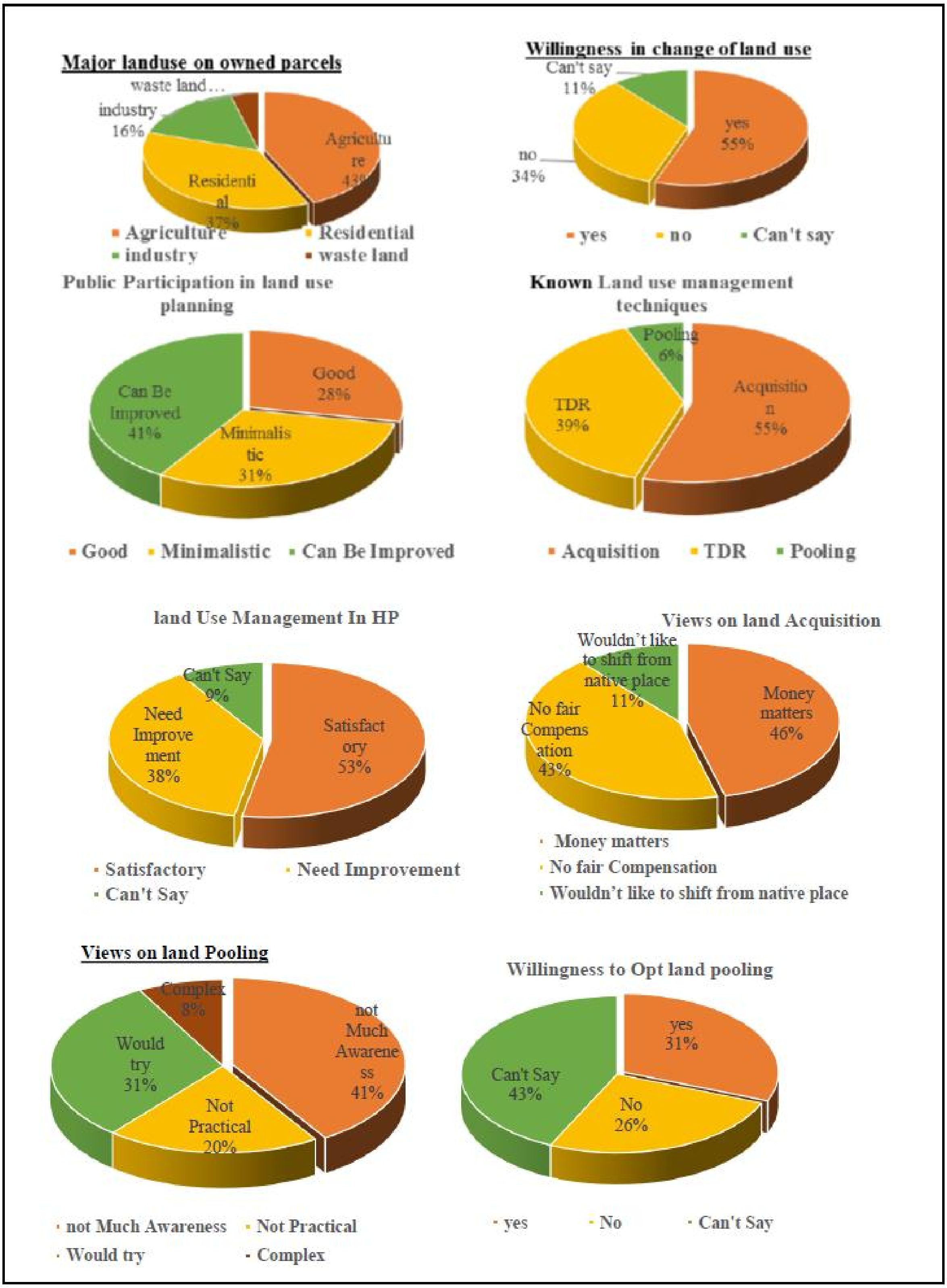

Figure 5.2: Major results of primary survey (Part 2). Source: Analysed by the Author

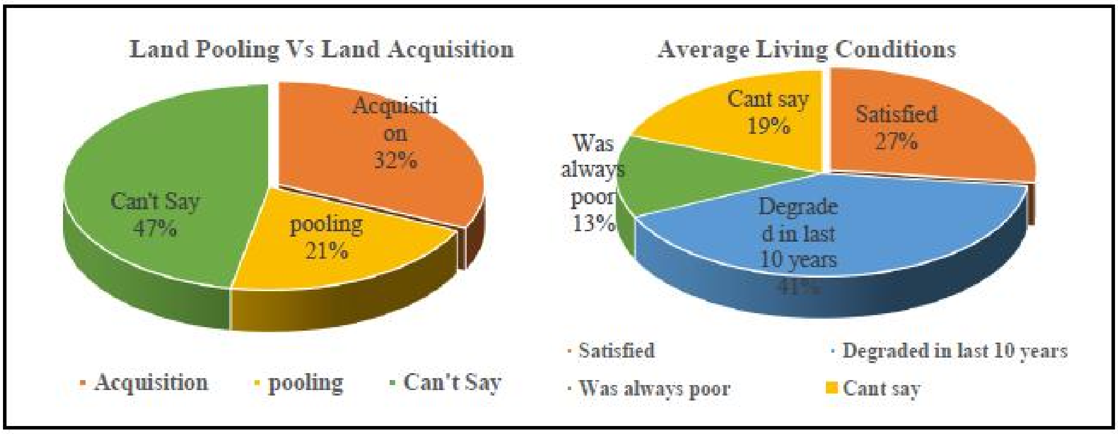

Figure 5.3: Major results of primary survey (Part 3). Source: Analysed by the Author

3.2 Sample Land Pooling Model

To analyse the future perspective of land pooling as a reform and an alternate to land acquisition, the basic understanding of the concept of land pooling was required amongst the local people. Then their views were to be analysed based on a secondary questionnaire survey. To develop this basic understanding a demonstrational land pooling model was prepared on an otherwise unplanned agricultural land with the help of guidelines studied in the various case examples.

A hypothetical site was taken with the help of department of revenue in the Harraipur village area of Baddi Barotiwala Nalagarh Special area (Fig. 6) and was developed for residential land use through land pooling mechanism for a better demonstration of the scheme to the common folk. An agricultural area of around 115 hectares with around 221 farmers or land owners and around 5 hectare of government land in the form of Plots ranging from 0.02 hectare to 0.6 hectare accounting to a total of 120 hectares was undertaken as the area of sample study.

Figure 6: Satellite image of Harraipur village (HP). (Source: Google Maps)

An attempt was made to convert the existing agricultural land use to residential area so as to meet the housing needs Plots were pooled from all the farmers of the study area. Deductions were made out of the total area for the development of basic facilities like community level commercial area, some small-scale industry and common green spaces. Area was also taken out for the development of certain public buildings like an institute etc. A total of 40% i.e. approximately 40 hectares were taken for the common facilities. For the understanding of individual deductions, given in table 5, guidelines from different case studies in the country were used. Road layout was given ensuring proper access to the area. Steps undertaken are shown in figure 7.

Table 5: Individual deductions in plot areas. (Source: Gujarat land pooling scheme)

%age deductions based on Plot Sizes		
Sl.No.	**Plot Area (Sq. m)**	**Deduction %age**
1	0-30	0
2	30-100	10
3	100-200	20
4	200-500	30
5	More than 500	40
6	Government plots	50

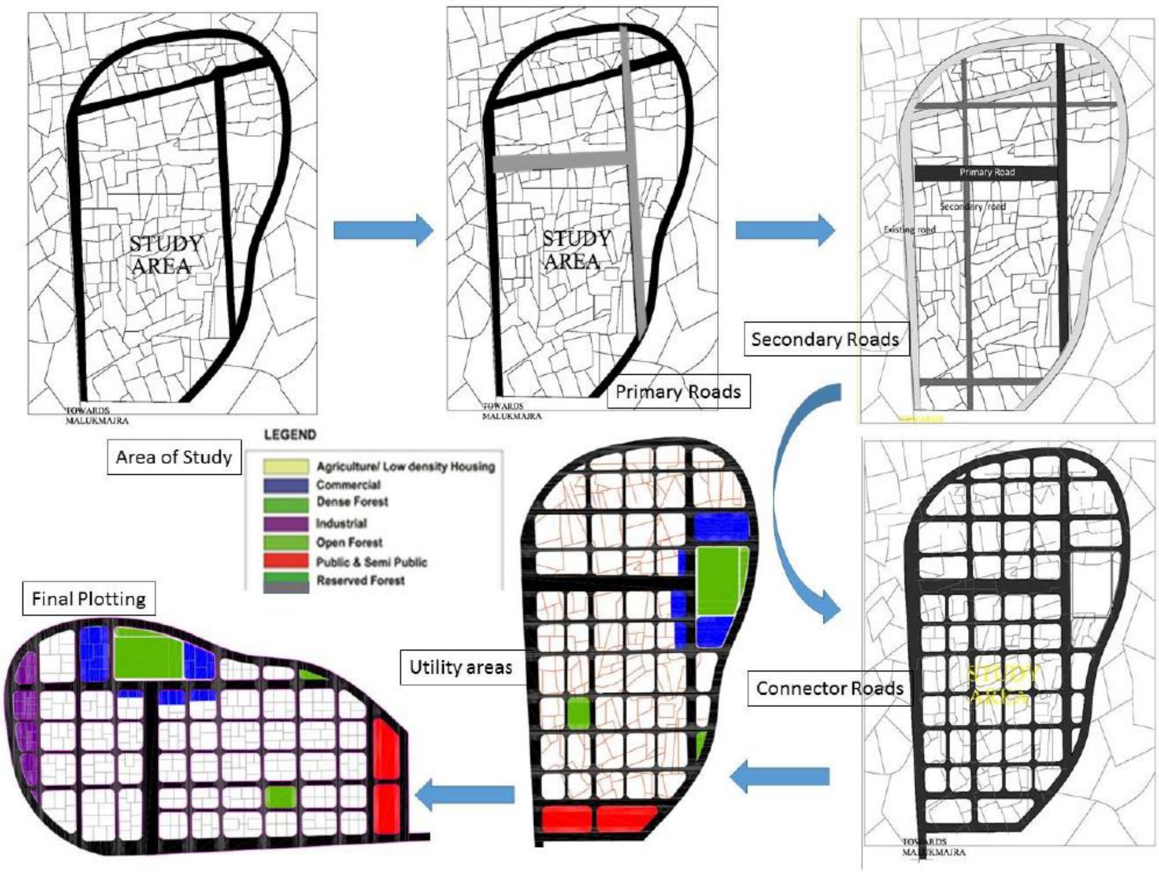

Figure 7: Steps used in the Land Pooling Example. (Source: Analysed by the Author)

3.3 Post demonstrational Survey

After the demonstrational model was prepared the need was to make the people go through the basics of the concept and experience the practicality of the scheme. The model was demonstrated for the public and a secondary survey was then conducted taking into account the views of the local people after they were given the basic idea of land pooling. The main focus now was to look into the understanding and acceptance of the scheme amongst common people. A sample size of 50 individuals, distribution shown in figure 8, was taken for the demonstration and questionnaire to analyse the scope of land pooling as an alternate for land acquisition for acquiring land for various purposes. The perception of the people on land pooling scheme is analysed based on both land pooling and land acquisition and they were asked to compare both the schemes as an option if the land attainment was to be done on their own property. Major results of the survey questionnaire which was conducted after the demonstration is represented graphically by the charts in figure 9.1 and 9.2.

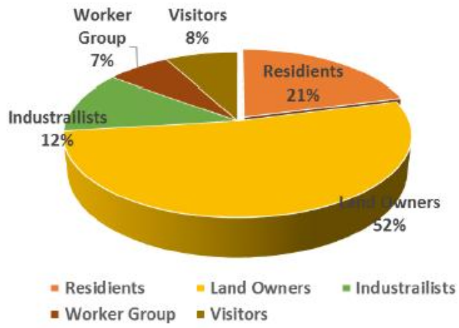

Figure 8: Sample size distribution for post-demonstration survey. (Source: Author)

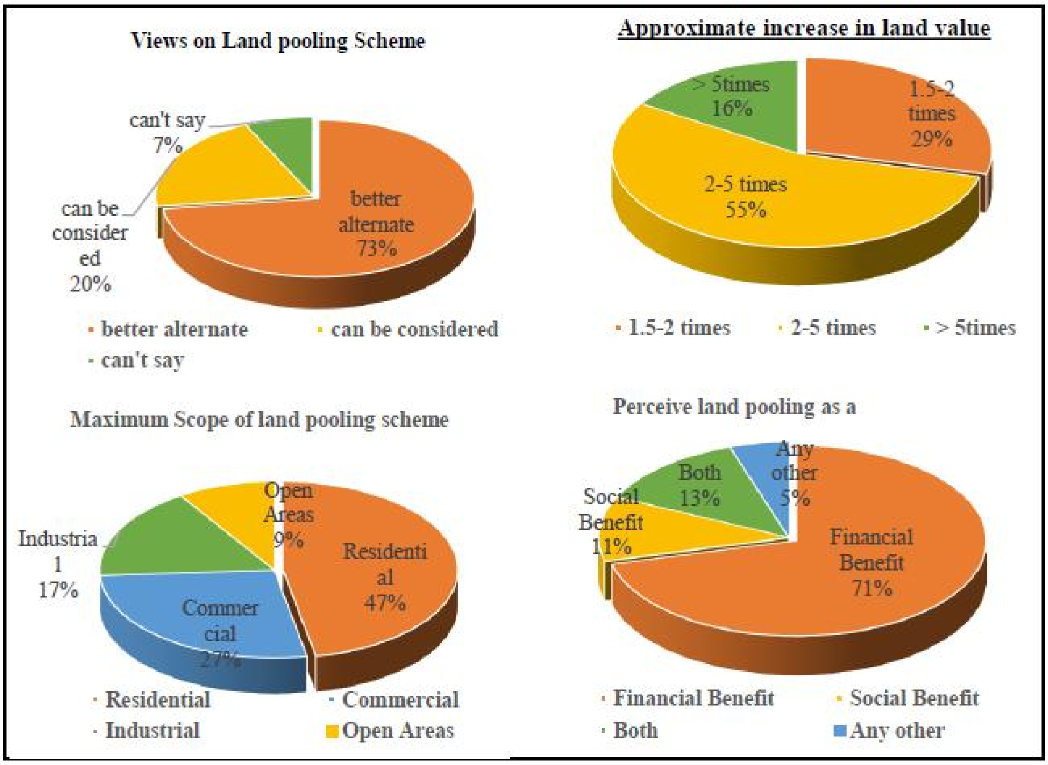

Figure 9.1: Major results of post-demonstration survey (Part 1). Source: Analysed by the Author

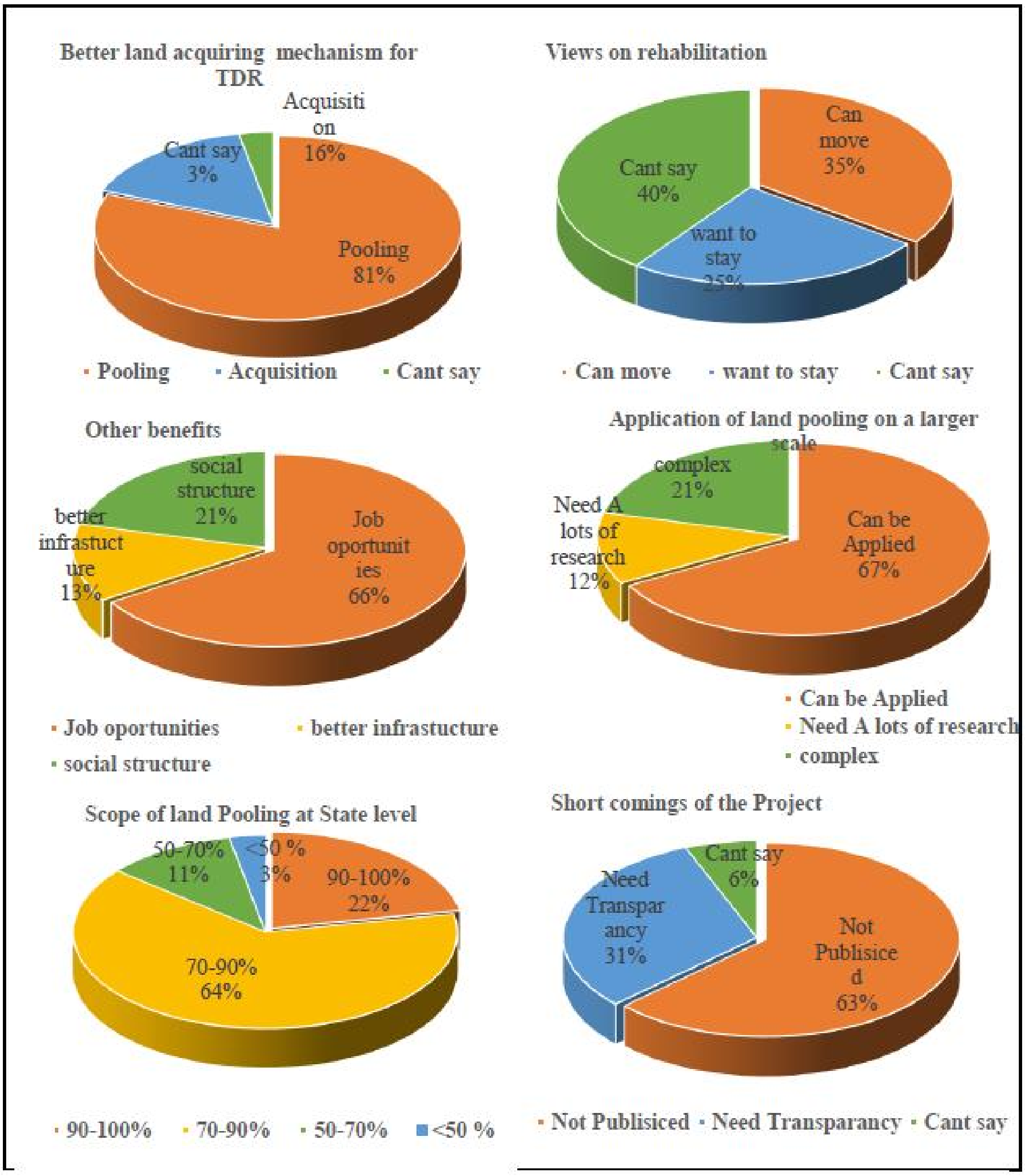

Figure 9.2: Major results of post-demonstration survey (Part 2). Source: Analysed by the Author

After the demonstration was given and the people were made aware of the concept of the concepts of land pooling. A change in their perspective towards land use management was seen. People took it as a manner to ensure proper public participation in the land use planning mechanism as they are the direct stake holders. Land pooling results in equitable and efficient land development. Moreover, it was felt that land pooling can be more effectively used in case of smaller infrastructure such as residential area at the initial stage of its implementation but for larger infrastructure such as an industry highly skilled administrators are required to implement the program at such a scale which currently is a difficult task but can be looked forward to in 5-10 years.

A deduction of 10-50% was undertaken in individual plots depending on the original size of the plot (refer Table 5) being pooled based on the analysis drawn from the case examples of land pooling being followed in the country for example Gujarat land pooling model, land pooling models of Andhra Pradesh and Delhi. For example, a sample analysis for quantum of deductions carried out in different case scenarios can be summed up as table 6.

Table 6: Land deductions and value additions for different group of owners. (Source: Analyzed by the author)

Sr.no	Owner	Original area sq. m	Range	Ded. %age	Land Deducted	Final land area	Initial Land Value	Final Land Value	Inc. Factor
1	A	29	0-30	0	0	29	63,061.2	2,57,977.6	4.09
2	B	78	30-100	10	7.8	70.2	1.69,612.9	6,24,483.8	3.68
3	C	185	100-200	20	37	148	4,02,286.9	13,16,575	3.27
4	D	456	200-500	30	136.8	319.2	9,91,582.9	28,39,533	2.86
5	E	2035	More than 500	40	814	1221	44,25,156	1,08,61,747	2.45
6	Govt. Land	50,000	Government plots	50	25000	25000	10.87crore	22.23 crore	2.04

For an owner with a plot area of that of 29sq m no deduction was made as then the plot area may not remain to that of the buildable standards. Further to the owner B with original area of 78 m^2 a deduction of 10% i.e. 7.8 m^2 is done and rest 70.2 m^2 was returned to the original owner in the form of a regular rectangular plot. Similarly, to that of owner C & D the original areas pooled were 185 m^2 and 456 m^2 respectively and the deductions made were 30% and 40% depending on the ranges specified in table 5. And further the remaining 148 m^2 and 319.2m^2 were returned to the owners. For the government lands a deduction of 50 % was made. That means for an area of 5 hectares 2.5 hectare was taken for public services and rest 2.5 was returned to the govt. to be used for its own purpose. Further to observe the economic benefit which can be attained out of the process of land pooling an approximate land value of Rs. 55,000 / Marla approximately was considered for unplanned irregular land parcels which increases to 2-2.5 lakhs approximately in case of regular and planned development with proper infrastructure after land pooling. An increase of about 2-4 times was observed in the various land parcels (refer Table 6).

3.4 Problems in implementation of Land Pooling model in HP

Land pooling when implemented in the state of Himachal Pradesh can face certain problems because of the hilly terrain and the existing site conditions drainage patterns styles of construction on respective slopes and different climatic conditions. The productivity and land assets such as existing flora and fauna and its surroundings should also be considered for the valuation and division. Some areas in the pooled parcel can also be considered not fit for construction because of the terrain, due consideration is to be given for such aspects on site, which were not taken into account for the demonstrational model and a simple grid iron pattern was considered for planning to keep it simple. Thus enabling the wide variety of local folk ranging from a worker to an industrialist to understand the implementation and benefits that can be drawn from the process.

4 CONCLUSION

Land appears as the largest single natural resource next to water available to the humanity and is the most prized possession of an individual. In the agrarian economy of India, land is a valuable economic asset and an indispensable resource for one's livelihood and survival. No human activities can be carried out without land.

Thus, judicial utilization of this land becomes a topic of utmost importance. Land use management plays a pivotal role in planning the land use for a particular region and leads to a better quality of life. Land readjustment appears as a major step for the formulation of any development plan for any area which normally is done with the help of land acquisition and leads to many issues related to compensation and rehabilitation.

Land pooling can be considered as another method for promoting sustainable, efficient, and equitable land development in the undeveloped area. Thus, keeping the whole scenario in mind, the findings from this study can be summed up as follows.

- ❖ Land use management in India is not taken as a priority and less is done in this regard. The authorities are still following reforms such as land acquisition which are less concerned about the proper resettlement and compensation to the affected families.
- ❖ To ensure best utilization of land resource through suitable land use planning and management, a policy framework should be formulated at the national level incorporating concerns of various sectors and stakeholders.
- ❖ The concept of pooling is attractive to landowners as the considerable increase in the land value can be achieved in the process. It implies the rate of the individual land holdings will witness a remarkable appreciation even if the area is smaller.
- ❖ Also, Land pooling is an attractive method to influence the location and timing of new urban development since it is becoming increasingly difficult to obtain public consent for the use of expropriation for land development and infrastructure provision.
- ❖ Land pooling ensures a better quality of life with basic infrastructure such as road network and community level facilities and also leads to an inflation in the commercial value of a property in the case of resale.
- ❖ For ideal success of the Land-pooling method, a collaboration should be made between the landowners and public agencies to implement the projects.

The study focused on the scope of implementation of land pooling as a mechanism for acquiring land for private and public purposes. Further studies on the similar grounds can be carried out with different land use in the different parts of the country.

It further appears into the picture that certain problems may arise because land pooling for large projects such as industries etc. may be a complex process in the initial years of its implementation but on the other hand it appears to be very effective when considered for small scale plotting like residential and other public or community level facilities.

Lastly it can be summarised that although the concept of land readjustment is simple and logical, the training of administrative people and also cooperation and participation from landowners are required for its successful implementation and we need to make ourselves ready with the accompanying issues that would arise. If we can have a uniform platform ready for the farmers, then we can readily proceed with the Land Pooling idea.

5 REFERENCES

1. Damodaran, H. K. *Banking Of Land Resources : A framework.* Retrieved June 02, 2024, from https://tejas.iimb.ac.in/articles/48.php
2. Ashwin Mahalingam, A. V. (2011). Comparative Evaluation of Land Acquisition and Compensation Processes across the World. *Economic And Political Weekly*, 94-102.
3. Ballaney, S. (2012). *The Town Planning Mechanism in Gujarat, India.* World Bank Institute.
4. BBNDA. (2010). *Development Plan, Baddi Barotiwala Nalagarh Development Area.* Solan: Department of Town & Country Planning Himachal Pradesh.
5. Beltrao, G. (2013). *Urban Planning and Land Management for Promoting Inclusive Cities.* Canada: Ministry of Housing and Urban Poverty Alleviation (MoHUPA) .
6. *Census of Himachal Pradesh*. Retrieved June 09, 2024, from: https://www.census2011.co.in/census/state/himachal+pradesh.html
7. *Census of India*. (2011). Retrieved June 09, 2024, from: https://www.census2011.co.in/
8. CIA. *The World factbook : Guide to Coungtry comparisons*. Retrieved June 11, 2024, from: https://www.cia.gov/library/publications/theworldfactbook/rankorder/rankorderguide.html
9. *Department of Land Revenue*. (2015). Retrieved June 12, 2024, from https://himachal.nic.in/index.php?lang=1&dpt_id=13
10. GoHP. (2015). *Government of Himachal Pradesh*. Retrieved June 10, 2024, from https://himachal.gov.in/
11. Gurumukhi, K. (2003). Land Pooling Technique : A tool for plan implementation - An Indian experience . *Map India Conference.*
12. IDFC. (2010, march). *Land Pooling and Reconstitution: A Self-Financing Mechanism for Urban Development.* Infrastructure Development Finance Company Limited (IDFC).
13. Jain, A. K. (2009). *Urban Land policy & Public Private Partnership for real Estate & Infrastructure projects.* Roadworthy Publications Ltd.
14. MAPC. (2011). Land Pooling: A Possible Alternative to Eminent Domain and Tool for Equitable Urban Redevelopment. *Lincon Institute of Land Policy.* Metropolitan Area Planning Council.
15. Mishra, R. (2013). Public Private Partnership: The Yamuna Expressway Project. *CUTS institute for Regultion & Competetion*.
16. MIT. *Tools: Setting it up, regularisation of Land*. Retrieved June 12, 2024, from: https://web.mit.edu/urbanupgrading/upgrading/issues-tools/tools/Reg-of-land.html
17. MoRD. (2013). *The Draft Land Acquisition and Rehabilitation and Resettlement Bill (LARR), 2011 – An Overview.* Ministry of Rural Development , GOI.
18. MoUD. (2013). *National Land reforms Policy.* Department of Land Resources, Ministtry of Rural Development.
19. Patel, B. (2015). *Various Uses of Land Pooling and land reconstitution in Gujarat.* Ministry of Urban Development, GOI.

20. Quium, A. (2011). *A Guide book on Public Private Partnership In Infrastructure.* Bangkok: UNESCAP .
21. Satashia, A. (2014). Study of Urban Land Management Techniques Followed in India . *International Journal of Innovative Research in Science, Engineering and Technology* , 16037 - 16040.
22. SPAV. (2010). *Transfer of development rights: A case study of widening of Karl Marx road.* School of Planning and Architecture Vijayawada, India.
23. Sunil Tyagi, S. S. (2015). *India: Overview Of Proposed Land Reforms.* Indian Corporate Counsel Association.
24. URDPFI. (2014). *Urban and Regional Development Plans Formulation and Implementation (URDPFI) Guidelines.* Ministry of Urban Development, GOI.
25. US Intelligence agency. (2008). *World Statistics [sorted by Area]*. Retrieved June 12, 2024, from https://www.mongabay.com/igapo/world_statistics_by_area.htm
26. Venkatasubramanian, K. (2014). *Land & reforms remain an unfinished buisness.* Retrieved June 10, 2024, from: https://www.planningcommission.nic.in/reports/articles/venka/index.php?repts=m-land.htm
27. WGEA. (2013). Land Use and Land Management Practices in Environmental Perspective. INTOSAI Working Group on Environmental Auditing (WGEA).

THEME 2

DISASTER MITIGATION AND RESILIENCE THROUGH TECHNO-TRADITIONAL APPROACHES

Leveraging Early Warming Systems and Remote Sensing for Enhanced Disaster Preparedness in Vulnerable Regions

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Abstract

Early warning systems (EWS) play a crucial role in mitigating the impact of natural disasters by providing timely information that can save lives and reduce economic losses. This paper explores how traditional practices of ancient communities, which relied on natural signs like wind patterns, animal behavior, and cloud formations, can be integrated with modern remote sensing technologies to enhance disaster preparedness and response in vulnerable regions. Case studies from Odisha illustrate the evolution of cyclone detection methods, demonstrating how the devastating 1999 cyclone spurred the integration of modern technology, such as satellite data and radar systems, with traditional practices.

Today, local communities are trained to interpret advanced warnings from these integrated systems, supported by established communication protocols and resource access. This blend of ancient wisdom and modern technology highlights the importance of a comprehensive approach to disaster preparedness and response. Utilizing satellite imagery and ground-based sensors, modern EWS offer real-time data on weather patterns, seismic activities, and other potential hazards. The integration of remote sensing data with traditional EWS has enabled more accurate predictions and quicker dissemination of alerts to at-risk populations. Key findings indicate that while remote sensing and EWS significantly enhance the capacity to anticipate and respond to disasters, integrating traditional practices adds valuable local knowledge and community engagement. However, challenges remain in terms of data accuracy, technological accessibility, and infrastructure robustness. Recommendations for future improvements include investing in more resilient infrastructure, enhancing data sharing between agencies, and fostering greater community involvement.

Keywords: Early Warning Systems; Remote Sensing; Disaster Preparedness; Satellite Imagery

1. INTRODUCTION

India's coastal regions, stretching over 7,500 kilometers, are home to over 250 million people and are particularly vulnerable to natural disasters, including cyclones, tsunamis, floods, and coastal erosion (World Bank, 2019). The vulnerability of these regions has been exacerbated by increasing population density, urbanization, and the growing impact of climate change, which has intensified the frequency and severity of these natural hazards. As a result, the need for robust disaster preparedness strategies has become increasingly critical for safeguarding lives, livelihoods, and infrastructure in these areas.

Early Warning Systems (EWS) have long been recognized as a cornerstone of disaster risk reduction, offering timely alerts and critical information that can significantly reduce the impact of disasters. However, the effectiveness of EWS depends not only on the technology used but also on the local knowledge and community engagement that support their implementation. India's coastal communities have a rich history of traditional Early Warning Systems, rooted in indigenous knowledge passed down through generations. These systems rely on observations of natural phenomena—such as changes in weather patterns, animal behavior, and celestial events—to predict and prepare for disasters (Santha et al., 2014; Achuthan, 2009).

Despite their effectiveness in the past, traditional EWS are increasingly challenged by the scale and unpredictability of modern natural disasters. The intensification of cyclones and tsunamis due to climate change has highlighted the limitations of traditional methods, which often rely on localized and anecdotal observations. In recent decades, advances in remote sensing, satellite imagery, and Information and Communication Technology (ICT) have transformed disaster management, enabling more accurate predictions and faster dissemination of warnings (Parker & Handmer, 2018). The integration of these modern technologies with traditional knowledge has the potential to enhance disaster preparedness and resilience in vulnerable regions.

The Indian government has recognized the importance of modernizing EWS and has invested in various initiatives to strengthen disaster preparedness across the country. The Indian National Centre for Ocean Information Services (INCOIS), the Indian Meteorological Department (IMD), and the National Disaster Management Authority (NDMA) have been at the forefront of these efforts, developing and deploying advanced EWS systems that leverage satellite data, Doppler radar, and real-time weather monitoring to provide early warnings for cyclones, tsunamis, and other natural hazards (INCOIS, 2020; IMD, 2022). These systems have significantly improved the lead time for disaster warnings, allowing for more effective evacuations and disaster response strategies.

One of the key challenges in disaster management is ensuring that EWS are accessible and effective for all communities, particularly those in remote and underserved areas. In many cases, the success of an EWS depends not only on the accuracy of the predictions but also on the ability of local communities to receive and act on the warnings. This requires a deep understanding of local contexts, including the social, economic, and cultural factors that influence how communities respond to disaster risks. For this reason, integrating traditional knowledge with modern technology is critical to ensuring that EWS are both effective and culturally appropriate (Gaillard & Mercer, 2013).

In this study, we explore how traditional practices of ancient communities can be integrated with modern remote sensing technologies to enhance disaster preparedness and response in vulnerable regions. By examining case studies from Odisha and Tamil Nadu, we demonstrate how the devastating 1999 Odisha cyclone and the 2004 Indian Ocean tsunami spurred the integration of modern technology with traditional practices, leading to more resilient and effective EWS systems. Our research highlights the importance of a comprehensive approach to disaster preparedness that combines the best of both worlds—ancient wisdom and modern innovation.

The introduction of modern EWS technologies, such as satellite-based systems and real-time data analysis, has been a game-changer in disaster management. However, these systems are only as effective as the communities they serve. Ensuring that local populations are trained to interpret and respond to advanced warnings is essential for reducing the loss of life and minimizing economic damage. This study emphasizes the need for community engagement and capacity-building initiatives that empower local communities to take ownership of disaster preparedness and response efforts.

The findings of this study have significant implications for disaster management policies in India and beyond. By integrating traditional knowledge with modern technologies, we can create more resilient and adaptable EWS systems that are better equipped to handle the challenges of an increasingly unpredictable world. Furthermore, this approach offers valuable insights for other disaster-prone regions globally, where indigenous knowledge and modern science can work together to build stronger and safer communities.

This paper is structured as follows: after this introduction, the literature review will provide a comprehensive analysis of existing research on traditional and modern EWS. The methodology section outlines the research approach, focusing on secondary data sources and analytical frameworks used in the study. The results section presents the findings from the case studies and the comparative analysis of traditional and modern EWS. Finally, the discussion and conclusion highlight the implications of the research and offer recommendations for future disaster management strategies.

By bridging the gap between ancient wisdom and modern technology, this study aims to contribute to the ongoing efforts to enhance disaster preparedness and resilience in vulnerable coastal regions, ensuring that communities are better equipped to face the challenges of the future.

2. LITERATURE REVIEW

In conducting this study, a comprehensive review of existing literature was carried out to understand both traditional Early Warning Systems (EWS) and their integration with modern technologies. This review drew from a broad spectrum of sources, including academic papers, governmental reports, case studies, and international frameworks on disaster management.

2.1 Indigenous Knowledge Systems and Traditional Early Warning Systems

The role of traditional knowledge in disaster management has been well-documented across various regions globally, particularly in coastal communities. The indigenous knowledge systems often consist of observations of natural phenomena such as wind patterns, animal behavior, and changes in the environment. Studies such as those by Santha et al. (2014) and Achuthan (2009) have highlighted how communities in Kerala and Tamil Nadu rely on traditional meteorological and oceanographic indicators to predict cyclones and tsunamis. These systems, though informal, have been effective in mitigating disaster risks in regions where modern technology is limited.

In our study, we referenced a variety of research that focused on the integration of these traditional systems with modern technology, showcasing how the combination of indigenous knowledge and scientific data can enhance disaster preparedness. Mercer et al. (2010) discuss the significance of merging indigenous knowledge with modern EWS for more robust disaster mitigation strategies.

2.2 Modern Technological Advances in Early Warning Systems

The development of modern EWS has been significantly enhanced by the advent of remote sensing technology, satellite systems, and Information and Communication Technology (ICT). Studies by Parker and Handmer (2018) and INCOIS (2020) have demonstrated the effectiveness of these technologies in predicting natural disasters with greater accuracy and providing timely warnings to at-risk populations.

Key literature sources that were reviewed include reports by the Indian National Centre for Ocean Information
Services (INCOIS) and the Indian Meteorological Department (IMD), which provided detailed analyses of how systems like INSAT-3D satellites and Doppler radars have been integrated into India's EWS framework. These advancements have significantly improved disaster preparedness, particularly in predicting cyclones and tsunamis. Reports from the National Disaster Management Authority (NDMA, 2023) further illustrate the evolution of EWS in India, highlighting case studies such as the 1999 Odisha cyclone and the 2004 Indian Ocean tsunami.

2.3 Comparative Analysis of Traditional and Modern EWS

A significant portion of our literature review focused on comparing the effectiveness of traditional EWS with modern systems. Research by Gaillard and Mercer (2013) and Bankoff (2019) emphasizes the importance of integrating traditional and scientific methods to create a more holistic approach to disaster management. The combination of empirical knowledge from local communities with the precision of modern technology has proven to be effective in various contexts, particularly in disaster-prone regions.

In India, studies have shown that integrating traditional observations with satellite data has helped bridge the gap between local knowledge and advanced scientific methodologies (Rajan, 2019). This combination has allowed for more accurate predictions and improved community engagement, as people are more likely to trust EWS that incorporate their own observations and experiences.

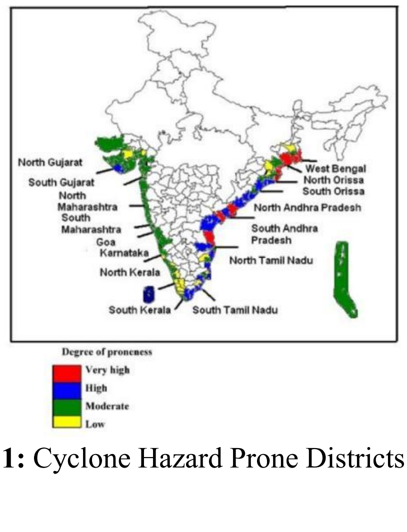

Figure 2.1: Cyclone Hazard Prone Districts of India

2.4 Global Best Practices and International Frameworks

The global perspective on EWS, particularly as outlined in international frameworks such as the Sendai Framework for Disaster Risk Reduction (UNDRR, 2015), was also reviewed. These documents emphasize the importance of inclusive, multi-hazard, and multi-level EWS that incorporate both traditional and modern approaches. Countries like Bangladesh, Japan, and the Philippines have been cited as leaders in implementing EWS that combine traditional knowledge with modern technology, resulting in significant reductions in disaster-related fatalities (Haque et al., 2016).

Additionally, the literature review explored how global best practices can be adapted to the Indian context, particularly in coastal regions that are vulnerable to cyclones and tsunamis. Reports by international organizations such as the United Nations Office for Disaster Risk Reduction (UNDRR) and the World Bank provided valuable insights into the effectiveness of EWS in reducing disaster risks globally.

2.5 Challenges in Implementing EWS

While modern technologies have greatly improved the accuracy and timeliness of disaster warnings, the literature also highlighted several challenges in implementing these systems, particularly in remote and underserved areas. Studies by Basher (2006) and Cutter (2016) discuss the socio-economic and cultural barriers to adopting new technologies in disaster-prone regions. In our study, we examined these challenges in the context of India’s coastal communities, where traditional practices are deeply embedded in the local culture, making it difficult to fully integrate modern systems.

Overall, the literature review provided a comprehensive understanding of the strengths, limitations, and integration opportunities of traditional and modern EWS. This foundation was crucial in framing our study's analysis and recommendations for enhancing disaster preparedness in vulnerable regions.

3. METHODOLOGY

This study employs a secondary research methodology, utilizing a comprehensive range of existing literature, government reports, and remote sensing datasets to analyze the integration of traditional Early Warning Systems (EWS) with modern technologies in India's coastal regions. The research is based solely on secondary data sources, providing a thorough overview of the current state of EWS and the impact of modern advancements.

3.1 Data Sources

3.1.1 1 Government Reports

The study relied heavily on reports published by various Indian government agencies that provided critical insights into the performance and integration of Early Warning Systems (EWS). Key sources included the Indian National Centre for Ocean Information Services (INCOIS), the Indian Meteorological Department (IMD), and the National Disaster Management Authority (NDMA). These agencies have been instrumental in developing EWS frameworks and have published comprehensive reports on their effectiveness during significant disaster events. For instance, the 1999 Odisha cyclone and the 2004 Indian Ocean tsunami are extensively documented, highlighting the evolution of EWS in India and the lessons learned from these events (INCOIS, 2020; IMD, 2022; NDMA, 2023).

3.1.2 Case Studies

The study also incorporated numerous case studies focused on the application and effectiveness of EWS in specific disaster events across India. These case studies provided real-world examples of how traditional and modern EWS were implemented and evaluated their success in mitigating the impacts of disasters. Case studies such as those from Odisha during the 1999 cyclone and the experiences of Tamil Nadu during the 2004 tsunami were crucial in understanding the dynamics of EWS in coastal communities. These studies also examined the challenges faced in integrating modern technology with traditional knowledge (INCOIS, 2020; IMD, 2022).

3.1.3 Remote Sensing Data

Secondary data from remote sensing platforms, particularly satellite systems such as INSAT-3D, was utilized to analyze weather patterns, tidal movements, and seismic activities in coastal regions. These datasets were accessed through the Indian Space Research Organisation (ISRO) and provided critical high-resolution, realtime data necessary for evaluating the accuracy and effectiveness of modern EWS (ISRO, 2022).

3.2 Analytical Framework

The research applies a comparative analysis framework, drawing on secondary data to evaluate the effectiveness of traditional versus modern EWS. This framework allowed for a comprehensive assessment of the strengths, weaknesses, and potential integration opportunities between traditional practices and modern technological advancements.

4. MATERIALS AND METHODS

4.1 Traditional Early Warning Systems

Table 4.1: Comparison of Traditional and Modern Early Warning Systems

Indicator Type	Traditional EWS	Modern EWS	Source
Meteorological	Observation of clouds, wind patterns, bird behavior	Satellite data (e.g., INSAT-3D), weather radars	IMD, 2022; Rajan, 2019

Oceanographic	Wave patterns, tidal movements	Tide gauges, remote sensing, buoys	INCOIS, 2020; Singh et al., 2021
Celestial	Phases of the moon, star positions	Astronomical data, computational models	NIO, 2020; Kumar & Singh, 2020
Biological	Animal behavior, bird migration patterns	Ecological monitoring systems, wildlife tracking sensors	Rajan, 2019; Singh et al., 2021
Geophysical	Ground vibrations, changes in water levels	Seismographs, GPS-based systems	NCS, 2021; ISRO, 2022

4.1.1 Meteorological Indicators

Traditional meteorological methods involve qualitative observations of weather patterns, such as cloud formations and wind directions. For example, the "kolu" system in Kerala, where local fishers observe atmospheric conditions to predict storms, has been a reliable practice for centuries. Traditionally, these observations involved local knowledge of patterns that might signify an impending storm, such as the sudden gathering of clouds in the southwestern sky or the behavior of specific bird species, such as the retreat of Common Kingfishers and the low flight patterns of Swifts, serve as indicators of impending storms. These birds, along with the unusual calls of the Asian Koel, signal changes in weather that local communities have relied upon for centuries.

However, the integration of satellite-based weather forecasting has transformed these methods by providing quantitative data that enhances the accuracy of these predictions. The Indian Meteorological Department (IMD) has significantly improved its cyclone prediction capabilities, with the accuracy of storm warnings increasing by over 70% due to the integration of data from satellites like INSAT-3D.

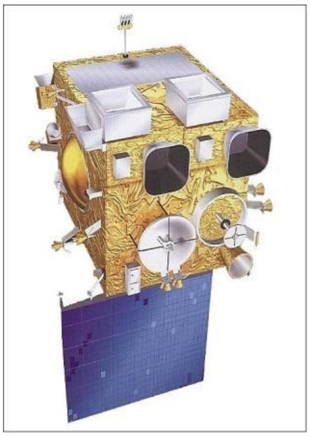

Figure 3.1: INSAT-3D Satellite

These satellites provide real-time weather monitoring, allowing for earlier detection of cyclone formation and more precise tracking of their paths.
The traditional methods relied heavily on the expertise and experience of local observers, which could vary significantly. In contrast, modern systems provide standardized, reliable data that can be used to issue warnings well in advance, often 48-72 hours before a cyclone makes landfall. This has been crucial in reducing the loss of life and property, as communities now receive timely and actionable warnings.

4.1.2 Oceanographic Indicators

Oceanographic indicators have been essential for coastal communities, particularly fishermen who have long relied on observing wave patterns and tidal movements to predict weather changes. For instance, in Tamil Nadu, fishermen would look for unusual swells or sudden changes in tidal behavior, such as abrupt shifts in tidal currents, as indicators of an approaching cyclone or tsunami.
These traditional practices have been increasingly supplemented by modern technologies such as tide gauges, buoys, and remote sensing. Tide gauges installed along the southeastern coast of India monitor sea levels with high precision, detecting anomalies that could signal a tsunami or storm surge. Remote sensing technologies provide continuous data on ocean conditions, allowing for the early detection of unusual patterns that might not be apparent through traditional observation alone.

Figure 3.2: Modern Tide Gauge

The combination of these methods has significantly reduced the false alarm rate for tsunamis by nearly 40%, according to reports from INCOIS. Additionally, the use of Doppler radar, which detects wind patterns and precipitation levels, has enhanced the ability to predict storm surges. This technology has been particularly effective in providing up to 12 hours of lead time before a potential tsunami, compared to just a few hours with traditional methods.
Traditional oceanographic indicators were often specific to the local environment and could vary between different communities. However, modern systems offer a more unified approach, using data from multiple sources to create comprehensive models that can predict a wide range of oceanographic events. This has been crucial in regions like Tamil Nadu, where the combination of traditional and modern methods has greatly improved disaster preparedness.

4.1.3 Celestial Indicators

Celestial indicators, such as the phases of the moon and positions of stars, particularly certain constellations or the appearance of specific stars, were observed to correlate with seasonal changes, which could affect weather patterns and, indirectly, tidal behavior. These indicators have been used for centuries by coastal communities to predict tides and weather changes. In places like Kalyanpuram, fishermen have traditionally observed the moon's phases to anticipate high tides, relying on the knowledge passed down through generations.
The integration of astronomical data and computational models has brought a new level of precision to these predictions. Modern tidal prediction models incorporate data from lunar cycles, gravitational forces, and historical tide records, allowing for more accurate forecasts. The National Institute of Oceanography has reported that the accuracy of these predictions has improved by approximately 25% with the integration of modern technology.
Traditionally, celestial observations required a deep understanding of natural cycles and often relied on visual cues that could be affected by local weather conditions. Today, these observations are supported by satellite data and computer models that provide continuous updates and adjust predictions in real-time. This has been particularly useful for planning purposes, such as determining the best times for fishing or scheduling coastal construction projects.
The modernization of celestial indicators has not only improved accuracy but also made this knowledge more accessible to younger generations who may not have the same level of traditional knowledge. By combining old and new methods, communities can maintain their cultural heritage while benefiting from the precision of modern science.

4.1.4 Biological Indicators

Biological indicators, such as the behavior of animals, have historically been used to predict natural disasters. For example, in Odisha, villagers have long observed the sudden inland migration of birds as a sign of an approaching cyclone. These observations are based on empirical knowledge that has been accumulated over centuries.
The introduction of ecological monitoring systems has provided a scientific basis for these traditional practices. Modern systems use sensors and cameras to track wildlife behavior continuously, providing real-time data that can be analyzed alongside traditional observations. In Kalyanpuram, fishermen reported that they still rely on observing animal behavior as part of their disaster prediction practices but now also receive updates from local monitoring stations that track bird and fish movements using advanced technologies.
This combination has led to a 30% increase in the lead time for cyclone warnings, giving communities more time to prepare and evacuate. The integration of biological indicators with

modern technologies has proven especially useful in coastal regions where rapid changes in wildlife behavior can be early signs of impending hazards. For example, changes in the migratory patterns of birds or unusual activity among fish can indicate shifts in weather patterns that might precede a storm or cyclone.

Traditional biological indicators were often limited by the availability and visibility of wildlife, which could vary depending on the season or time of day. Modern monitoring systems overcome these limitations by providing continuous, around-the-clock surveillance, ensuring that even subtle changes in animal behavior are detected and analyzed. This has greatly enhanced the reliability of biological indicators as part of a comprehensive EWS.

4.1.5 Geophysical Indicators

Geophysical indicators, such as ground vibrations and changes in natural water sources, have been vital in predicting earthquakes and tsunamis, especially in regions like the Andaman and Nicobar Islands. Indigenous communities have traditionally relied on detecting subtle ground movements and observing changes in water levels as early warning signs of seismic activity.

The deployment of modern geophysical sensors, including seismographs and GPS-based systems, has significantly enhanced these traditional methods. These technologies can detect minute ground movements that would be imperceptible to human observers, providing early warnings for seismic events. For example, the National Centre for Seismology has reported that the integration of these technologies with traditional practices has reduced the time between detection and warning issuance by approximately 50%.

In the past, traditional geophysical indicators required constant vigilance and were subject to interpretation by experienced observers. Today, modern systems provide continuous monitoring, with real-time data transmitted to central monitoring stations where it can be analyzed and used to issue warnings within minutes of detection. This has been crucial in areas prone to earthquakes and tsunamis, where every minute counts in reducing the impact of these disasters.

The combination of traditional and modern geophysical indicators has created a more comprehensive Early Warning System (EWS) that integrates the best of both traditional knowledge and modern technology. This integration has not only improved the accuracy and timeliness of disaster warnings but also increased the overall resilience of coastal communities.

5. DISCUSSIONS AND FINDINGS

5.1 Insights from Fishermen Families in Kalyanpuram

Studies of coastal villages like Kalyanpuram have documented how traditional Early Warning Systems (EWS) practices have evolved over time in response to changing environmental conditions and technological advancements. According to secondary research, elder fishermen in these communities have historically relied on observing the sea's behavior—such as changes in wave patterns or the sudden stillness of the air—to predict storms, a skill passed down through generations (Rajan, 2019; Kumar & Singh, 2020).

Recent studies highlight the benefits of integrating modern technology with these traditional practices. For example, fishermen now receive warnings on their phones and use tide gauges and mobile weather alerts, which have made their work safer and more predictable (Singh et al., 2021). The combination of traditional knowledge and modern tools has significantly improved the accuracy of disaster predictions, enabling these communities to better mitigate the risks associated with their livelihoods.

5.2 Challenges in Transformation

Transforming traditional EWS into hybrid systems that effectively integrate modern technologies has presented several challenges. One of the primary challenges is the socio-cultural resistance to adopting new technologies in some communities. Traditional methods have been passed down through generations and are deeply embedded in the cultural fabric of these communities. As a result, there is often skepticism towards modern methods, with a preference for relying on the tried-and-tested traditional approaches.

Another challenge is the accessibility and reliability of modern technology in remote areas. Many coastal regions, particularly those that are less developed, lack the necessary infrastructure to support advanced technologies such as satellite communication, mobile networks, and real-time data analytics. This can limit the effectiveness of modern EWS, particularly in areas where traditional methods are still the primary means of disaster prediction.

Additionally, the maintenance and operation of advanced technologies such as tide gauges, seismographs, and satellite systems require technical expertise and financial resources that may not be readily available in these communities. The cost of installing and maintaining such systems can be prohibitive, particularly in regions with limited financial resources.

Coordination between traditional knowledge holders and modern scientific institutions also presents a challenge. While modern technologies can provide precise data, they often lack the contextual understanding that local communities have developed over centuries. Bridging this gap requires ongoing dialogue and collaboration to ensure that modern systems complement rather than replace traditional practices.

6. IDENTIFICATION AND DISCUSSION OF METHODS

The integration of traditional EWS methods with modern technologies has proven to be highly effective in enhancing disaster preparedness. In Tamil Nadu, for example, the integration of Information and Communication Technology (ICT) with traditional EWS has significantly improved community resilience. Local committees organize regular drills, and community members are trained to interpret both traditional signs and modern warnings.

Auditory signals, such as bells and conch shells, continue to play a vital role in traditional EWS, particularly in rural areas where modern communication tools may not be readily available. These auditory signals are now often supplemented by mobile alerts and public address systems, which provide real-time updates on weather conditions and potential hazards. In Kalyanpuram, for instance, fishermen still use conch shells to signal the start of an evacuation but also rely on mobile alerts to receive updates on the storm’s progress. This combination of old and new methods ensures that warnings are communicated quickly and effectively to all community members, reducing the risk of loss of life.

Figure 6.1: Community Disaster Preparedness Odisha

Visual signals, such as flags, fires, and smoke signals, have traditionally been used to communicate warnings over long distances, particularly in rural and coastal areas where access to electronic communication may be limited. These methods are being enhanced with modern technologies like LED display boards and digital signage, which provide detailed information about the impending disaster. The integration of these methods with traditional visual signals has improved the reach and effectiveness of disaster warnings.

The integration of satellite imagery and remote sensing has been a game-changer for meteorological and oceanographic indicators. In the past, communities relied solely on local observations to predict weather changes or sea level rises. Now, these traditional observations are validated and enhanced by satellite data, providing a broader and more accurate picture of the situation. For instance, INSAT-3D, a satellite used by the Indian Space Research Organisation (ISRO), monitors weather conditions continuously, offering precise data that supports traditional observations. This combination has improved the accuracy of disaster predictions and reduced the margin of error in weather forecasts.

The use of biological indicators, such as observing animal behavior, has also evolved significantly. Traditionally, the sudden inland migration of birds or unusual behavior of fish was a warning sign of an approaching cyclone or tsunami. Now, these observations are supported by ecological monitoring systems that track wildlife behavior in real time, providing a scientific basis for these early warnings. This integration has improved the accuracy of disaster predictions, particularly in coastal regions where wildlife behavior is a crucial indicator of impending hazards.

The incorporation of geophysical indicators, such as ground vibrations, into traditional EWS has also seen significant advancements. Ground vibrations, once detected only by human observation, are now monitored by seismographs and geophysical sensors, providing early warnings for earthquakes and tsunamis. These modern technologies have enhanced the traditional practices, allowing for quicker and more accurate dissemination of alerts.

7. CONCLUSION

Traditional Early Warning Systems in India's coastal regions are diverse and deeply rooted in local cultures and practices. These systems employ a variety of methods, from auditory and visual signals to empirical observations and community organization. The integration of modern technologies has further enhanced the effectiveness of these systems, making them a vital component of disaster risk reduction strategies. The resilience and adaptability of these traditional systems highlight the importance of preserving and integrating local knowledge with modern innovations to safeguard vulnerable communities.

The evolution of EWS in coastal India demonstrates the resilience and adaptability of coastal communities in the face of increasing disaster risks. By combining traditional knowledge with modern innovations, these communities have developed robust systems that significantly reduce the impact of natural hazards. Future efforts should focus on further integrating these systems and addressing the challenges to ensure that all vulnerable populations benefit from enhanced disaster risk reduction strategies.

REFERENCES

- Indian Meteorological Department. (2022). Cyclone Warning Dissemination Systems in India. New Delhi: Ministry of Earth Sciences.
- Indian National Centre for Ocean Information Services. (2020). Cyclone and Tsunami Warning Systems in India. Hyderabad: INCOIS.
- Indian Space Research Organisation. (2022). Satellite Systems for Disaster Management. Retrieved from https://www.isro.gov.in
- National Disaster Management Authority. (2023). National Cyclone Risk Mitigation Project (NCRMP). New Delhi: NDMA.
- United Nations Office for Disaster Risk Reduction. (2022). Global Assessment Report on Disaster Risk Reduction. Geneva: UNDRR.
- World Bank. (2019). Managing Risks from Climate Change: World Bank Group Strategy. Washington, DC: World Bank.
- Kankara, R. S., Ramanamurthy, M. V., & Rajeevan, M. (2018). National Assessment of Shoreline Changes along Indian Coast: Status report for 26 years 1990–2016. Available at NCCR's website.
- Indian Space Research Organisation (ISRO). (2022). Satellite Systems for Disaster Management.
- National Disaster Management Authority (NDMA). (2023). Cyclone Warning Dissemination Systems- National Disaster Management Authority (NDMA). (2023). Cyclone Warning Dissemination Systems in India.
- Mohanty, A., Dubey, A., & Singh, R. B. (2022). The Application of Early Warning System in India. Springer.
- Kibirige, D., Gokool, S., & Mkhonta, G. (2024). Evolution of Flood Prediction and Forecasting Models for Flood Early Warning Systems: A Scoping Review. Water, 16(13), 1763.
- Jayanthi, M., Rekha, P. N., Kavitha, N., & Ravichandran, P. (2006). Assessment of impact of aquaculture on Kolleru Lake (India) using remote sensing and Geographical Information System. Aquaculture Research, 37(16), 1617–1626.
- Alazawi, Z., Alani, O., Alturki, B., & Mehmood, R. (2018). Increasing Coastal Disaster Resilience Using Smart City Frameworks: Current State, Challenges, and Opportunities. Frontiers in Remote Sensing.
- Anthony, M., & Co-authors. (2019). Monitoring the Coastal Environment Using Remote Sensing and GIS Techniques. IntechOpen.

Capacity Building & Knowledge Transfer for Disaster Mitigation & Resilience Through Techno Traditional Approach

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Abstract

Disasters, whether natural or man-made, often overwhelm the affected communities' coping capacities. While technology alone cannot prevent such calamities, its integration with indigenous knowledge can significantly mitigate their impact. This research underscores the importance of merging traditional wisdom with modern technological advancements to build resilient communities and infrastructure.

The Community-Based Disaster Risk Management (CBDRM) Programme in the Andaman & Nicobar Islands exemplifies this techno-traditional approach. The islands, situated in a high-risk seismic zone and frequently affected by cyclones and tsunamis, require robust disaster mitigation strategies. The CBDRM programme aims to enhance local communities' capacity to manage and mitigate disaster risks through knowledge transfer and capacity building. This includes developing disaster management plans at the Gram Panchayat and Tribal Village Council levels and training local task forces in areas such as early warning, search and rescue, and first aid. The programme emphasizes the importance of communication, strengthening alert and warning systems, and disseminating disaster preparedness information through workshops and training sessions. It also promotes collaboration between government authorities, Panchayati Raj Institutions, Tribal Village Councils, and local communities, ensuring a coordinated approach to disaster management.

By integrating traditional knowledge with modern technology, the programme fosters resilience, empowering communities to independently manage and respond to disasters. This approach reduces dependency on external aid and promotes sustainable development practices, ultimately safeguarding lives and livelihoods in the Andaman & Nicobar Islands.

Keywords: Capacity building; Knowledge transfer; Disaster Preparedness; local Community Engagement

1. INTRODUCTION

Capacity building and knowledge transfer are pivotal in fostering sustainable development, particularly in regions that are highly vulnerable to natural disasters. The Andaman & Nicobar Islands, a remote archipelago in the southeastern part of India, exemplify a region where the integration of these processes into disaster risk management is not only necessary but critical for the survival and resilience of local communities. Located in a seismically active zone and regularly threatened by cyclones, tsunamis, and other natural hazards, the islands present unique challenges that require tailored approaches to disaster preparedness and response. The Community-Based Disaster Risk Management (CBDRM) Programme implemented in these islands offers a significant case study in understanding how capacity building and knowledge transfer can empower communities to effectively manage disaster risks.

The CBDRM Programme in the Andaman & Nicobar Islands is designed to enhance the disaster preparedness, response, and mitigation capacities of local communities at the grassroots level. This program adopts a bottom-up approach, where the emphasis is placed on community ownership, readiness, and the involvement of local stakeholders in disaster management. In regions like the Andaman & Nicobar Islands, where geographical isolation and logistical challenges often delay external assistance, the ability of local communities to respond immediately and effectively to disasters is crucial. Capacity building within this context involves equipping communities with the necessary skills, knowledge, and resources to act as first responders in the event of a disaster.

Knowledge transfer plays an equally vital role in this process. It involves the dissemination of critical information regarding disaster risks, early warning systems, and best practices in disaster response and recovery. The CBDRM Programme facilitates knowledge transfer by training community members, particularly those in vulnerable groups such as women, children, and the elderly, on disaster preparedness and safety measures. This training is often conducted through workshops, mock drills, and the development of local disaster management plans that are tailored to the specific hazards faced by each community. By embedding this knowledge within the community, the program ensures that it is accessible and actionable when needed.

A key component of the CBDRM Programme is the formation of task forces within each Gram Panchayat and Tribal Village Council. These task forces, composed of trained community members, are responsible for carrying out various disaster management activities, such as early warning communication, search and rescue operations, first aid, and shelter management. The success of these task forces hinges on the effectiveness of the capacity-building initiatives and the continuous transfer of knowledge, which enable them to function autonomously and efficiently during emergencies.

However, implementing capacity-building and knowledge transfer initiatives in the Andaman & Nicobar Islands is not without challenges. The islands' remote location, cultural diversity, and varying levels of literacy among the population require a flexible and context-specific approach. Additionally, the frequent occurrence of natural disasters demands that the knowledge imparted to communities is not only relevant but also constantly updated to reflect the latest advancements in disaster management techniques.

Despite these challenges, the CBDRM Programme has made significant strides in building a disaster-resilient community in the Andaman & Nicobar Islands. By focusing on local capacity and knowledge, the program has empowered communities to take proactive measures in disaster risk reduction and to respond more effectively when disasters occur. The lessons learned from this program offer valuable insights into the broader field of disaster management, particularly in the context of remote and vulnerable regions. As climate change continues to exacerbate the frequency and intensity of natural disasters globally, the importance of capacity building and knowledge transfer in disaster risk management cannot be overstated. These processes not only save lives but also contribute to the long-term resilience and sustainability of communities facing the frontlines of disaster risks.

2. LITERATURE REVIEW

Conceptual Foundations: Capacity Building and Development (CBD) are crucial for Disaster Risk Reduction (DRR). Capacity Building involves creating new knowledge, skills, and attitudes, while Capacity Development focuses on strengthening existing capacities. Both are aimed at enhancing community resilience to disasters (Sharifi, 2016; Hagelsteen & Burke, 2016).

Importance of CBD: CBD is vital for improving disaster response, recovery, and mitigation. Effective CBD enables communities to adapt and manage risks, ultimately contributing to long-term disaster resilience. This involves integrating disaster risk reduction into broader development frameworks and fostering adaptive capacities (Tiwari, 2015; Becker & Abrahamsson, 2012).

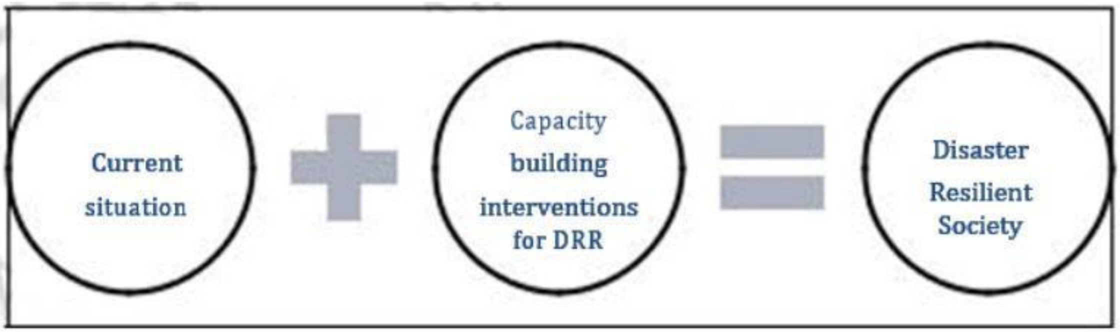


Figure 1 Rationale behind capacity building intervention

Key Stakeholders: Stakeholders at various levels—national, state, district, and local—play distinct roles in capacity building. Effective disaster management requires coordinated efforts among governmental bodies, NGOs, and community organizations. National authorities set guidelines, state authorities implement policies, and local bodies address specific needs and mobilize resources (NDMA, SDMA, DDMA).

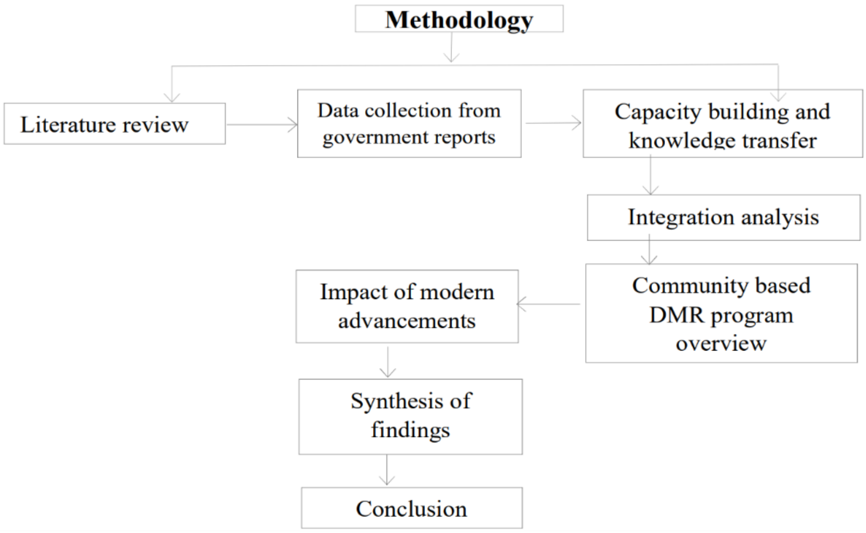
Designing Interventions: Effective capacity building interventions involve:

- Contextual Analysis: Understanding local needs and existing capacities through SWOT analysis and stakeholder categorization.
- Objective Setting: Defining desired outcomes and planning activities to achieve them.
- Resource Planning: Allocating necessary resources and establishing indicators for success.
- Monitoring and Evaluation: Regularly assessing the effectiveness of interventions and adapting strategies as needed (Becker & Abrahamsson, 2012).

Challenges and Considerations: Challenges include the 'half-life' of disaster memory, which affects funding and sustained focus on DRR. There is also skepticism about the effectiveness of capacity building in reducing disaster risks. Therefore, interventions must be context-specific, involve local ownership, and adapt to changing conditions (Eade, 2010; Tiwari, 2015).

3. METHODOLOGY

This study employs a secondary research methodology, utilizing a comprehensive range of existing literature, government reports, and capacity building and knowledge transfer to analyze the integration of techno-traditional approaches for disaster mitigation for with modern technologies in India's coastal regions. The research is based solely on secondary data sources, providing a thorough overview of the current state of community-based disaster risk management programme in Andaman and Nicobar Islands and the impact of modern advancements.



3.1 Data Sources

3.1.1 Literature Review

A detailed literature review was conducted to gather insights from peer-reviewed journals, academic books, and conference papers. The review focused on traditional knowledge systems, the evolution of capacity building in disaster management. Sources included works published by scholars in environmental science, geography, and disaster management, as well as reports from Capacity development for disaster management (NIDM), international organizations like the United Nations Office for Disaster Risk Reduction (UNDRR) and the World Bank (UNDRR, 2022; World Bank, 2019).

3.1.2 Government Reports and Case Studies

The study also relied heavily on reports and case studies published by Indian government agencies, including Capacity development for disaster management (NIDM), the Indian Meteorological Department (IMD), and the National Disaster Management Authority (NDMA). These documents provided extensive data on the performance and integration knowledge transfer and capacity building during significant disaster events, such as the Disaster risk management program in A&N island.

The National Institute of Disaster Management (NIDM), established under the Ministry of Home Affairs in India, was created to enhance disaster management capacities across the country. Initially founded as the National Centre for Disaster Management (NCDM) in 1995, it evolved through several stages and was officially established as NIDM by the Disaster Management Act of 2005. Its mandate includes training, research, and the development of policies and frameworks for disaster management.

NIDM focuses on capacity development through a multi-hazard, multi-level, and multi-sector approach. Its goals include improving disaster response, mitigation, recovery, and resilience, and addressing emerging risks such as climate change and pandemics. The institute provides various training programs, including face-to-face, online, and self-study modules, and collaborates on projects with national and international organizations. The institute operates through its campuses in Rohini, Delhi, and Vijayawada, and engages in a range of activities including policy support, capacity building, and awareness programs. It aims to integrate disaster risk reduction into development practices and support ministries and states in implementing effective disaster management strategies.

3.2 Analytical Framework

The analytical framework for a research paper on capacity building and knowledge transfer for disaster mitigation involves a structured approach that begins with setting the context, research objectives, and key questions. It explores the theoretical foundation, including relevant concepts and theories, to understand how capacity building enhances disaster preparedness. The framework is divided into key analytical dimensions, such as human capacity building (skills development, leadership), institutional capacity building (organizational structures, policy), community-based efforts (local knowledge, public engagement), and knowledge transfer mechanisms (formal and informal education, technology). Methodology outlines the research design, data collection, and analysis methods. The analysis then evaluates capacity building initiatives, knowledge transfer processes, and presents case studies. The discussion critically compares findings with existing literature, while the policy implications section provides actionable recommendations. The conclusion summarizes key findings and suggests future research directions, ensuring a comprehensive examination of capacity building and knowledge transfer in disaster mitigation.

4. MATERIALS AND METHODS

4.1 Techno Traditional Approaches

Table 4.1: Techno-Traditional Approach for capacity building in disaster management

Aspect	Technological Approach	Traditional Approach	Integration
Definition and Scope	Focuses on advanced tools, systems, and innovations for disaster management.	Relies on local knowledge, practices, and community-based methods.	Combine advanced technologies with local practices to create comprehensive disaster management strategies.
Tools and Methods	GIS, remote sensing, early warning systems, data analytics, and simulation models.	Traditional knowledge, community drills, indigenous practices, and oral histories.	Use technology to enhance traditional methods, e.g., digital mapping combined with local hazard knowledge.
Data Collection and Analysis	Utilizes sensors, satellite imagery, and automated data collection systems.	Uses community observations, historical records, and local surveys.	Integrate technological data with local knowledge for more accurate and context-aware disaster assessments.
Risk Assessment	Relies on quantitative risk models, predictive analytics, and simulations.	Based on historical events, local observations, and traditional risk indicators.	Use predictive models to complement historical knowledge, providing a fuller picture of risk.
Communication Systems	Employs mass communication technologies like SMS alerts,	Utilizes community networks, local meetings, and	Integrate digital alerts with traditional communication

	social media, and emergency apps.	traditional communication channels.	methods to reach diverse populations effectively.
Training and Capacity Building	Offers technical training, workshops on new tools, and simulation exercises.	Conducts community-based workshops, drills, and knowledge-sharing sessions.	Combine technical training with community drills, ensuring that new technologies are understood and accepted locally.
Response and Recovery	Employs rapid response teams, automated systems for resource allocation, and real-time monitoring.	Relies on community volunteers, local knowledge for resource mobilization, and traditional recovery practices.	Coordinate high-tech response efforts with community-led recovery initiatives to enhance overall effectiveness.
Stakeholder Engagement	Engages technical experts, government agencies, and international organizations.	Involves local leaders, community groups, and traditional authorities.	Foster collaboration between tech experts and local stakeholders to ensure that solutions are culturally and contextually appropriate.
Monitoring and Evaluation	Uses performance metrics, automated reporting systems, and data visualization tools.	Applies community feedback, traditional evaluation methods, and local observations.	Combine quantitative data with qualitative community feedback for a comprehensive evaluation of disaster management efforts.

4.1.1 Capacity building key driving Indicators

Key focus indicators for capacity building in disaster management encompass a range of critical elements aimed at enhancing the resilience and effectiveness of communities and institutions in responding to disasters. These indicators include the development of human resources, such as training programs that equip individuals with the necessary skills and knowledge for disaster preparedness, response, and recovery. Institutional capacity is another crucial indicator, focusing on the strengthening of organizational structures, governance frameworks, and inter-agency coordination mechanisms. Community engagement is vital, emphasizing the participation and empowerment of local populations in disaster planning and decision-making processes. The transfer and integration of knowledge through education, technology, and best practices also play a significant role, ensuring that lessons learned from past experiences are effectively utilized. Additionally, the availability and accessibility of resources, including financial, technological, and logistical support, are key indicators that determine the capacity to manage and mitigate the impacts of disasters effectively. These indicators collectively form a comprehensive approach to building resilience against disasters.

4.1.2 Knowledge transfer indicators

Key focus indicators for knowledge transfer in disaster management for coastal settlements include the effectiveness of communication channels, the accessibility and relevance of the information shared, and the level of community engagement in the learning process. It's essential to assess how well knowledge is being disseminated through both formal and informal networks, ensuring that critical information reaches all community members, including vulnerable groups. Indicators also include the frequency and quality of training programs, the adaptability of the knowledge to local contexts, and the incorporation of traditional knowledge systems. Additionally, the sustainability of knowledge retention and the community's ability to apply learned skills during disasters are crucial. Monitoring these indicators helps ensure that the knowledge transfer process contributes effectively to the resilience and preparedness of coastal communities against disaster risks.

4.1.3 Integrating capacity building and knowledge transfer in disaster preparedness

Integrating capacity building and knowledge transfer in disaster management requires a holistic and inclusive approach that is both adaptable and sustained over time. Inclusive planning is paramount, as it ensures that diverse stakeholders, particularly vulnerable populations, are actively involved in the development and implementation of disaster preparedness strategies. By including marginalized groups—such as the elderly, disabled, women, and economically disadvantaged—decision-makers can craft more equitable and effective plans that address the unique needs and risks faced by all community members. This participatory approach not only increases the relevance of the strategies but also fosters a sense of ownership and empowerment among the population, leading to higher levels of preparedness and resilience.

Cross-sector collaboration is equally critical, as no single entity can manage disaster risks and responses alone. By bringing together government agencies, non-governmental organizations (NGOs), the private sector, academia, and local communities, a more comprehensive and coordinated response can be achieved. This collaboration allows for the sharing of expertise, resources, and innovative solutions, thereby enhancing the overall capacity of the system to manage and mitigate disasters. For example, while governments may provide policy direction and resources, NGOs can offer on-the-ground knowledge and experience, private companies can contribute technological solutions, and local communities can provide insights into cultural practices and local vulnerabilities. This synergy between different sectors ensures that disaster management strategies are well-rounded and robust.

Finally, ensuring sustainability and continuity in both capacity building and knowledge transfer is crucial for long-term disaster preparedness. They evolve with changes in climate, population dynamics, and socio-economic conditions. Therefore, capacity-building efforts must be continuous, with regular updates to training programs, the incorporation of new technologies, and the refinement of strategies based on lessons learned from past events. Similarly, knowledge transfer should be an ongoing process, with mechanisms in place for capturing and disseminating new information, best practices, and innovations. By embedding sustainability and continuity into disaster management efforts, communities and organizations can remain agile and responsive, ensuring they are prepared not just for the disasters of today, but also those of tomorrow.

5. CASE AREA

5.1 Introduction

The Andaman & Nicobar Islands are in the southeastern part of India. Andaman and Nicobar are a group of islands, consisting of 572 islands, 37 of which are inhabited. The region faces year-round vulnerability to multiple hazards, including earthquakes due to its location in Seismic Zone V, tsunamis, cyclones, erratic rainfall, and tidal surges.

These hazards severely impact coastal villages and exacerbate issues like soil erosion, mud volcanoes, and severe waterlogging, which destroy agricultural lands. Overall, the approximately 400,000 residents are consistently at risk from these environmental threats.

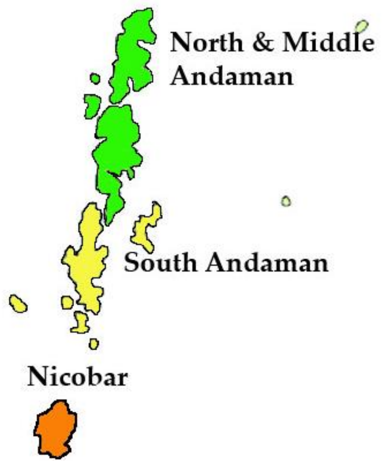


Figure 2 Andaman and Nicobar Islands.

5.1.1 Physical Features

The Andaman & Nicobar Islands feature undulating terrain with ridges running north-south and spurs east-west. Most islands have few flat areas and lack perennial streams, except for Great Nicobar, which has five perennial rivers. Geologically, the islands are primarily composed of Eocene sediments on pre-Tertiary rocks, with some volcanic activity. The active Volcano of Barren Island is in line with Nicobar, these form one of the principal lines of weakness in the earth’s surface. The Andaman Islands generally avoid the violent earthquakes that affect the Nicobar Islands due to their location relative to geological fault lines. The soils of the Andaman and Nicobar Islands are categorized into three types: Entisols, Inceptisols, and Alfisols. The primary agricultural soils, located in the valleys, are of alluvial and colluvial origin. Coastal regions susceptible to tidal flooding may have acid sulphate soils. The soils in Andaman and Nicobar are nutrient deficient for major agricultural activities.

5.1.2 Climate

Figure 3 The Great Nicobar Island.

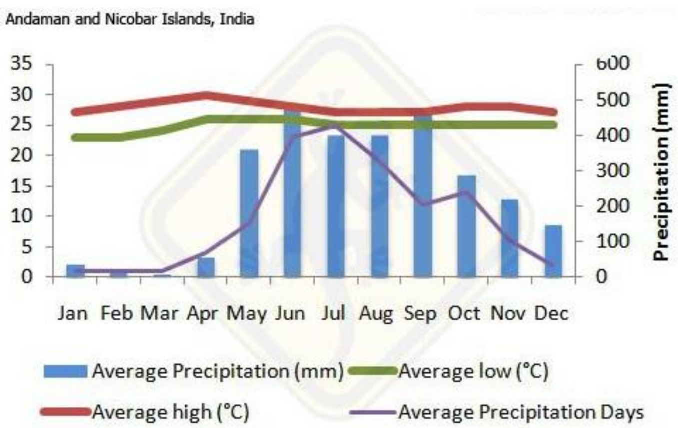


Figure 4 ANI climate graph 2023.

The Andaman and Nicobar Islands have a tropical climate and are in the Hot or Torrid Zone. Forests cover about 86% of the islands. They experience two main seasons: the Rainy Season (May to December) and the Summer Season (January to April), with no winter season. The islands receive an average annual rainfall of 3000 mm and are influenced by the South-West and North-East monsoons. The mean relative humidity is 79%, with temperatures ranging from a mean minimum of 23°C to a mean maximum of 30.2°C.

5.2 Hazard Profile of Andaman and Nicobar Islands

The Andaman & Nicobar Islands face multiple hazards year-round, including earthquakes, heavy rainfall, cyclones, active volcanoes, and mud volcanoes. The primary and secondary communities in these regions are continuously exposed to these threats. The primary and secondary communities refer to distinct groups living in the region, each with different levels of vulnerability to hazards.

5.2.1 Primary Communities

Primary Communities include the Indigenous Tribes of the Islands and other local settlers. The Indigenous Tribe include, Great Andamanese originally spread across the Andaman Islands, now mainly residing on the northern part of the Great Andaman Group, Onge inhabit Little Andaman Island and are known for their hunter-gatherer lifestyle, Jarwa live in the forests of South and Middle Andaman Islands, Nicobarese inhabiting the Nicobar Islands, particularly in the central and southern parts, and Sentinalese residing on North Sentinel Island currently isolated from external contact.

Local settlers include community groups who have migrated generations before to the Island group known as Andamanese and Nicobarese. Majority of these are settled in various parts of the islands, including areas near major towns like Port Blair.

5.2.2 Secondary Communities

Migrants and Settlers who came in post-independence to the islands from mainland India for various reasons, including agriculture, government jobs, and economic opportunities. Refugees’ communities may include refugees from conflicts or natural disasters in neighbouring regions. Tourists are people visiting the islands for travel and leisure and temporary workers employed in tourism, construction, and other temporary industries are part of secondary communities residing on the Islands.

Both primary and secondary communities face challenges related to natural disasters, such as cyclones, tsunamis, and earthquakes, but the indigenous and local populations are often more vulnerable due to their dependence on the environment and less access to modern infrastructure and services.

5.2.3 Present Scenario

Villagers endure prolonged heavy rainfall for 6 to 7 months each year, accompanied by strong cyclones, tsunami risks, and high tidal surges. Many interior villages are isolated, located 2-10 kilometres from roads with inadequate infrastructure such as roads, bridges, and culverts, and experience soil salinity from sea water intrusion, which threatens their agricultural lands. This situation jeopardizes local livelihoods due to soil erosion and the loss of cultivable land. During the monsoon, vulnerable groups such as children, the elderly, and pregnant women face increased risks as villages become cut off from essential services. Existing shelters are

Figure 5 Visuals from 2004 tsunami.

often poorly equipped to withstand disasters, especially earthquakes. The islands are situated in Seismic Zone V, one of the most seismically active areas globally, and have experienced significant earthquakes, including the devastating 2004 earthquake that triggered a deadly tsunami.
The islands fall within a cyclogenesis zone, with numerous cyclones forming in the Andaman Sea and impacting the region. Heavy monsoon rains frequently cause localized flooding. Recent cyclones, such as PHAILIN and LEHAR in October and November 2013, intensified into severe storms with wind speeds exceeding 100 km/h, causing widespread disruption and damage to properties.

Figure 6 Impacts of cyclone LEHAR on ANI.

5.2.4 Earthquakes

The Andaman and Nicobar Islands are part of a seismically active region due to their proximity to the boundary between the Indian Plate and the Eurasian Plate. This area experiences frequent seismic activity, including earthquakes, which can cause significant damage. Historical earthquakes that incurred tremendous damage have leading to loss of life and properties include;

- 2004 Indian Ocean Earthquake and Tsunami, a massive undersea earthquake with a magnitude of 9.1-9.3. This earthquake triggered a devastating tsunami that affected the Andaman and Nicobar Islands. The tsunami caused extensive damage in the region.
- 2012 Andaman Earthquake, a major earthquake with a magnitude of 8.6, this earthquake, along with a subsequent 8.2 magnitude aftershock, caused concern in the Andaman and Nicobar Islands. The event heightened awareness about the seismic risks in the region.
- The Andaman and Nicobar Islands experience smaller earthquakes periodically due to the ongoing tectonic activity in the region. While these smaller quakes can cause localized damage, they generally do not have the widespread impact.

The damage and impacts caused by earthquakes frequently hitting the group of islands are majorly on infrastructure including roads, bridges, and buildings. Human impact is the impact on local communities resulting in loss of life, injuries, and displacement of residents. Environmental impacts caused lead to coastal erosion, damage to mangroves, and disruption of local ecosystems. Post-disaster recovery often involves humanitarian aid, relocation, and rebuilding efforts.
Many earthquakes of magnitude more than 5.0 occurred in and around these Islands. In the table below, the number of earthquakes occurred above 5.0 magnitude in a year is listed.

Table 4.2: Number of earthquakes in and around ANI in each year and total number of earthquakes occurring in Seismic Zone V.

Year	ANI Islands	Indonesia	Total
2010	50	31	81
2011	48	68	116
2012	97	577	674
2013	35	298	333
2014	76	191	267
2015	42	132	174
2016	05	28	33

5.2.5 Cyclones

The Andaman and Nicobar Islands are also susceptible to cyclones, which can cause severe damage due to their high winds, heavy rainfall, and storm surges. One of the severely impactful cyclones was the Cyclone Ockhi, a severe tropical cyclone that affected the Andaman and Nicobar Islands in December 2017. It caused significant damage, including flooding and landslides. Due to heavy rains this led to flooding in various parts of the islands. Infrastructure damage from the cyclone damaged homes, roads, and communication infrastructure resulting in disruption of services causing interruptions in essential services, including electricity and water supply. Another such cyclone was the Cyclone Phailin. It primarily affected the eastern coast of India, its peripheral effects reached the Andaman and Nicobar Islands, causing heavy rainfall that contributed to localized flooding and infrastructure damage. Increasing the risk of coastal erosion and flooding.

Infrastructural damages can be mend and restored but the agricultural lands damage takes sometimes decades or more to restore due to eroding soil. The loss of agricultural produce impacts local economies and food supply. Storm surges and high waves can lead to significant coastal erosion, affecting beaches, mangroves, and coastal infrastructure. Displacement and Human Impact due to cyclones often lead to displacement of communities, with people forced to evacuate their homes. The loss of livelihoods and disruptions to daily life can have long-term effects on affected populations

Table 4.3: Cyclone that affected ANI severely, causing tremendous damage.

Year	ANI Islands
26.12.2011	‘Thane” The depression over southeast Bay of Bengal moved north-west wards, intensified into deep depression and bay centred at 05.30 hrs.
08.10.2013	Cyclone PHAILIN that affected Thailand, Myanmar, Andaman and North Indian Ocean Basin.
25.11.2013	Cyclone Storm “LEHAR” affected South Andaman with wind speed of 110 km per hr.
08.11.2014	Cyclone Storm ‘HUDHUD”

6. TRADITIONAL KNOWLEDGE SYSTEM APPROACHS

Traditional knowledge systems in disaster mitigation encompass the collective wisdom and practices developed over generations by communities living in disaster-prone areas. These systems include local techniques for building resilient structures, such as elevated homes and flexible materials, which are designed to withstand environmental stresses like cyclones and floods. Traditional knowledge often includes early warning indicators based on observations of natural phenomena, as well as culturally ingrained practices for community cooperation and preparedness.

6.1 Coastal and Environmental Management

Majorly it is the environment that protect from the environment. To achieve this leading a sustainable and balanced lifestyle is necessary, preserving and maintain certain ecological zones can be game changers in mitigation strategies.

- Mangrove conservation communities in the Andaman and Nicobar Islands traditionally recognize the importance of mangroves in protecting coastal areas from storm surges and erosion. These natural barriers help to buffer the impact of cyclones.
- Traditional practices include the protection of coral reefs, which act as natural barriers to reduce the impact of waves and storm surges on coastal areas.
-

6.2 Community Practices and Knowledge

- Early warning systems in the indigenous knowledge includes observing natural signs such as changes in animal behaviour, wind patterns, and sea conditions to anticipate cyclones. These observations are often used to provide early warnings within communities.
- Traditional knowledge includes established evacuation routes and community shelters. These shelters are often built in elevated areas and are designed to withstand cyclone impacts.
- Traditional seasonal calendars and environmental indicators help communities anticipate and prepare for cyclones. These calendars are based on long-term observations of weather patterns and natural events.

6.3 Cultural Practices

- Traditional practices often involve communal efforts in building and maintaining infrastructure, as well as in responding to emergencies. Community cooperation and collective action are crucial for cyclone preparedness and response.
- Some communities engage in rituals and spiritual practices aimed at invoking protection from natural disasters. These practices are part of a broader cultural approach to managing environmental risks.

6.4 Gender-Based Response

The relationships between men and women are powerful forces in every culture. The way these relationships are defined creates differences in the roles and responsibilities of men and women. It also leads to inequalities in their access to, and control over, resources and decision-making powers.

6.4.1 Gender-Based Disparities in Disasters

Cultural constraints can limit women's mobility, making it difficult for them to evacuate or seek shelter. Women might require male permission to leave the home or face barriers such as lack of privacy in communal shelters. Poverty exacerbates vulnerabilities, with poor women, particularly those left behind in the family home while men migrate for work, facing increased risks. The intersection of poverty and gender can intensify disaster impacts on women and girls.

Traditional gender roles often mean women are less likely to be trained in survival skills like swimming or climbing, which can be crucial during disasters. Women may be less physically strong due to both biological factors and prolonged nutritional deficiencies practiced in many cultures.

6.4.2 Discrimination and Access to Assistance

Women and girls may encounter difficulties accessing disaster relief and recovery assistance. They may also face threats of sexual violence and exploitation in temporary shelters or relief camps. During and after disasters, women's responsibilities for caregiving and household tasks often increase, even as traditional support systems may be disrupted. This can strain their capacity to manage additional challenges and maintain their well-being.

7. DISASTER MANAGEMENT FOR NATURAL HAZARDS

Community-Based Disaster Risk Management (CBDRM) focuses on a bottom-up approach, involving community ownership, readiness, and advocacy. For bridging this gap, the development of Gram Panchayat/Tribal Village Council Disaster Management Plans (GPDMP/TVCDMP) is proposed.

7.1 CBDRM: Bottom-Up and Top-Down Approaches

7.1.1 Bottom-Up Approach

CBDRM emphasizes a bottom-up approach where communities are actively involved in disaster risk management. This approach fosters a sense of ownership and enhances community readiness through active participation. Local communities are engaged in advocacy and lobbying to push for necessary changes and support at higher levels of governance.

7.1.2 Top-Down Approach

Existing top-down strategies focus on district and Union Territory (UT) level disaster management plans, which often concentrate on response strategies during and after hazard events.

Gap Identification: These plans, while comprehensive in response, frequently lack adequate emphasis on mitigation measures. This gap in addressing disaster risk reduction at the grassroots level has been identified.

7.2 Development of Local Disaster Management Plans

Focus on Preparedness: To address the identified gaps, a facilitation approach will be used to develop GPDMPs and TVCDMPs. These plans will focus on crisis and disaster preparedness tailored to the specific needs and resources of each Gram Panchayat or Tribal Village Council.

Mitigation Measures: The plans will also allow for the allocation of funds and resources for mitigation measures, leveraging national flagship programs and general plan funds. Prioritization of disaster risk reduction will be a key component.

7.3 Development Process

7.3.1 Format and Approval

The format for GPDMP/TVCDMP will be developed by a facilitation team, incorporating local context, learning, and reference materials. The plans will be reviewed and approved by the district/UT administration, the department of disaster management, and local governing bodies such as Panchayats or Tribal Village Councils.

7.3.2 Capacity Building

Training will be provided to grassroots-level government functionaries, Panchayat or Tribal Village Council members, youth, women, and community leaders on disaster management aspects and the CBDRM concept.

8. DISCUSSIONS AND FINDINGS

The coastal areas of the islands are rich in mangrove forests, which are crucial for coastal protection and biodiversity. The islands host several plant species that are found nowhere else, such as the Andaman and Nicobar Island's *Dendrocalamus* bamboo species. The surrounding waters of the islands are teeming with marine biodiversity. Coral reefs, such as those around the Nicobar Islands, are rich in coral species and support a variety of fish, including the clownfish and the Napoleon Wrasse.

Combining Traditional and Modern Methods: There is a growing recognition of the importance of integrating traditional knowledge with modern scientific methods for cyclone mitigation. Collaborative efforts between local communities, scientists, and government agencies help in developing more effective mitigation strategies.

The integration of capacity building and knowledge transfer within the Community-Based Disaster Risk Management (CBDRM) Programme in the Andaman & Nicobar Islands demonstrates the value of localized, community-driven approaches to disaster preparedness. The program’s emphasis on grassroots involvement and the empowerment of local communities as first responders is critical in this remote, disaster-prone region where external aid can be delayed.Key findings reveal that combining advanced technologies, such as GIS and early warning systems, with traditional knowledge creates a more effective and culturally relevant disaster management strategy. This techno-traditional approach enhances risk assessment, communication, and response, while respecting local practices.

The study also highlights the necessity of continuous capacity building and knowledge transfer. Given the evolving nature of disaster risks due to climate change and other factors, regular updates to training and strategies are essential. Sustained efforts ensure that communities remain resilient and adaptable to new challenges.

9. CONCLUSION

Andaman and Nicobar Islands are situated in the Seismic Zone V, which is actively prone to cyclones and earthquakes due to continuous tectonic plate activities. The Islands have an interesting biodiversity mix and rich marine ecosystem. The coastal areas of the islands are rich in mangrove forests, which are crucial for coastal protection and biodiversity.

The Andaman & Nicobar Islands face a complex array of environmental hazards due to their geographical location and unique physical features. The region's vulnerability to earthquakes, cyclones, tsunamis, and other natural disasters is compounded by its challenging terrain, nutrient-poor soils, and inadequate infrastructure. Indigenous and local communities, who rely heavily on the environment for their livelihoods, experience heightened risks from these

hazards. The ongoing threats of heavy rainfall, cyclones, and seismic activity have a profound impact on the daily lives and economic stability of approximately 400,000 residents.
Traditional knowledge systems and community practices, including mangrove conservation and early warning indicators, play a crucial role in mitigating these risks. However, there remains a significant need for improved disaster management strategies, particularly through community-based approaches and the development of localized disaster management plans. Emphasizing a bottom-up approach in disaster risk management will help build resilience and ensure that the needs of both primary and secondary communities are adequately addressed, ultimately enhancing the overall preparedness and response capacity of the region.
Integrating the time-tested traditional knowledge strategies with modern scientific approaches, can help in enhancing resilience and reducing vulnerability to natural disasters. They complement modern approaches by offering insights into local environmental conditions, enhancing community resilience, and fostering sustainable practices. Integrating traditional knowledge with contemporary technology and planning can help improve overall disaster preparedness and response.

REFERENCES

1. Indian Meteorological Department. (n.d.). Weather updates. Indian Meteorological Department.
2. https://www.imd.gov.in/
3. Andaman & Nicobar Islands State. (2021). Onefivenine.com. https://www.onefivenine.com/india/villag/state/Andaman-&-Nicobar-Islands
4. 2004 Indian Ocean tsunami - Times of India. (2016, October 26). The Times of India. https://timesofindia.indiatimes.com/event/2004-Indian-Ocean-tsunami/articleshow/55071172.cms
5. DISASTER PREPAREDNESS IN ANI DIRECTORATE OF DISASTER MANAGEMENT ANDAMAN AND NICOBAR ADMINISTRATION www.ddm.and.nic.in. (n.d.). Retrieved August 18, 2024, from https://ndma.gov.in/sites/default/files/PDF/Reports/Andaman-Nicobar-Disaster-preparedness.pdf
6. NATIONAL INSTITUTE OF DISASTER MANAGEMENT (Ministry of Home Affairs, Government of India) Capacity Development For Disaster Management. (n.d.). https://ndma.gov.in/sites/default/files/PDF/Reports/NIDM.pdf
7. Sethi, R. K. (2011). Prediction and management of natural disasters. Indian Council of Agricultural Research.
8. https://krishi.icar.gov.in/jspui/bitstream/123456789/42904/1/Sethi_2011_Prediction%20and%20management%20of%20natural%20disasters.pdf

9. Gonzalez, J., & Zhang, L. (2024). Integrating traditional knowledge with modern technology: A new paradigm for disaster risk reduction. International Journal of Disaster Risk Reduction, 75, 103388. https://doi.org/10.1016/j.ijdrr.2024.103388

10. United Nations Office for Disaster Risk Reduction. (n.d.). Integrating traditional knowledge into disaster risk reduction planning. United Nations. https://www.undrr.org/integrating-traditional-knowledge-drr-planning

11. United Nations International Strategy for Disaster Reduction (UNISDR). (2009). Indigenous knowledge for disaster risk reduction: A case study in the Philippines. https://www.unisdr.org/files/3646_IndigenousKnowledgeDRR.pdf

12. García, J. J., & Schilling, R. (2020). Traditional knowledge and modern technology for disaster risk reduction: Bridging the gap for resilient communities. CORE. https://core.ac.uk/download/pdf/195631292.pdf

13. Kandel, S., & Delica, W. (2019). Bridging traditional knowledge and modern technology: An integrative approach to disaster risk reduction. Environmental Science & Policy, 92, 28-35. https://doi.org/10.1016/j.envsci.2018.11.012

Geo-spatial Approach to Identifying Multi-Hazard Risk Areas in Coastal Regions: A Case Study of Coastal Villages in Prakasam District, Andhra Pradesh

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Abstract

Coastal villages are at the forefront of climate- related hazards, facing increasing risks from coastal erosion, floods, tropical cyclones, storm surges, and other environmental stressors. An examination of coastal vulnerabilities in predominantly rural coastal regions reveal that enhancing the resilience of susceptible coastal communities is the paramount factor in mitigating the consequences of such hazards. Nearly two-thirds of the world's population, or 3.6 billion people, will reside on or within 100 miles of a coastline. In three decades, it is anticipated that nearly 75 percent of the world's population will reside along the coast for better employment opportunities. The case area, Prakasam district coast is a regular victim of severe cyclones, coastal erosion, floods and people residing along the coast are highly vulnerable. So, assessing multiple hazards is the crucial step to identify high susceptible zones, and to find out the multi-hazard risk zones a geospatial approach has been followed. In this study, firstly the DSAS technique was employed to predict how the shoreline has changed along the coast over the past four decades. Following which, the flood susceptibility was assessed in the study area to identify areas that are most likely to be affected. In addition, the IDW approach in ArcGIS 10.8 was used to forecast cyclone-induced wind hazards. Using AHP technique and weighted-overlay method the Multi-Hazard susceptibility of the selected case study (10 villages) was derived. A primary survey (sample size - 267 HHs) was conducted to collect data on physical, social, and economic indicators, and grouped under Exposure, Sensitivity and Adaptability parameters to get the Composite Vulnerability Index (CVI). Integrating the outputs of CVI and Multi-Hazard susceptibility the Multi-Hazard Risk areas were identified. These findings can help the panchayats and local bodies to provide effective mitigation strategies to reduce the disaster risk in the coastal villages.

Keywords: Geo-spatial; Coastal Vulnerability; Multi-Hazard Risk; Andhra Pradesh; Coastal Villages

1. INTRODUCTION

Environmental problems are considered huge challenges for human populations and communities. These issues, such as tropical cyclones, floods, coastal erosion, storm surges and wind hazards are essentially related to natural disasters and climate change (Smith, 2013). Urbanization and climate change pose significant challenges to coastal communities worldwide. Recent studies indicate that nearly two-thirds of the global population will reside within 100 miles of coastlines, intensifying the need for sustainable urban planning. Despite this, many coastal regions, particularly in developing countries, lack adequate infrastructure and disaster preparedness, leading to increased vulnerability to hazards such as flooding and erosion. In three decades, it is anticipated that nearly 75 percent of the world's population will reside along the coast for better employment opportunities. Coastal regions are home to two-thirds of Southeast Asian cities with populations of 2.5 million or more. A study conducted by NCCR predicts that by the end of the twenty-first century, the flood plain and inundation height along the coast will have changed because of sea level rise. And some case studies by DJ Wrathall stated in 2021 that migration towards the coastlines of Bangladesh is anticipated to increase even if the coast is susceptible to of sea-level rise by 2100. These studies give a clear indication that when we compare environment and livelihood people are giving more importance to livelihood than environmental hazards. So, identifying the risk areas in the coastal regions is a paramount factor for the local bodies and panchayats for effective disaster management. However, the assessment of vulnerability differs from place to place, depending on various factors and metrics, particularly oceanographic and metrological conditions, geomorphological structure, soil types, population density, infrastructure, and proximity to sea offshores (Cutter et al., 2008) . In addition, the destructive nature of cyclones is an essential criterion in evaluating vulnerable areas, particularly storm surges, wind speed, and rainfall (Emanuel et al., 2006; Henderson-Sellers et al.) . The coastal regions of Prakasam District are susceptible to multiple hazards like cyclonic winds, floods and erosion. The people residing along the coast are involved in different economic activities and may be vulnerable to coastal hazards. So, assessing the coastal hazards and identifying the risk areas through geo spatial assessment is essential to create the maps of high susceptible areas and the multi hazard risk indices. In this study we aimed to develop a geospatial approach to assess the multiple coastal hazards and to identify the multi-hazard risk areas in the 10 coastal villages of Prakasam District. Three hazards which are most frequently occurs in the district were considered, those are cyclone induced wind hazards, floods and erosion. The hazards were first individually assessed later AHP technique and weighted overlay method in ArcGIS is used to get the multi hazard susceptibility. The methodology to assess each hazard will be explained in the following section.

On the other hand, coastal vulnerability assessments in earlier research were laid on the physio-geological characteristics of the landscape and severity of the coastal hazards (Hopley & Fisher, 1992) (Hopley 1992; (A1 & Bakri, 1996; Brundrit, 1992) . Consideration of elevation, slope and proximity to coast have been crucial in the identification of population sensitive coastal areas (Small & Nicholls, 2003). Assessment of vulnerability is an imperative task of environmental management while coastal vulnerability assessment is a spatial concept which intends to identify the population affected by coastal hazards (Bevacqua et al., 2018). Vulnerability refers to the susceptibility and inability of a system to adapt implications of hazards (Rehman et al., 2021). IPCC in its fifth assessment report (IPCC, 2014) broadened its definition by including three important components i.e., exposure, sensitivity and adaption. Exposure refers to the degree a system or region which is exposed to the climate variability and change. Sensitivity refers to the degree to which a system is affected by climate variability and change. It is determined by the ability of the coastal communities to withstand with the exposures and socio-economic factors. Adaptation is the ability of a system and population to respond to the consequences (White, 2001). Several concepts of vulnerability assessment in response to various natural hazards have been adopted by various scholars like social vulnerability (Cutter et al., 2009) (Rufat et al., 2015) socio-economic vulnerability (Hajra et al., 2017) environmental vulnerability (Dasgupta et al., 2011; Marcomini et al.,) population vulnerability (Liu et al., 2015), infrastructural vulnerability (Mallick et al. 2011; Mansur et al. 2016), socio-ecological vulnerability (Bhuiyan & Dutta, 2012; Damm, 2010; Nicholls et al., 2008; Sebesvari et al., 2016) and delta vulnerability (Tessler et al., 2015).The present study utilizes the Composite Vulnerability Index (CVI) by considering site specific indicators which consists of 14 sensitivity and 15 Adaptability indicators. The present study aims to identify the multi-hazard risk areas by incorporating both multi-hazard susceptibility and CVI.

1.1 Study Area

Prakasam district which is in Andhra Pradesh lies in eastern coastal plain is geographically positioned in the path of cyclones originating in the Bay of Bengal, exposing it to a higher frequency of cyclonic events. The flat topography of the eastern coastal plain makes it more susceptible to storm surges associated with cyclones, leading to increased vulnerability to coastal flooding. The prime factor to consider Andhra Pradesh over the other states in eastern coastal plain is it has experienced a higher frequency of cyclones over the years, contributing to its reputation as a cyclone-prone area. During the North-East Monsoon season 96 cyclonic storms crossed Andhra Pradesh coast making it more susceptible to cyclones than Odisha coast. Consequently, Prakasam District has become recognized as one of the most susceptible areas to hazards in the region, encountering recurring difficulties in endeavors to enhance resilience and manage disasters. The present study was carried out in the 280.70 km^2 area consisting of 10 coastal villages with a coastline of 48.7km of Prakasam District.

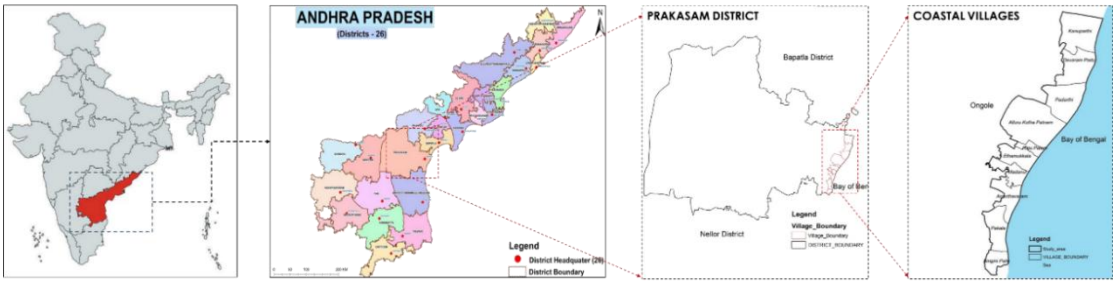

Figure 1: showing location of study area

1.2 Methodology and Datasets

The entire study is divided into two objectives. The first objective is to assess the coastal hazards susceptibility. Here three coastal hazards i.e., floods, cyclone induced wind hazards and coastal erosion are taken into consideration to find the multi hazard susceptibility. The second objective is to identify the susceptible areas that are socially, physically and economically vulnerable. For that, A Composite Vulnerability Index (CVI) is calculated. The source of data for CVI is primary data, where a Household Survey consists of sample size 267 was conducted in the ten coastal villages. We identified and selected the following site-specific indicators to calculate the Composite Vulnerability Index. These indicators are grouped under exposure, sensitivity and adaptability parameters. Sensitivity Indicators: tribal population, Population Density, Rented Houses, Kutcha Houses, Informal Settlements, Irregular Houses, Mud as Wall material, Sheets as roof material, plinth at ground level, closeness to hazardous activity, marginal worker population, water stagnation, water scarcity.

Adaptability Indicators: Female literacy, total literacy, Renewable energy, quality of internet, access to internet, quality of water, garbage collection, drainage network, rainwater harvesting, financial aid, availability of emergency vehicle, doctor patient ratio, road density, and access to toilet. The rationale for selecting these indicators and their sources is mentioned in the **Table 1** and **Table 2**. The indicators of exposure, sensitivity and adaptability are normalized using min-max rescaling technique.

Then the composite vulnerability index of the study area was calculated and categorized into five ranging from very low to very high. Very low vulnerability indicates the study area is less exposure and sensitivity but having higher adaptability to hazards. Similarly, higher vulnerability indicates the study area is high exposure and sensitivity but having higher adaptability to hazards. Then the risk areas of the study area were identified using the function risk=f (hazard, vulnerability).

To assess the multi-hazard susceptibility three hazards were assessed and the detailed methodology for assessing each hazard was discussed below **Figure 2**.

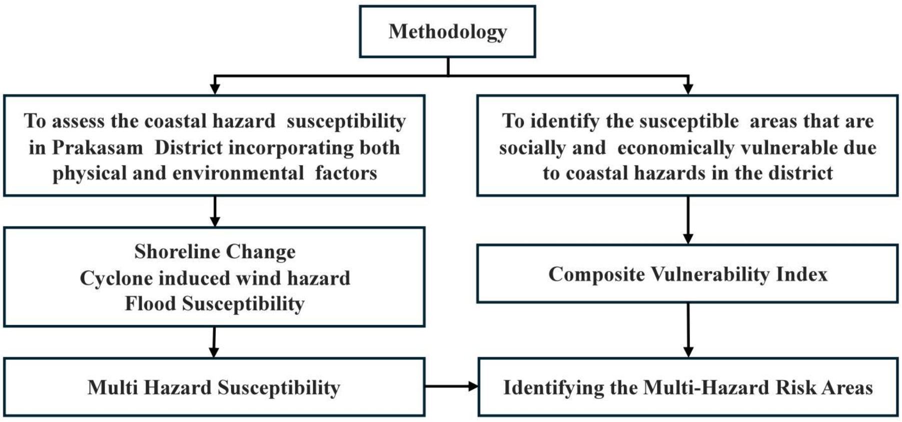

Figure 2: showing overall methodology of the study

Table 1: showing data sets of the study

Category	Indicators/Data	Measurement	Source
Exposure	Wind speed	meter/sec	IMD and NDMA
	Rainfall	milli meters	IMD
	Temperature	degree Celsius	IMD
	Elevation	meters	SRTM DEM, (USGS)
Sensitivity	Tribal Population	Percentage	Census of India 2011 (PCA)
	Population Density	persons per sq.km	Census of India 2011 (PCA)
	Rented Houses	Percentage of houses	Primary Source (HHS)
	Kutcha Houses	Percentage of houses	Primary Source (HHS)
	Informal Settlements	Percentage	Primary Source (HHS)
	Irregular Houses	Percentage	Primary Source (HHS)
	Mud as wall Material	Percentage	Primary Source (HHS)
	Sheets as roof material	Percentage	Primary Source (HHS)
	Plinth at ground level	Percentage	Primary Source (HHS)
	Closeness to hazardous activity	Percentage	Primary Source (HHS)
	Marginal Worker population	Percentage	Census of India 2011 (PCA)
	Water Stagnation	Percentage of Area	Primary Source (HHS)

Adaptability	Female Literacy	Percentage	Census of India 2011 (PCA)
	Total Literacy	Percentage	Census of India 2011 (PCA)
	Renewable Energy	Percentage	Primary Source (HHS)
	Quality of Internet	Percentage	Primary Source (HHS)
	Access to Internet	Percentage	Primary Source (HHS)
	Quality of Water	Percentage	Primary Source (HHS)
	Garbage collection	Percentage of Area Covered	Primary Source (HHS)
	Drainage Network	Percentage of Area Covered	Primary Source (HHS)
	Rainwater harvesting	Percentage	Primary Source (HHS)
	Financial Aid	Percentage	Primary Source (HHS)
	Emergency Vehicle	Percentage	Primary Source (HHS)
	Doctor Patient Ratio	Percentage	Primary Source (HHS)
	Road Density	Percentage of Area Covered	Secondary Source
	Access to toilet	Percentage	Primary Source (HHS)

Table 2: showing rationale for selected indicators

Indicators/Data	**Rationale**
Wind speed	High wind speed increases the intensity of cyclones and hurricanes
Rainfall	High rainfall will contribute to flood occurrence
Temperature	Temperature affects exposure
Elevation	Places with higher elevation will be less susceptible to exposure
Tribal Population	They are the most disadvantageous section of the society
Population Density	High population density may have burden on evacuation time and will be more affected by disasters
Rented Houses	
Kutcha Houses	These houses are more susceptible to disasters
Informal Settlements	These settlements are more susceptible to disasters
Irregular Houses	It is difficult to help in the areas where houses are built in irregular
Mud as wall Material	These houses are more susceptible to disasters
Sheets as roof material	These houses are more susceptible to disasters
Plinth at ground level	These houses are more susceptible to disasters
Closeness to hazardous activity	Increases the risk of exposure to environmental hazards
Marginal Worker population	More dependent on climate-sensitive livelihoods
Water Stagnation	Significantly affect the health of communities
Female Literacy	Literate females can play a key role in creating awareness of disasters
Total Literacy	Literate population may have better understanding and awareness about adaptation measures
Renewable Energy	having renewable energy will have better adaptive capacity

Quality of Internet	can help in transmitting information during disaster
Access to Internet	having access to internet will have better adaptive capacity
Quality of Water	having quality of water will have better adaptive capacity
Garbage collection	having garbage collection will have better adaptive capacity
Drainage Network	drainage network plays a key role during flood disasters
Rainwater harvesting	having rainwater harvesting will have better adaptive capacity
Financial Aid	financial aid plays a critical role in enhancing adaptability
Emergency Vehicle	having emergency vehicle will have better adaptive capacity
Doctor Patient Ratio	Higher the doctor patient ratio better adaptive capacity
Road Density	better roads can help in fast evacuation during disasters
Access to toilet	having toilet facility will have better adaptive capacity

1.3 Hazard Assessment

This section presents the hazard assessment of the selected hazards, in this section we have assessed the shoreline change assessment to identify the erosion and accretion areas, flood susceptibility to identify the areas which are highly susceptible and last cyclone induced wind hazards to identify the area which are most prone to wind hazards during cyclones. After assessing each hazard, a multi hazard susceptibility was done to find the critical areas which are prone to these multiple hazards.

1.3.1 Shoreline Change Assessment

Shoreline change assessment entails the examination and scrutiny of alterations in the shoreline across a period. Assessing changes in the shoreline is essential for creating sustainable plans to manage coastal areas (Natarajan et al., 2021). This includes prioritizing tasks like protecting the coastline, restoring the ecosystem, and investing in the economy. It also helps address the difficulties caused by coastal erosion and rising sea levels (Velsamy et al., 2020).

For the assessment of shoreline change along the coast of the study area, Landsat 5(1993), Landsat 7 (2003), Landsat 8 (2013), and Landsat 8 (2023) were used to extract the shorelines. Using ArcGIS, Shorelines and baselines were drawn using the Landsat images. Then using the DSAS tool in ArcGIS transacts rates were calculated at an interval of 30m. The DSAS methodologies were used to provide statistical reports of Linear Regression Rate (LRR) for the four years of shorelines on each transect. Finally, the shoreline changes demarcated using Linear Regression Rate. The erosion and accretion rate were calculated for the entire coast of the study area. The LRR was classified into 5 classes as shown in the below **Table 3**.

Table 3: showing classes for LRR.

Class	Erosion Rate (m/year)
High Erosion	< -4
Moderate Erosion	-4 to -0.4
Almost No Change	-0.4 to 0.5
Moderate Accretion	0.5 to 4
High Accretion	> 4

The erosion rate was calculated for the entire study area and the **Figure 3** shows the areas of erosion and accretion. The condition of the shore was mapped village wise in the study area. The average erosion rate on the coast is 1.19m/year and the maximum erosion rate was -5.1m/year observed at Bingini Palle. The villages i.e., Kanuparthi and Devarampaduand Ananthavaram show Moderate level of erosion compared to coastal areas in Paratha, Kothapatnam, Raju Palem, Ethamukkala, Madhanur and Pakala that show Moderate Accretion. The highest level of erosion was observed at Bingini Palle. It has been observed that northern and southern parts of the coast are more susceptible.

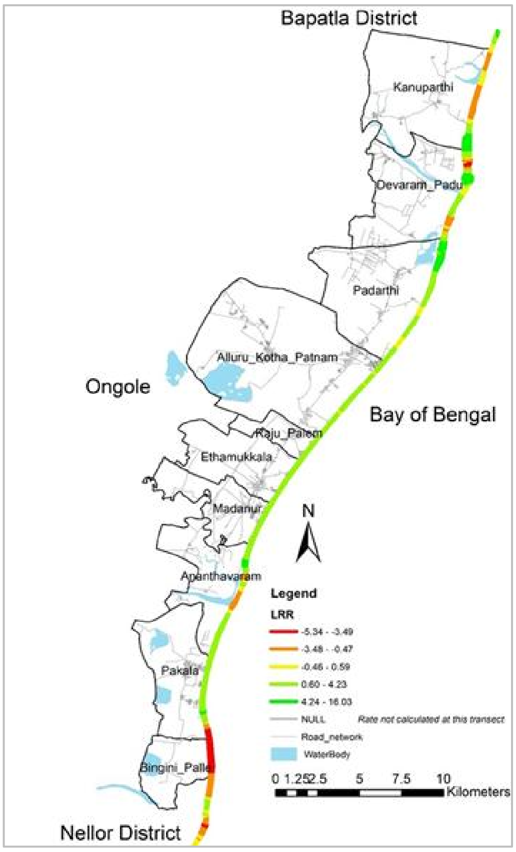

Figure 3: showing condition of shore as per LRR.

1.3.2 Flood Susceptibility

Flood susceptibility is the probability of a specific place experiencing flooding, determined by its physical and environmental attributes. It aids in the identification of places with a heightened susceptibility to flooding and allows for the prioritization of these regions for the implementation of flood mitigation measures. Flood susceptibility mapping is a complex process that includes identifying flood-prone places, choosing appropriate flood-related factors, and utilizing statistical models to forecast the probability of flooding in various locations. The parameters used to determine the flood susceptibility in the study area are slope, elevation, Soil type, TWI, Rainfall, Distance from stream, distance from road, previously flooded areas and LULC. A scoring logic was made and classified each parameter into 5 categories ranging from very high to very low and weights were assigned using AHP.

The selected parameters were reclassified in ArcGIS 10.8 according to the scoring logic. Then using the weighted overlay technique in ArcGIS 10.8 the flood susceptible areas in the study area were identified. The below **Table 4** shows the scoring logic and weightage for each parameter.

Table 4: showing scoring logic for the flood susceptibility.

Parameter	Weights	Very High	High	Moderate	Low	Very Low
Slope	12	0 - 1	1 to 2	2 to 3.2	3.2 to 5.3	> 5.3
Elevation	12	-14 to 2	2 to 4	4 to 6	6 to 8	8 to 32
Soil Type	5	Silty Clay	-	Silty Sediments	-	Sandy Clay
TWI	12	14 - 19	8.6 - 14	3.35 - 8.68	-1.9 to 3.3	-7.3 to -1.9
Rainfall *(mm)*	12	> 1445	1420 - 1445	1400 - 1420	1375 - 1400	< 1375
Distance from stream*(m)*	12	< 100	100 - 250	250 - 450	450 - 700	> 700
Distance from road*(m)*	10	0 - 50	50 - 100	100 - 150	150 - 200	>200
Previously flooded areas *(last 30 years)*	10	> 10	10-8	8-5	5-3	< 3
LULC	15	Water-bodies	Cropland	Built-up/Grassland/Shrubs	Tree Cover	Waterbodies /Wetlands/ Mangroves/ Vegetation

The **Figure 4** shows the flood susceptible areas in the study area. The flood susceptible areas are classified into five categories ranging from very high (indicated red in color) to very low (indicated a green in color). From the analysis it has been observed that Kanuparthi and Padarthi are Very High Susceptible to flood hazards due to the presence of Gundlakamma river and some parts of Kotha Patnam, Raju Palem and Ethamukkala are in high susceptible areas. It is due to the presence of drains passing through these villages and the elevation profile is very low. The average rainfall is also very high in the central part of the study area. Compared to the entire study area the southern part of the villages are less susceptible to flood hazards.

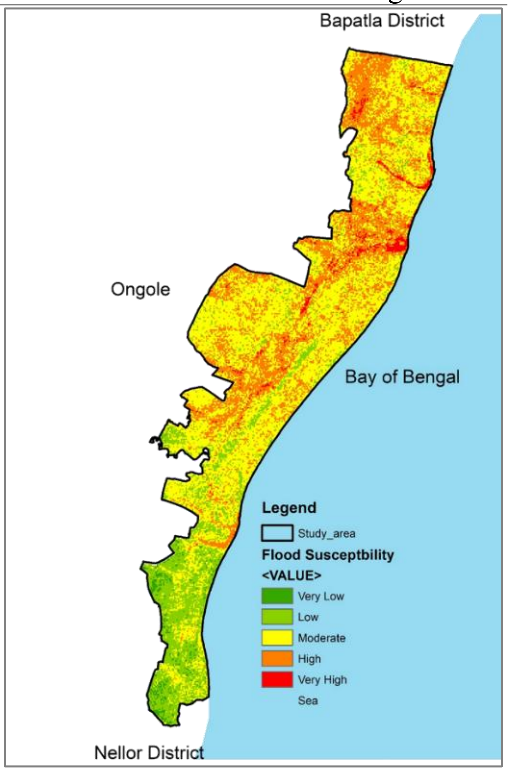

Figure 4: showing flood susceptibility of the case area.

1.3.3 Cyclone Induced Wind Hazards

Cyclone-induced wind risks pertain to the devastating winds produced by tropical cyclones, commonly referred to as typhoons or hurricanes. These winds have the potential to inflict substantial harm on structures, infrastructure, and natural surroundings, especially in coastal regions. The wind risks caused by cyclones are closely linked to the activity, strength, and structure of the tropical cyclone. These hazards are influenced by numerous intricate elements and interactions between the cyclone and the atmospheric and oceanic conditions.

The first step is to digitize the cyclone tracks then classify the cyclones as Depression, Cyclonic Storm, Sever Cyclonic Storm as specified by IMD. The **Figure 5** showing the cyclonic storms crossed in the study area during 1968 to 2023. These classified cyclones have a specific wind speed when it hits the land. These speeds were considered and used for the interpolation of the wind hazards during cyclonic storm. Then using interpolation techniques called IDW in ArcGIS the cyclone induced wind hazards were interpolated for the entire study area. The **Figure 6** shows the cyclone induced wind hazards in the study area.

Figure 5: showing cyclone track from 1968-2023

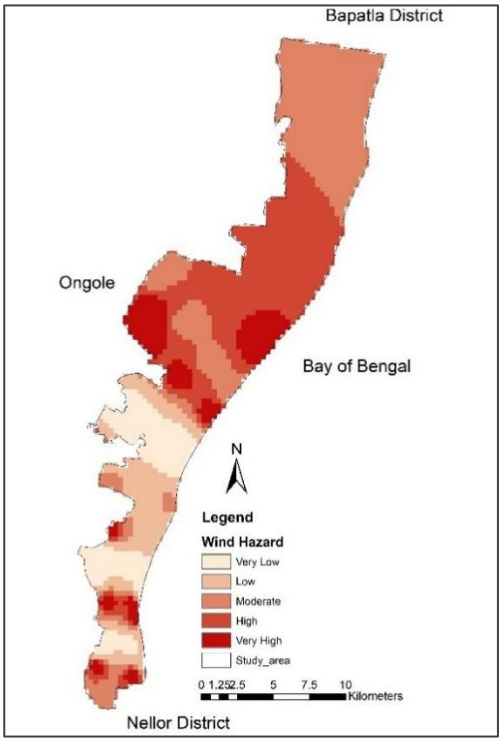

Figure 6: showing cyclone-induced wind hazard map

The wind hazard map shows that the central part of the area i.e., the villages Allur Kotha Patnam, Raju Palem and Padarthi are more prone to wind hazards. Due to the greatest number of cyclones with high intensity are crossed through those villages.

1.3.4 Multi Hazard Susceptibility

Multi hazard susceptibility refers to occurrence of multiple hazards such as floods, cyclones, wind hazards, shoreline change and storm surge in a specific area. For this study the multi hazards susceptibility is used to identify the potential areas which are more prone to these hazards like floods, cyclones and coastal erosion. In the above sections we have assessed each hazard and identified the susceptible areas, to identify the combined effect of these hazards in particular we have done multi hazard susceptibility. For that we have used AHP Priority Calculator to find out the weightage for each hazard. Following are the weights obtained for each hazard i.e., Floods (30) and Cyclone induced wind hazards (40) got high weightage. Followed by Shoreline change (30). The weightages for each hazard were listed in the below **Table 5**. Once the weightages for each hazard was obtained the multi hazard susceptibility areas were identified using weighted overlay method in ArcGIS 10.8

Table 5: showing weightages for each hazard

Hazard	Weightage
Cyclone induced wind hazards	40
Floods	30
Shoreline Change	30

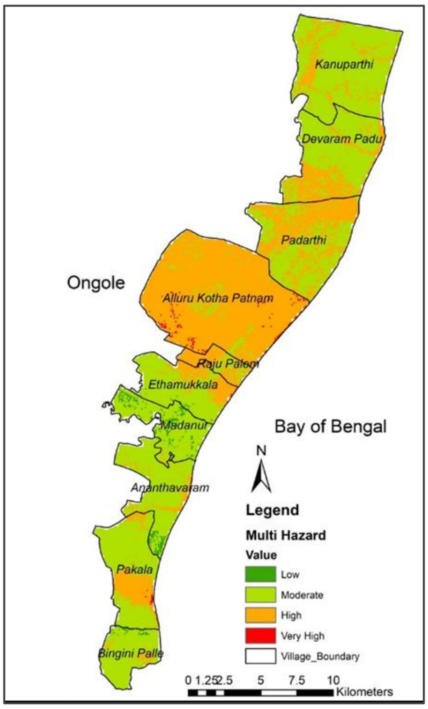

Figure 7: showing multi hazard susceptibility of the study area

The multi hazard map shows the villages Allur Kotha Patnam and some parts of Pakala, Padarthi and Devarampadu are in high hazard zone due to High Floods, Cyclones and Wind hazards. Pakala and some parts of the Allur Kothapatnam villages are in very high hazard zone.

1.3.5 Composite Vulnerability Index

In the previous sections we have identified the multiple hazards areas, in this section we will identify the areas which are vulnerable to physical, social and economic stresses. A composite vulnerability samy index (CVI) is a technique utilised to evaluate the susceptibility of a system, community, or area to environmental threats, such as drought, climate change, or coastal erosion. CVIs are created by integrating many indicators or sub-indices that represent distinct aspects of vulnerability, such as exposure, sensitivity, and adaptive capability. This is done by integrating indicators of exposure, such as rainfall patterns, with indicators of sensitivity, such as agricultural productivity, and indicators of adaptive capacity, such as access to irrigation or drought-resistant crops (Ali et al., 2020) To find out the Composite Vulnerability Index for the study area (10 coastal villages) we used the formula

$$Vulnerability = Exposure + Sensitivity - Adaptability$$

The indicators were grouped according to the formula as we mentioned in the methodology section. The indicators and data sets were already mentioned in the above **Table 1** and **Table 2**. The adaptability and sensitivity indicators for all the ten villages were calculated and mentioned in the below **Table 6** and **Table 7**. These scores are obtained by using min-max rescaling technique from the data collected through household samples. These values are ranging from zero (0) to one (1).

Table 6: showing sensitivity scores for the 10 coastal villages

Sensitivity	Allur Kotha Patnam	Ananth avaram	Bingin i Palle	Devara m Padu	Etha mukk ala	Kanu parthi	Mad anu r	Padarth i	Pakal a	Raju Palem
Tribal Population	0.56	0.21	1.00	0.00	0.84	0.06	0.49	0.24	0.08	0.13
Population Density	0.50	0.00	0.45	0.17	0.48	0.06	0.59	0.25	1.00	0.88
Rented Houses	0.41	0.25	1.00	0.00	0.10	0.36	0.80	0.38	0.35	0.75
Kutcha Houses	0.00	0.00	1.00	0.00	0.00	0.32	0.00	0.33	0.62	0.33

Informal Settlements	0.33	0.00	1.00	0.00	0.00	0.95	0.00	0.00	0.31	0.00
Irregular Houses	0.92	0.92	0.45	0.00	0.73	0.67	1.00	0.39	0.22	0.99
Mud as Wall Material	0.00	0.00	1.00	0.00	0.16	0.19	0.00	0.40	0.37	0.20
Sheets as Roof Material	0.82	0.63	0.63	0.22	0.67	0.00	1.00	0.63	0.87	0.63
Plinth at Ground Level	0.22	0.51	0.69	0.30	0.45	0.87	0.03	0.51	1.00	0.00
Close to Hazardous activity	0.10	0.00	0.61	0.32	0.37	0.44	0.00	0.61	1.00	0.00
Marginal Worker Population	0.99	0.79	0.39	0.96	0.66	0.00	1.00	0.76	0.81	0.69
Water Stagnation	0.44	0.22	0.75	0.23	0.30	0.87	0.00	0.81	1.00	0.00
Water Scarcity	0.18	0.85	0.00	0.20	0.71	0.17	1.00	0.12	0.13	0.85
Overall Score	**0.42**	**0.34**	**0.69**	**0.18**	**0.42**	**0.38**	**0.45**	**0.42**	**0.60**	**0.42**

The overall sensitivity scores for all the 10 villages were calculated and identified the villages which are highly and low sensitive. The overall scores are obtained by averaging all indicators. The villages Bingini Palle (0.69) and Pakala (0.60) are highly sensitive and the villages Devarampadu (0.18), Ananthavaram (0.34) and Kanuparthi (0.38) are least sensitive.

Table 7: showing adaptability scores for the 10 coastal villages

Adaptability	**Allur Kotha Patnam**	**Ananth avaram**	**Bingini Palle**	**Devara m Padu**	**Etham ukkal a**	**Kanu parthi**	**Madanu r**	**Pad arthi**	**Paka la**	**Raju Pale m**
Female Literacy	0.59	0.97	0.31	0.44	1.00	0.76	0.49	0.28	0.26	1.00
Total Literacy	0.49	1.00	0.13	0.38	0.87	0.72	0.33	0.12	0.14	1.00
Renewable Energy	0.30	0.00	0.61	0.00	0.25	0.59	0.00	0.92	1.00	0.69
Quality of Internet	0.93	0.86	0.80	1.00	0.91	0.62	0.99	0.91	0.92	0.05
Access to Internet	1.00	1.00	0.85	0.95	0.96	0.90	0.92	0.90	0.84	0.00
Quality of Water	0.94	0.97	0.87	1.00	0.92	0.68	0.95	0.89	0.88	0.01
Garbage collection	0.93	1.00	0.80	0.95	0.96	0.81	1.00	0.95	0.88	0.00
Drainage Network	1.00	0.72	0.54	0.00	0.91	0.46	0.91	0.72	0.45	0.10
Rainwater Harvesting	0.82	0.15	1.00	0.80	0.29	0.83	0.00	0.88	0.87	0.85
Financial Aid	0.76	0.64	0.03	0.25	0.79	0.00	1.00	0.12	0.39	0.19
Emergency Vehicle	0.24	0.65	0.25	0.00	0.47	0.10	1.00	0.52	0.46	0.75
Doc Patient Ratio	1.00	0.00	0.54	0.36	0.95	0.77	0.69	0.54	0.55	1.00
Road Density	0.49	0.35	0.00	0.52	0.58	0.16	1.00	0.37	0.57	0.22
Access to Toilet	0.93	0.95	0.65	0.95	1.00	0.71	0.96	0.80	0.56	0.05
Overall Score	**0.74**	**0.66**	**0.53**	**0.54**	**0.78**	**0.58**	**0.73**	**0.64**	**0.63**	**0.42**

The overall adaptability scores for all the 10 villages were calculated and identified the villages which have high and low adaptive capacity. The overall scores are obtained by averaging all indicators. The villages Ethamukkala (0.78), Allur Kothapatnam (0.74) and Madanur (0.73) are having high adaptability scores and the villages Raju Palem (0.42), Bingini Palle (0.53) Devarampadu (0.54) and Kanuparthi (0.58) are having less adaptability scores.

Here CVI is based solely on sensitivity and adaptive capacity, and we will incorporate exposure separately when assessing risk this avoids duplication (Raghavan Sathyan et al., 2018) . The scores obtained in the above **Table 6** and **Table 7** are then converted into raster data in the ArcGIS. Then the Composite Vulnerability Index of the study area is calculated.

The Composite vulnerability map shows that southern part of the study area consists of villages Pakala, and Bingini Palle are having highest composite vulnerability index it is due to lack of adaptability scores in the villages Raju Palem (0.42), Bingini Palle (0.53) Devarampadu (0.54) and Kanuparthi (0.58) and villages Bingini Palle (0.69) and Pakala (0.60) are highly sensitive due to high population density, tribal population, kutcha houses and water stagnation.

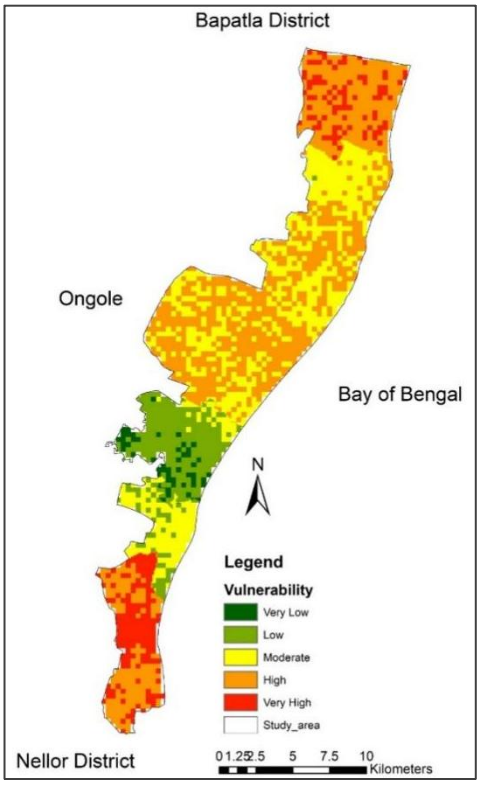

Figure 8: showing composite vulnerability index for the study area

1.4 Multi-Hazard Risk Areas

The identification of multi-hazard risk areas was conducted using two primary inputs derived from the preceding sections: Multi-Hazard Susceptibility and Composite Vulnerability. Subsequently, these multi-hazard areas were determined using the formula: Risk = Hazard × Vulnerability. The below is the showing multi-Hazard risk areas.

The colour red denotes areas with very high risk, such as the village of Pakala. The orange colour signifies areas with high risk, including the villages of Allur Kotha Patnam, Kanuparthi, and Padarthi. In contrast, the green colour represents areas with very low risk, encompassing the villages of Madanur, Ethamukkala, and Ananthavaram.

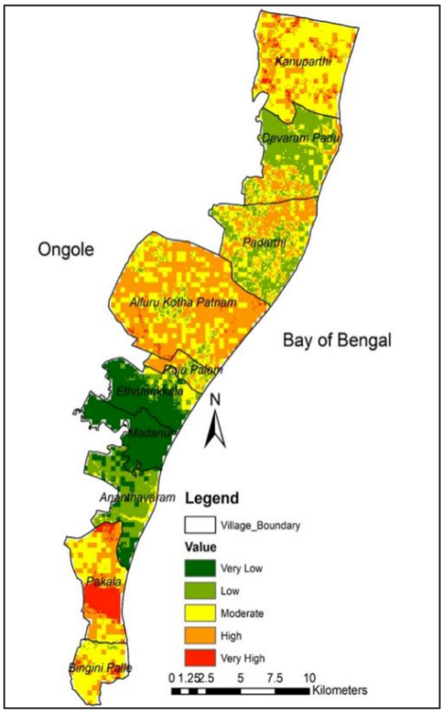

Figure 9: showing multi-hazard risk areas

1.5 Results and Findings

This section presents the key findings of the study, in this study we have assessed three coastal hazards and find out the areas which are prone to multiple hazards. Then the using composite vulnerability index and multi hazard susceptibility the multi hazard risk areas were identified. The critical areas were detailed in the respective sections, here the overall findings of the study will be presented. The very high multi hazard risk areas were identified in the Pakala Village, it is due to the village is prone to coastal erosion and also if we look into CVI, Sensitivity indicators reveal that factors such as water stagnation, proximity to hazardous activities, plinth of the houses built at ground-level, and population density are significantly high in Pakala village. Additionally, adaptability indicators, including literacy rates, female literacy rates, access to roads and sanitation facilities, and the doctor-to-patient ratio, are notably low. These combined indicators contribute to Pakala being classified as a high-risk village within the entire study area. And few other villages i.e., Allur Kotha Patnam, Kanuparthi, northern part of Padarthi and southern part of Devarampadu village are also in high risk zone this is mainly because of combined effect of floods and wind hazards and also the low road density, lack of emergency vehicles during disasters time, low female literacy and lack of renewable energy sources and also higher amount of marginal worker population, irregular houses, water scarcity during summer seasons causing these villages in high risk zone.

1.6 Discussions

Traditional multi hazard, vulnerability and risk studies consider single hazard to find out the risk areas of the study area. Due to climate change and other anthropogenic activities, the coastal areas are more prone to multiple hazards at different times. Suppose if a cyclone is crossing a coastal region it also brings heavy rainfall, heavy winds and damages everything whatever is there in its path. For that, we should identify the multi-hazard risk areas before the hazard. This study used a geospatial approach to identify the multi hazard risk areas and identified a few indicators which causes the high risk in village level. Also, methods like Multiple Criteria Decision Making (MCDM), such as the Analytical Hierarchy Process, depend on the assessments of experts or users with experience to determine the significance of vulnerability variables. In this study we used the AHP Priority Calculator to find the weightages for each hazard, it is an effective method and reduces the time for researchers. GIS and remote sensing techniques along with data driven approaches to identify the multi hazard risk areas. In addition, some of the presented methods for estimating individual hazard assessment will require up to date and more advanced predictions for accurate results in future.

1.7 Conclusions

The present study explored the hazard susceptibility and composite vulnerability and prioritized thematic areas in each component also identified the multi hazard risk areas. These areas need intervention to become resilient against coastal hazards. Some studies stated that frequent coastal disasters in response to climate variability and change have significantly impacted the local communities and coastal regions. Nearly 171 million population living in coastal districts of India are at greater risk due to sea level rise, cyclones, floods, storm surges and coastal erosion (Rehman et al., 2021) . From the findings of the present study, these villages are severely affected by flood hazards, cyclone induced wind hazards. High sensitivity and low adaptability in Pakala and Bingini Palle villages causes a high degree of vulnerability. Early warning systems for cyclones and storm surges need to be strengthened to save vulnerable people and assets. Proper monitoring of coastal hazards and cyclone shelters needs to be built in the study area. For that land suitability analysis for critical infrastructure and evacuation routes for floods must be planned in the study area. Flood control techniques like riparian corridors along the river and rainwater harvesting in individual houses and ponds for agricultural fields can reduce the flood susceptibility of the villages. Erosion control techniques like groins and living shorelines must be built in Bingini Palle and Kanuparthi villages. Capacity Building and Training Programs has to be conducted for the people and the local bodies in the villages. It plays a crucial role in enhancing community resilience and preparedness for hazards. Finally, an integrated spatial plan has to be developed for the study area which consists of interventions for village level. The aim of this plan is to deliver the critical infrastructure for the need people and make the village resilient for coastal hazards.

References and Citation

A1, D., & Bakri. (1996). GHHORPHDI DGY A geomorphological approach to sustainable planning and management of the coastal zone of Kuwait. In *Geomorphology* (Vol. 17). ELSEVIER.

Academies, N. *Highlights of National Academies reports*.

Ahammed, K. K. B., & Pandey, A. C. *Climate Change Impacts on Coastlines in Eastern Coast of India: A Systematic Approach for Monitoring and Management of Coastal Region*. https://www.researchgate.net/publication/349237163

Ali, S. A., Khatun, R., Ahmad, A., & Ahmad, S. N. (2020). Assessment of Cyclone Vulnerability, Hazard Evaluation and Mitigation Capacity for Analyzing Cyclone Risk using GIS Technique: a Study on Sundarban Biosphere Reserve, India. *Earth Systems and Environment*, *4*(1), 71–92. https://doi.org/10.1007/s41748-019-00140-x

Bevacqua, A., Yu, D., & Zhang, Y. (2018). Coastal vulnerability: Evolving concepts in understanding vulnerable people and places. In *Environmental Science and Policy* (Vol. 82, pp. 19–29). Elsevier Ltd. https://doi.org/10.1016/j.envsci.2018.01.006

Bhuiyan, M. J. A. N., & Dutta, D. (2012). Analysis of flood vulnerability and assessment of the impacts in coastal zones of Bangladesh due to potential sea-level rise. *Natural Hazards*, *61*(2), 729–743. https://doi.org/10.1007/s11069-011-0059-3

Brundrit, G. B. (1992). An index to assess South Africa's vulnerability to sea-level rise. In *NEWS AND VIEWS South African Journal of Science* (Vol. 88).

Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., & Webb, J. (2008). A place-based model for understanding community resilience to natural disasters. *Global Environmental Change*, *18*(4), 598–606. https://doi.org/10.1016/j.gloenvcha.2008.07.013

Cutter, S. L., Emrich, C. T., Webb, J. J., & Morath, D. (2009). *Social Vulnerability to Climate Variability Hazards: A Review of the Literature Final Report to Oxfam America Social Vulnerability to Climate Variability Hazards: A Review of the Literature Final Report*.

Damm, M. (2010). *Mapping Social-Ecological Vulnerability to Flooding - A sub-national approach for Germany*. http://hss.ulb.unibonn.de/diss_online

Dasgupta, S., Laplante, B., Murray, S., & Wheeler, D. (2011). Exposure of developing countries to sea-level rise and storm surges. *Climatic Change*, *106*(4), 567–579. https://doi.org/10.1007/s10584-010-9959-6

Emanuel, K., Ravela, S., Vivant, E., & Risi, C. (2006). Supplement to A Statistical Deterministic Approach to Hurricane Risk Assessment. *Bulletin of the American Meteorological Society*, *87*(3), S1–S5. https://doi.org/10.1175/bams-87-3-emanuel

Hajra, R., Szabo, S., Tessler, Z., Ghosh, T., Matthews, Z., & Foufoula-Georgiou, E. (2017). Unravelling the association between the impact of natural hazards and household poverty: evidence from the Indian Sundarban delta. *Sustainability Science*, *12*(3), 453–464. https://doi.org/10.1007/s11625-016-0420-2

Henderson-Sellers, A., Zhang, H., Berz, / G, Emanuel, # K, Gray, @ W, Landsea, C., Holland, G., Lighthill, / J, Shieh, ++ S-L, Webster, ## P, & Mcguffie, K.. *Tropical Cyclones and ^^^ Global Climate Change: A Post-IPCC Assessment*.

Hopley, D., & Fisher, G. (1992). Global change and the coastline: assessment and mitigation planning. In *Journal of Southeast Asian Earth Sciences* (Vol. 7, Issue 1).

Liu, X., Li, Z., Liao, C., Wang, Q., Zhu, A., Li, D., Li, Y., & Tang, Z. (2015). The development of ecological impact assessment in China. In *Environment International* (Vol. 85, pp. 46–53). Elsevier Ltd. https://doi.org/10.1016/j.envint.2015.08.004

Marcomini, A., Torresan, S., Critto, A., Rizzi, J., Zabeo, A., & Furlan, E. *Elsevier Editorial System(tm) for Ocean & Coastal Management Manuscript Draft Manuscript Number: Title: DESYCO: a decision support system for the regional risk assessment of climate*

change impacts in coastal zones.
Natarajan, L., Sivagnanam, N., Usha, T., Chokkalingam, L., Sundar, S., Gowrappan, M., & Roy, P. D. (2021). Shoreline changes over last five decades and predictions for 2030 and 2040: a case study from Cuddalore, southeast coast of India. *Earth Science Informatics*, *14*(3), 1315–1325. https://doi.org/10.1007/s12145-021-00668-5
Nicholls, R. J., Wong, P. P., Burkett, V., Woodroffe, C. D., & Hay, J. (2008). Climate change and coastal vulnerability assessment: Scenarios for integrated assessment. *Sustainability Science*, *3*(1), 89–102. https://doi.org/10.1007/s11625-008-0050-4
Raghavan Sathyan, A., Funk, C., Aenis, T., Winker, P., & Breuer, L. (2018). Sensitivity analysis of a climate vulnerability index - a case study from Indian watershed development programmes. *Climate Change Responses*, *5*(1). https://doi.org/10.1186/s40665-018-0037-z
Rehman, S., Sahana, M., Kumar, P., Ahmed, R., & Sajjad, H. (2021). Assessing hazards induced vulnerability in coastal districts of India using site-specific indicators: an integrated approach. *GeoJournal*, *86*(5), 2245–2266. https://doi.org/10.1007/s10708-020-10187-3
Rufat, S., Tate, E., Burton, C. G., & Maroof, A. S. (2015). Social vulnerability to floods: Review of case studies and implications for measurement. *International Journal of Disaster Risk Reduction*, *14*, 470–486. https://doi.org/10.1016/j.ijdrr.2015.09.013
Sebesvari, Z., Renaud, F. G., Haas, S., Tessler, Z., Hagenlocher, M., Kloos, J., Szabo, S., Tejedor, A., & Kuenzer, C. (2016). A review of vulnerability indicators for deltaic social–ecological systems. In *Sustainability Science* (Vol. 11, Issue 4, pp. 575–590). Springer-Verlag Tokyo. https://doi.org/10.1007/s11625-016-0366-4
Small, C., & Nicholls, R. J. (2003). A Global Analysis of Human Settlement in Coastal Zones. In *Source: Journal of Coastal Research* (Vol. 19, Issue 3). https://about.jstor.org/terms
Tessler, Z. D., Vörösmarty, C. J., Grossberg, M., Gladkova, I., Aizenman, H., Syvitski, J. P. M., & Foufoula-Georgiou, E. (2015). Profiling risk and sustainability in coastal deltas of the world. *Science*, *349*(6248), 638–643. https://doi.org/10.1126/science.aab3574
Velsamy, S., Balasubramaniyan, G., Swaminathan, B., & Kesavan, D. (2020). Multi-decadal shoreline change analysis in coast of Thiruchendur Taluk, Thoothukudi district, Tamil Nadu, India, using remote sensing and DSAS techniques. *Arabian Journal of Geosciences*, *13*(17). https://doi.org/10.1007/s12517-020-05800-1

Integrating Indigenous Knowledge with Modern Coastal Disaster Risk Reduction: Case of Chennai

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ABSTRACT

Indigenous communities along the coast of Tamil Nadu, particularly in Chennai, possess a rich repository of traditional knowledge which has played a crucial role in strengthening the city's ability to withstand natural disasters. These have been considered an essential part of the Chennai City Disaster Management Plan GCC 2021, which puts forward the idea of combining traditional practices with modern scientific measures for efficient management of coastal disasters. Notable coastal disasters that the city has faced include the 2004 Indian Ocean tsunami, which devastated life and property, and the more recent events of flooding in 2015 and 2021, where thousands of people lost their homes and their loved ones. This induced the requirement and importance of DRR strategies as an imperative for the protection of vulnerable populations and the enhancement of urban resilience. The GCC 2021 Chennai City Disaster Management Plan showcases some of the successful DRR practices based on environmental cues for early warnings, traditional elevated structure construction to mitigate the risk of flooding, and the sustainable management of coastal resources to reduce erosion and increase the role of natural buffers. The Chennai Master Plan of 2026 emphasizes the need to preserve and integrate indigenous knowledge in urban planning. The document called for community representatives to be involved in decision-making processes, ensuring their lived experiences help in shaping disaster preparedness and resilience strategies. Restoring and conserving natural ecosystems like mangroves and wetlands that act as a natural barrier to hazards along coastlines were some of the main recommendations. Of the many practices that were adopted, traditional elevated structures and sustainable coastal resource management have been the most successful. These greatly reduced, if not eliminated, the effects of flooding and erosion in areas considered to be prone to these disasters, thus proving that traditional methods do work in conjunction with modern ones. This paper will qualitatively analyze the integration of traditional knowledge with contemporary DRR strategies, through case studies and interviews, and provide recommendations for enhancing urban resilience in Chennai.

Keywords: Coastal Disaster Risk Reduction (DRR); Urban Resilience; Coastal Resource Management; Environmental Cues; Early Warning Systems.

1. INTRODUCTION

The phenomenon of tsunamis, known for their immense destructive potential, has been a focal point of scientific inquiry for over six decades, particularly since the catastrophic Chilean earthquake of May 22, 1960. This earthquake, the largest ever recorded, not only unleashed a powerful tsunami but also marked a pivotal moment in the advancement of Solid Earth Geophysics. The subsequent development of the Plate Tectonics theory, alongside improved instrumentation and computational capabilities, has significantly enhanced our understanding of tsunamis and their societal impacts.

Tsunamis are primarily generated by the sudden vertical displacement of the seafloor, often due to tectonic activities such as earthquakes, volcanic eruptions, or landslides. While traditional theories emphasized vertical movements, recent studies have highlighted the importance of horizontal seafloor displacement in tsunami generation, suggesting that both types of movement contribute to the energy that drives these waves. This evolving understanding underscores the complexity of tsunami formation and necessitates a multifaceted approach to their study.
The past sixty years have witnessed remarkable progress in tsunami research, driven by a combination of analytical methodologies, advanced computational models, and extensive field studies. Theoretical models have been developed to simulate tsunami wave behavior in deep ocean settings and their interactions with coastal topographies, which are crucial for assessing potential impacts. Post-event surveys, such as those conducted after the 1992 Nicaragua tsunami, have become systematic, allowing researchers to gather valuable data on the effects of tsunamis and refine predictive models. Furthermore, the field of paleo-tsunami studies has emerged, employing sedimentary geology techniques to reconstruct historical tsunami events and understand their recurrence over millennia.
The devastating 2004 Sumatra–Andaman tsunami, which resulted in over 250,000 fatalities, catalyzed significant advancements in tsunami hazard mitigation. This tragedy highlighted the inadequacies of existing warning systems and spurred the establishment of regional tsunami warning centers, the systematic instrumentation of the seafloor, and enhanced public education initiatives. The integration of modern scientific methods into evacuation planning and risk assessment has been instrumental in improving community resilience against future tsunami threats.

The 2004 Indian Ocean tsunami had a devastating impact on the economies and societies of the affected countries. The economic losses were substantial, with estimates ranging from $5.597 billion in damages to $4.333 billion in losses across Indonesia, Thailand, India, Sri Lanka, and the Maldives. The hardest hit sectors were fishing and tourism, which are crucial for the livelihoods of many coastal communities in the region.
The fishing industry suffered significant losses, with 66% of the fishing fleet and industrial infrastructure destroyed in Sri Lanka alone. This had a devastating impact on the artisanal fishery, which is an important source of income for local markets, as well as the industrial fishery, which provides direct employment to about 250,000 people and generates substantial foreign exchange earnings. The destruction of boats and fishing gear left many coastal communities without their primary means of income. The tourism industry also experienced major setbacks, with many tourists cancelling vacations and trips to the affected regions due to the extensive media coverage of the event. Even beach resorts that were untouched by the tsunami were hit by cancellations, as tourists were reluctant to visit the area for psychological reasons. This ripple effect was felt in inland provinces as well, such as Krabi in Thailand, which serves as a starting point for many tourist destinations. The social impacts of the tsunami were equally devastating, with over 225,000 lives lost. The loss of income earners and the destruction of education infrastructure disrupted schooling, depleting human capital in the affected regions. The psychological trauma of the event also had long-lasting effects on survivors, particularly children.
The tsunami disproportionately impacted the poorest coastal communities, many of whom were already living in precarious conditions. The loss of homes, livelihoods, and loved ones exacerbated existing inequalities and made recovery more challenging for these vulnerable populations.
The tsunami also had significant environmental impacts, including the contamination of soil and water resources, the destruction of coastal habitats, and the disruption of marine ecosystems. The saltwater intrusion into agricultural lands made it difficult for farmers to resume their livelihoods, and the loss of mangroves and coral reefs reduced the natural barriers that protect coastal communities from future disasters.

Protective measures and preparedness strategies have evolved significantly over the years due to the lessons learned from past tsunami events. The implementation of early warning systems, which utilize real-time data from seismic and oceanographic sensors, has become a critical component in mitigating tsunami risks. These systems are designed to detect seismic activity and monitor changes in sea level, providing timely alerts to coastal communities. Additionally, public education campaigns have been developed to inform at-risk populations about tsunami risks and evacuation procedures, ensuring that communities are better prepared to respond in the event of a tsunami.

Moreover, the recognition of diverse tsunami sources, including those triggered by landslides and meteorological events, has broadened our understanding of tsunami risks. This diversity necessitates a comprehensive approach to tsunami research, encompassing not only geological and oceanographic studies but also social science perspectives to address the societal implications of these natural disasters.

2. LITERATURE REVIEW

Coastal flooding is a serious and growing threat to many communities around the world. It occurs when seawater inundates land areas that are typically dry, often due to a combination of factors that lead to abnormally high-water levels along the coast.

The primary cause of coastal flooding is storm surges, which are large rises in sea level driven by the strong winds and low atmospheric pressure associated with powerful storms like hurricanes, cyclones, and winter storms. As these storms approach the coast, their winds push water towards the shore, creating a mound of water that can be several feet higher than normal tide levels. At the same time, the low pressure within the storm system allows the sea surface to bulge upwards. When this storm surge coincides with high tide, the resulting water levels can be high enough to overcome coastal defenses and flood low-lying areas. Climate change is exacerbating the coastal flooding threat in several ways. As the planet warms, sea levels are rising due to the expansion of warmer ocean water and the melting of glaciers and ice sheets. Higher sea levels mean storm surges start from a higher baseline, increasing their inland reach. Climate change is also fueling more intense and frequent storms in many regions, leading to more powerful storm surges. Human activities like coastal development, groundwater extraction, and the destruction of natural buffers like wetlands and mangroves are further increasing flood risks. The impacts of coastal flooding can be devastating. Floodwaters can destroy homes, businesses, and critical infrastructure like roads, bridges, and power systems. Flooding can also contaminate freshwater supplies, damage agricultural land, and disrupt transportation networks. Perhaps most tragically, coastal floods often lead to loss of life, particularly when they strike densely populated areas with inadequate warning systems or evacuation plans.

Beyond the immediate impacts, coastal flooding can have long-lasting economic and social consequences. Businesses may struggle to recover from flood damage, leading to job losses and reduced tax revenues for local governments. Families may be displaced for months or years if their homes are destroyed. The psychological trauma of experiencing a flood can also take a heavy toll on survivors, especially children.

Coastal flooding also poses serious environmental threats. Saltwater intrusion can kill freshwater plants and contaminate soils, while the physical force of floodwaters can destroy sensitive habitats like coral reefs and mangrove forests. Floodwaters can also spread pollutants and pathogens, harming ecosystems and human health.

To address the growing coastal flooding challenge, a multi-pronged approach is needed. Investing in robust early warning systems, evacuation plans, and disaster response capabilities is crucial to save lives and reduce immediate impacts. Strengthening and restoring natural coastal defenses like wetlands and dunes can help buffer communities from storm surges. Carefully planned coastal development that avoids high-risk areas and incorporates flood-resilient design is also important. Ultimately, however, the most effective long-term solution is to curb the greenhouse gas emissions driving climate change and sea level rise. By working to reduce emissions and adapt to the changes we can no longer avoid, we can build a safer, more resilient future for coastal communities worldwide.

2.1. Pre-20th century

In pre-20th century Europe, coastal communities employed various measures to protect against flooding and manage water resources. One of the most notable examples is the Netherlands, where land reclamation and water management techniques have been developed since the middle Ages.
The Dutch began building dikes and levees to prevent seawater from inundating low-lying areas and protect agricultural lands and settlements. These structures were constructed using earthen materials and required regular maintenance to remain effective. Over time, the Dutch refined their techniques, incorporating sluices and pumps to control water levels and enhance the efficiency of their water management systems.

In addition to engineered structures, European coastal communities also recognized the importance of natural barriers in flood protection. Mangroves and dunes were often left intact or even enhanced to provide a natural buffer against storm surges and erosion. These ecosystems not only offered protection but also supported local livelihoods and biodiversity.
The integration of traditional ecological knowledge and modern engineering practices allowed European coastal communities to adapt to their dynamic environments and mitigate the risks associated with flooding. As populations grew and development intensified, these early water management techniques laid the foundation for more sophisticated and comprehensive coastal disaster management strategies that continue to evolve today.

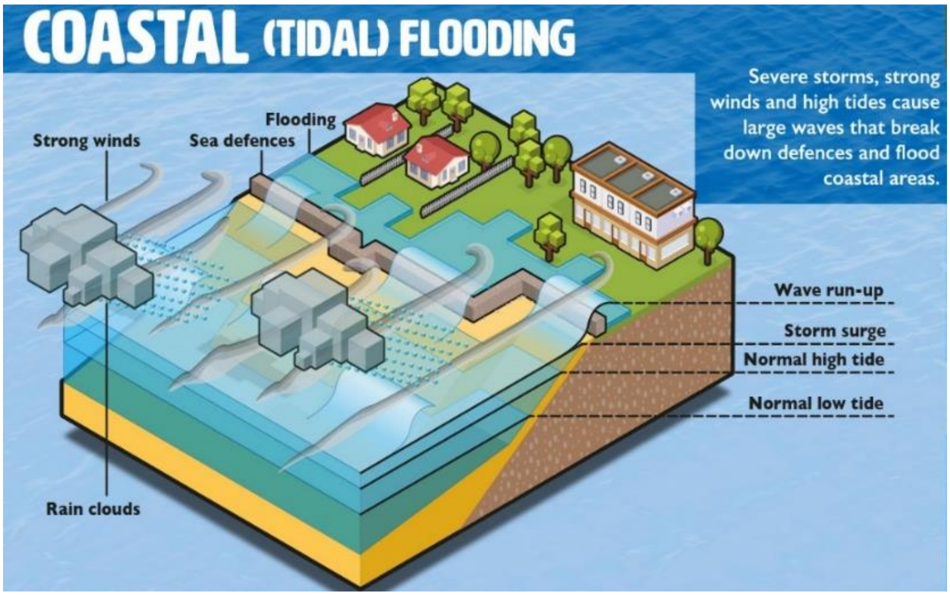

Figure 1 : Measures taken for the Coastal Flooding

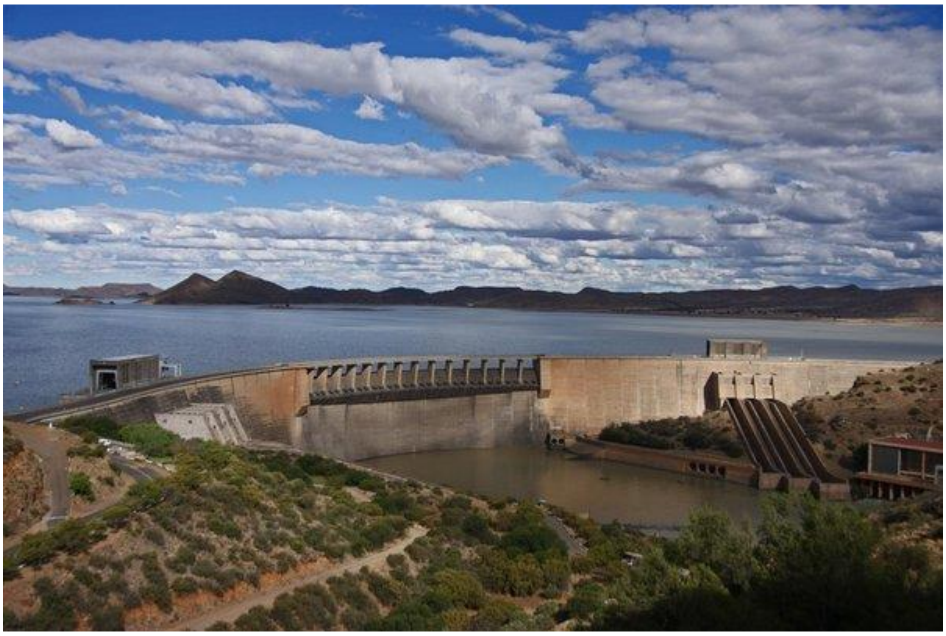

Figure 2 : Gariep Dam, Free State

2.2. 20th Century

In Nigeria, the recognition of local knowledge and practices in flood management has gained significant traction, particularly during the 1970s and 1980s. This period marked a growing global awareness of the importance of integrating traditional methods into contemporary environmental management strategies. Coastal communities in Nigeria have effectively utilized their understanding of local ecosystems to implement various flood mitigation practices, demonstrating resilience and adaptability to their changing environment.

One of the key strategies employed by these communities was the cultivation of early-maturing crops. By selecting crop varieties that could be harvested before the onset of flood seasons, farmers were able to safeguard their food security and reduce the impact of flooding on their livelihoods. This practice not only ensured that communities had access to food during critical periods but also highlighted the importance of agricultural adaptation in the face of environmental challenges. Additionally, traditional practices such as using local plant species for shoreline stabilization and erosion prevention became increasingly prominent. These methods provided effective, low-cost solutions to combat flooding and protect livelihoods. For instance, communities utilized native vegetation to reinforce shorelines, which helped to absorb excess water and reduce the velocity of floodwaters. This approach not only mitigated flooding but also contributed to the preservation of local biodiversity.

The integration of local knowledge into formal flood risk management strategies is crucial for developing sustainable and effective responses to flooding in Nigeria. By leveraging the insights of local communities, flood management efforts can be more adaptive and responsive to the specific challenges faced by vulnerable populations. This approach fosters collaboration between traditional practices and modern engineering solutions, creating a more holistic framework for flood risk management. Moreover, the recognition of local knowledge aligns with the broader global movement towards community-based disaster risk reduction. Engaging communities in the planning and implementation of flood management strategies empowers them to take ownership of their resilience efforts. This participatory approach not only enhances the effectiveness of flood management initiatives but also builds social cohesion and trust within communities.

2.3. 21st Century

The integration of traditional knowledge into modern urban planning has become increasingly vital in addressing coastal flooding challenges. In Ghana, for example, communities have historically employed methods such as building structures away from shorelines and engaging in rituals to appease water deities. These practices reflect a deep understanding of local environmental dynamics and have proven effective in mitigating flood risks. By incorporating such indigenous knowledge into contemporary flood management strategies, urban planners can enhance resilience against flooding.

In the 21st century, various coastal communities worldwide have adopted similar approaches to bolster their defenses against flooding. In the Philippines, local fishermen utilize traditional mangrove planting techniques to restore coastal ecosystems. Mangroves serve as natural barriers against storm surges and flooding, providing not only protection but also critical habitat for marine life. This practice highlights the importance of ecological solutions in urban planning, as it combines environmental restoration with community livelihoods.

Similarly, Indonesia's "Sustainable Coastal Management" initiative encourages the use of local materials and knowledge in constructing flood defenses. For instance, bamboo structures are employed to adapt to changing water levels, showcasing the potential of traditional building techniques in modern applications. This approach not only respects local customs but also promotes sustainability by utilizing renewable resources.

In addition to these practices, many coastal areas are increasingly recognizing the importance of integrating ecological solutions, such as restoring wetlands and coral reefs, which act as natural buffers against flooding. In the United States, communities along the Gulf Coast have implemented controlled burns and managed retreat strategies to reduce flood vulnerability and enhance ecosystem resilience. Controlled burns help maintain healthy ecosystems by reducing underbrush and promoting the growth of fire-adapted species, which can stabilize soils and reduce erosion.

The recognition of diverse tsunami sources, including those triggered by landslides and meteorological events, has broadened our understanding of flood risks. This diversity necessitates a comprehensive approach to flood management that includes not only geological and oceanographic studies but also social science perspectives to address the societal implications of these natural disasters. Engaging local communities in the planning process ensures that their knowledge and experiences are valued, fostering a sense of ownership and responsibility toward flood management efforts.

Moreover, integrating traditional ecological knowledge (TEK) into urban planning can enhance the effectiveness of disaster risk reduction (DRR) strategies. TEK encompasses a wealth of information about local ecosystems, weather patterns, and sustainable practices that have been developed over generations. By combining this knowledge with modern scientific methods, urban planners can create more resilient communities that are better equipped to handle the challenges posed by climate change and coastal flooding.

3. METHODOLOGY

This research employs a qualitative methodology to review existing literature on the integration of traditional knowledge with contemporary disaster risk reduction (DRR) strategies in Chennai, particularly in the context of coastal flooding. The study adopts a systematic literature review approach, focusing on case studies and research articles that highlight the effectiveness of traditional practices in enhancing urban resilience against coastal disasters. Data collection involves sourcing relevant academic papers, government reports, and policy documents, such as the Chennai City Disaster Management Plan (GCC 2021) and the Chennai Master Plan of 2026. These documents will be analyzed to assess the formal recognition of traditional knowledge in urban planning and disaster management frameworks. The analysis will utilize thematic analysis to identify key themes and patterns related to the integration of traditional practices into modern DRR strategies. This process includes coding the literature to extract significant insights regarding community engagement, the effectiveness of indigenous knowledge, and the role of ecological solutions in flood management. To ensure the validity and reliability of the findings, triangulation will be employed by comparing data from multiple sources, enhancing the credibility of the results. Ethical considerations will be maintained throughout the research process by ensuring proper citation of all sources and respecting the intellectual property of the original authors. By synthesizing existing research, this methodology aims to provide valuable insights into how traditional knowledge can be effectively integrated into modern disaster risk management strategies, ultimately enhancing urban resilience in Chennai's coastal communities.

4. CITY PROFILE

Chennai, a low-lying coastal city in southeastern India, faces significant challenges due to its location, rapid urbanization, and the impacts of climate change, including pollution, poor drainage systems, and rising sea levels, particularly affecting seashore settlements like Tondiarpet and Adyar.

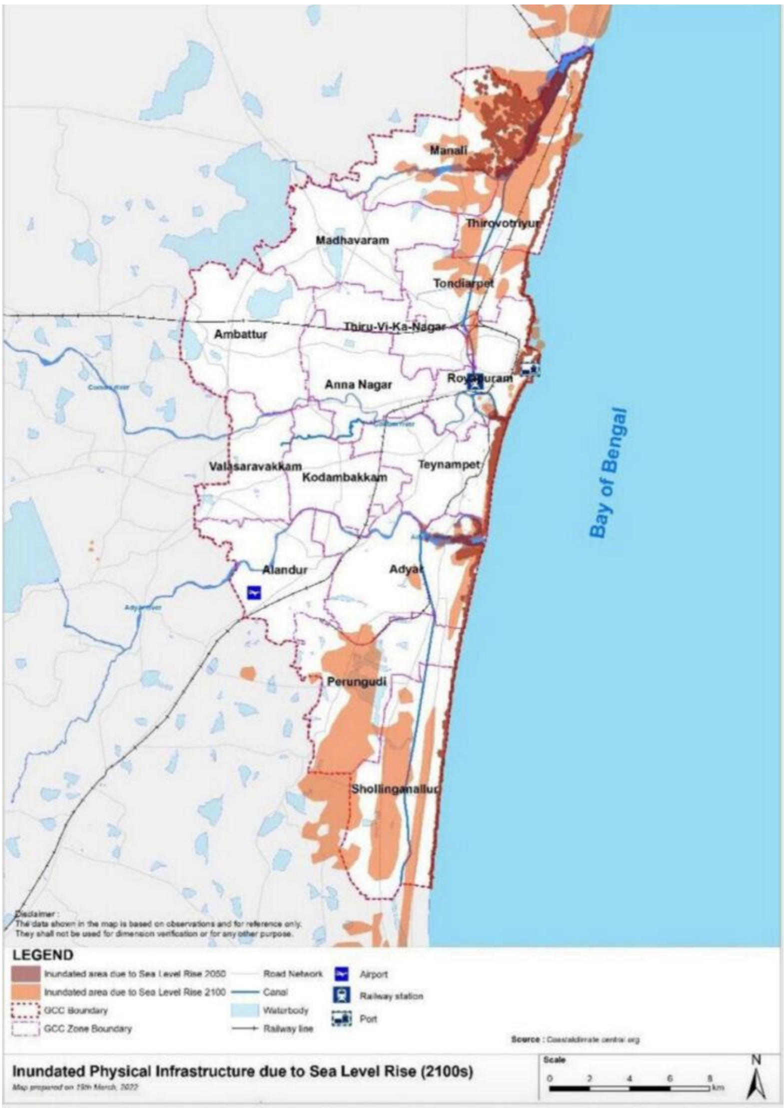

Figure 3: Chennai Map With Sea level Rise (C40 Report,coastal.climatecentral.org/)

The city, situated between 13°04'N latitude and 80°17'E longitude with an average elevation of about 67 meters above sea level, has a land area of approximately 426 square kilometres and a coastline of about 26 kilometres, with the Marina Beach being the second-longest urban beach in the world.
With a population of over 7 million and a density of about 26,553 people per square kilometre, Chennai comprises a mixture of clayey, sandy, and hard rock areas interspersed with several water bodies, including the Cooum and Adyar rivers, which contribute to the city's drainage problems

4.1. Historical Impact of Coastal Hazards

Chennai has a history of many important coastal disasters that have had strong social, physical, and economic impacts on its landform. One such catastrophic event happened in 2004 when the Indian Ocean Tsunami struck, killing over 10,000 people on the 26th of December in Tamil Nadu state. Due to its impact, Chennai has suffered massive infrastructural, housing, and livelihood losses, whose estimated long-term economic impact is approximately $1 billion. The city has also, from time to time, borne the brunt of cyclones, including Cyclone Vardah in December 2016 and Cyclone Nivar in November 2020, with torrential rains and gale-force winds causing massive destruction to housing, transport networks, and power infrastructure for days. Cyclone Nivar alone took 17 lives, and widespread flooding occurred with rainfall exceeding 1,000 mm over four weeks. Of these, the 2015 South India floods were the worst, with a death toll of about 500 people, displacing hundreds of thousands of residents, and costing economic damages of more than $1 billion due to property and infrastructure destruction, and disruption of various services like transport and healthcare. These disasters have exposed the vulnerability of Chennai, driven by rapid urbanization and inadequate drainage, and have underlined the need for an effective disaster risk reduction strategy that marries traditional knowledge with of modern technological solutions to build resilience within the urban coastal city.

Figure 4 : Havocs in Chennai due to Vardah Cyclone (FP Staff, Firstpost)

Figure 5: The Marina Beach raved by the 2004 Indian Ocean Tsunami (S.R.Raghunathan-Frontline)

4.2. Impact of Coastal Disasters on various aspects

4.2.1. Caste Communities-Based Vulnerabilities

Dalit and other marginalized communities in Chennai, such as those from informal settlements or low-lying coastal areas, are most affected by coastal disasters because of entrenched systemic inequality. In fact, after the 2004 tsunami, which killed more than 10,000 people in Tamil Nadu and displaced around 1.89 million, Dalit communities in Nochikuppam said they faced serious discrimination in rehabilitation relief. It had been documented that while aid and rehabilitation efforts provided predetermined and preferential access to non-Dalit fishing communities, often, reports indicated that Dalits were being side-lined, increasing their vulnerability to man-made disasters. For example, in Cyclone Vardah, a manmade disaster in 2016 that had 17 fatalities and several billion rupees in property damage, some 1.5 people were left in dark action, and reports of delays in the distribution of relief in areas like Ennore and Kasimedu are further complicated by the fact that Dalit communities were not well documented and their settlements were not legally recognized. The state's response was derided as tardy, and the caste colors the agencies that offered contributions on time. Again, in the 2015 floods that were a result of Cyclone Vardah—the death toll was quoted as being close to 500 people and around 1.8 million people were displaced—Dalit families in Maduravoyal and Velachery were some who were affected last and reports state that the dominant caste groups in the same localities, based on their influence, got quicker access even to basic relief. The poor drainage and waste management systems similarly worsened health security in these areas. The National Dalit Watch has documented these actively and taken up challenges of caste-based discrimination in disaster relief in post-emergency response contexts from all over India, including the case of Chennai. Morbidity increased while outbreaks of some diseases occurred, and health security decreased, among other serious social harms. As per the National Dalit Watch, around 60% of Dalit families reported not having received sufficient relief during major disasters; this situation indicates desperation for much-needed reforms in the practices of disaster management to prevent caste discrimination.

4.2.2. Gender-Based Vulnerabilities

Women, particularly in the lower socioeconomic stratum, are vulnerable during coastal disasters due to societal role expectations, resource constraints, and gender norms. More than 1.8 million people were displaced by the Chennai floods in 2015, with women worst affected. In Velachery, a flood-affected area, women could not visit the relief camps due to reasons of safety and lack of toilets. According to an IFRC study, 70% of the women in those areas are unable to easily access relief materials due to a lack of gender-sensitive channels of distribution. In addition, domestic burdens increased, as women had to care for children, the elderly, and the sick in very difficult conditions. A post-flood survey showed that while 45% of men in Chennai's slums reported a loss of livelihood, this surged to 65% for women. Women working as informal laborers, be it as street vendors or domestic workers, were severely affected by the loss in income due to the floods, and many reports pegged the figure at 80% of women working in this sector. The risks of gender-based violence, which are major challenges in the temporary shelters, including cases of harassment, have reportedly risen by 20% in the relief camps during the 2015 floods. Healthcare, particularly reproductive health services, has been grossly disrupted, with women from the affected areas at 58 percent reporting no access to required health services after disaster events. In coastal disasters, pregnant women are vulnerable because of their increased need for health care and nutrition. Damages occasioned by Cyclone Vardah included nearly all institutions, including health facilities, an aspect that saw 40% of pregnant women in the affected areas not able to get access to antenatal care during the cyclone and after, according to a study by UNICEF. Moreover, the level of stress and trauma due to the disaster was reported to have led to preterm births. Around 35% of pregnant women reported complications during pregnancy, while 15% of them had a miscarriage or stillbirth owing to a lack of timely medical intervention. Only 25% of the relief camps could boast separate spaces for pregnant women, and less than 10% of them were supplied with essential items like prenatal vitamins and sanitary products.

4.2.3. Age-Related Vulnerabilities

Coastal disasters pose a significant threat to the older population because of their limited mobility, reliance on medication, and frailty. The elderly population of Chennai, which is coastal, was severely affected by the 2004 tsunami. A HelpAge India research found that 30% of the elderly in the impacted districts were forced to leave their homes due to flooding. Many elderly survivors claimed that the upheaval caused them to become estranged from their relatives, which exacerbated their loneliness and contributed to mental health issues. According to HelpAge India, half of the senior respondents stated they could no longer get regular medicine, and 25% said that the lack of medical attention they received in the weeks after the tsunami had negatively impacted their physical health. Only 15% of the relief camps were reported to be elderly-friendly, with proper bedding and access to requisite health care services. Nearly 40% of the elderly respondents to the survey conducted by HelpAge India, an NGO, expressed feelings of isolation and disconnection from the community post-disaster. A UNICEF report said that during Cyclone Vardah in December 2016, 45% of children from these affected areas lost at least three months of schooling. On the other hand, NIDM documented a rise of 20% in the hospitalization of elderly people after the cyclone, with many showing complications from previously existing medical conditions. These statistics underscore the pressing need for targeted interventions to help elderly populations during and after coastal disasters, ensuring that their specific needs are heeded in disaster preparedness and response strategies.

4.2.4. Impacts based on Class

The impact of the 2015 Chennai floods was particularly severe in low-income zones, especially in slum settlements and informal housing. According to the Tamil Nadu Slum Clearance Board, approximately 1.5 million people from slum areas were affected, with nearly 60% of them experiencing either complete or partial damage to their homes. This widespread devastation highlighted the vulnerability of marginalized communities to natural disasters. Research from the Madras Institute of Development Studies revealed that while middle-income households typically took an average of four to six months longer to recover economically, low-income households faced significantly longer recovery times. The disparity in recovery rates underscores the systemic inequalities that exacerbate the challenges faced by the poorest segments of the population during and after disasters. The 2004 Indian Ocean Tsunami also had a profound impact on Chennai's coastal communities, particularly the fishing sector. The United Nations Development Programme reported that over 150,000 people from these communities were affected, with 75% losing their primary source of livelihood. An International Labour Organization survey indicated that it took affected fishermen an average of three years to regain their pre-tsunami income levels, illustrating the long-term economic repercussions of such disasters. In the case of Cyclone Vardah in 2016, Chennai's migrant workers in the informal sector faced unique challenges. Due to their transient status and lack of local networks, many were unable to access proper shelter and relief services. A study by the Indian Institute of Human Settlements estimated that around 40% of informal workers in the affected areas were migrants, with approximately 65% reporting their homes destroyed and 50% experiencing significant reductions in income during the months immediately following the cyclone. The cumulative effects of these disasters reveal a pattern of vulnerability among low-income and marginalized communities in Chennai, exacerbated by inadequate infrastructure, limited access to resources, and systemic inequalities. Addressing these challenges requires a multifaceted approach that incorporates local knowledge, enhances community resilience, and ensures equitable access to recovery resources for all affected populations. By focusing on the specific needs of vulnerable communities, future disaster management strategies can be more effective in mitigating the impacts of natural disasters and promoting sustainable recovery.

4.3. Impacts on Physical Infrastructure

With most of the key highways still submerged, bridges broken, and public transportation systems crippled, Chennai's transportation infrastructure was all but destroyed by the 2015 floods. The Chennai Corporation reports that the flood caused damage to almost 2,000 kilometers of roadways, with an estimated ₹1,500 crore, or over $200 million, in repair expenditures. Southern Railways stated that rail services had been cut by 60% during the height of the floods, and delays continued for several weeks. The city's drainage systems were found to be inadequate due to the flooding, and in November 2015, the heaviest rainfall recorded in 1918—1,049 mm—overtook them. Chennai's coastal communities were severely damaged by the 2004 Indian Ocean Tsunami, especially the low-lying and unofficial colonies. . According to the Government of Tamil Nadu, more than 10,000 houses were either fully or partially demolished in Chennai and the surrounding Coastal area. According to the Tamil Nadu State Disaster Management Authority, the estimated cost for rebuilding and rehabilitation purposes will be more than ₹3,000 crore (approximately USD 400 million). The winds from Cyclone Vardah in December 2016 seriously disrupted the power and water supply in Chennai, as over 12,000 electricity poles and 1,500 transformers were damaged. The event resulted in prolonged power outages, with almost two weeks needed to reinstate the full power supply in the city. Long-term disruptions to the water supply continued for more than a week, with the Chennai Metropolitan Water Supply and Sewerage Board indicating that 30% of the city's water supply was disrupted. These disasters brought out the requirement for better infrastructure resilience and preparedness for disasters in Chennai.

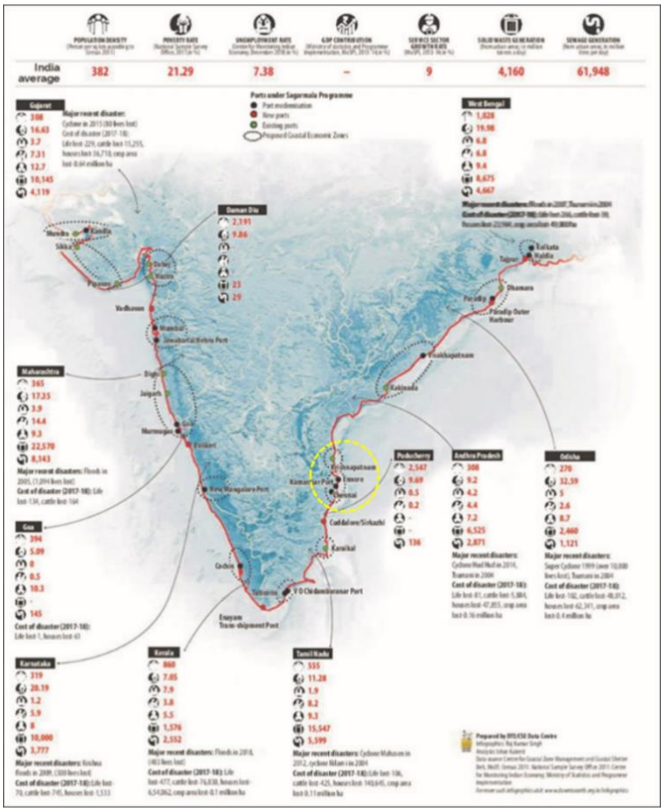

Figure 6: The Vulnerability of India's Coastal Infrastructure (Down to Earth, 2019)

4.4. Impacts on Economic Aspects

The 2015 Chennai floods caused massive disruption to the activities of various economic sectors; SMEs were badly hit since they are the backbone of the economy. Flooding spoiled commercial property, inventory, and machines, leading to huge losses. The losses were pegged at ₹15,000 crore according to an estimate by the Confederation of Indian Industry. A survey conducted by the Tamil Nadu Small and Tiny Industries Association, TANSTIA, shows that almost 75% of SMEs in the affected areas suffered losses; many units remain closed or are still far from recovery. The 2004 Indian Ocean Tsunami destroyed the coastal economies of Chennai—fishing and tourism. The economic losses from the tsunami have been assessed by the United Nations Development Programme as ₹4,000 crore (about USD 500 million) for the State of Tamil Nadu, with a considerable part of its contribution from the fisheries sector itself. State officials in the government estimated that tourist arrivals dropped by 30% in the year after the disaster. According to them, due to the destruction of fishing boats and gear, there had been a sharp drop in fish catch and earnings for fishing communities. Added to this is the tourism sector, which suffered because of the losses at coastal resorts and the general drop in visitors after the disaster; it further compounds the economic impact on these vulnerable sectors. The 2004 tsunami wrought havoc on the coastal economies of Chennai, such as fishing and tourism. Destruction of fishing boats and gear translated into a sudden drop in fish catch and incomes of fishing communities; indeed, the United Nations Development Programme has reported that more than 150,000 persons from fishing communities in Chennai and the surrounding areas were affected, and 75% of them lost their primary source of income. Further, tourism suffered a jolt due to damaged coastal resorts and the total fall of tourists post-disaster, while the state government claimed a 30 percent drop in tourist arrival during the year post-tsunami.

4.5. Impacts on Social Aspects

Many were the neighborhoods whose social cohesion was disrupted due to Cyclone Vardah, especially with migrant workers in large numbers. Winds were strong enough to damage houses, community centers, and places of worship, thereby causing the loss of communal spaces and weakening the social fabric. According to a study by the Indian Institute of Human Settlements, 40% of the affected population reported a loss of community ties; the social networks have been disrupted seriously. Moreover, 50% of the population in the affected areas reported feeling less connected to their neighbors and communities compared to before the cyclone. The social impacts resulting from the 2015 floods were very deep, especially on education and health. According to UNICEF, more than 1.8 million children were affected by school closures during the weeks of floods. Healthcare services also faced much pressure, which is seen from an increase in cases of water-related diseases, like cholera and dysentery, by 30%, according to Tamil Nadu Health Department, further increasing the health challenges in the affected area.

5. TIMELINE OF INDIGENOUS KNOWLEDGE OF DISASTER RISK MANAGEMENT IN CHENNAI

5.1. Ancient Times (Before 10th Century)

Knowing the threats of the seas, early coastal communities in the region relocated their settlements to higher ground or further inland, away from immediate coastal areas, to avoid the full force of storm surges and high tides. For example, the archaeological remains at Arikamedu, a site close to contemporary Puducherry, demonstrate that during ancient times, the cores of coastal settlements were constructed inland, a bit away from the sea lines, on naturally high places and protected by barriers against tides and storms. While protecting their settlements from coastal erosion and storms, natives integral to their use were natural barriers like mangroves, sand dunes, and vegetation along coastlines. According to studies, mangroves can reduce wave energy by as much as 66%, thus considerably attenuating storm impacts. These natural defenses were thus kept and treated as sacrosanct areas, a testament to the great regard of the communities for their environment. For generations, indigenous communities have been learning about seasonal changes, signs of stormy weather, and behaviors of animals and birds indicating coastal hazards through oral traditions.

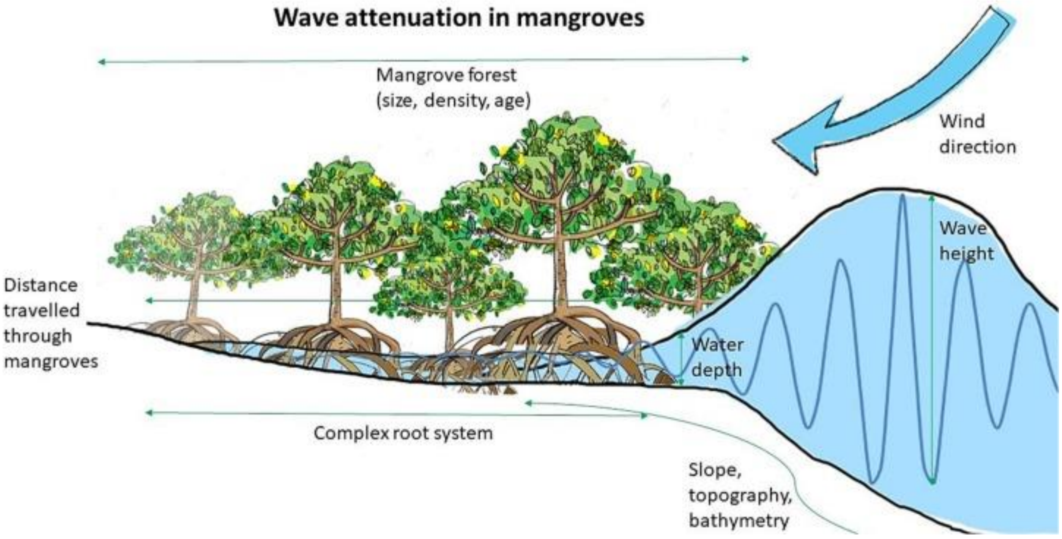

Figure 7: Mangroves root system (Sunkur et al., 2023)

5.2. Medieval Period (10th to 16th Century)

Temples in the medieval period served a double purpose as religious centers and as community refuges managed with associated temple tanks and water management systems to prevent flooding in the nearby settlements caused by its bordering and sometimes dramatic rainfall. In contrast, the shore temple at Mamallapuram, built in the 7th century, is known to evince advanced knowledge not just of coastal geology, but also of coastal engineering. Sited and built using materials and techniques that allow it to survive both coastal erosion and storms, the temple underlines the principal role of coastal engineering in matters to do with coastal community life. Historic records show that houses used to be built on raised platforms that prevent water ingress in the event of flooding—practices that can trace back to medieval times, when the communities started to adapt their construction methods to mitigate risks. Villages set aside stores for grains and other needs such that, even in the case of an extended monsoon, or after a storm, food security was maintained: records exist of well-stored communities recording much lower levels of food shortages during the heavy monsoon years of the late fifteenth century. Also in common use is that of temple tanks as reservoirs for the harvesting of rainwater, and the historical records also demonstrate that the excess of rainwater could be managed well via these systems, not making the surrounding areas at a high risk of rainfall. It is in this way that the combination of religious and pragmatic functions in temple architecture and community organization is emblematic of the high level of disaster risk management characteristic of medieval coastal settlements.

5.3. Colonial Period (17th to 19th Century)

Indigenous practices were, therefore partly regularized in the 17th to 19th-century periods when European introduced colonial urban planning. Traditional knowledge was thus diminishing while European construction methods and materials were introduced in this period. The British colonial administration put up lighthouses, storm shelters, and seawalls by incorporating indigenous knowledge of the local terrain and climate. After the catastrophic Madras cyclone of 1871, which claimed nearly 20,000 lives and caused enormous destruction, the colonial state began constructing more robust structures and building an early weather-warning system. This was the beginning of modern weather information in India. People in the Indian coastal region also relied on various traditional techniques of prediction, such as the appearance of the sea and the use of instruments like a barometer that might have been introduced by the colonial rulers. The knowledge of natural indicators amalgamated the indigenous people's knowledge of natural indicators with colonial tools and helped to make greater preparedness for future storms. The establishment of the Public Works Department of the Madras Presidency in 1858 enabled the execution of projects pertaining to enhanced drainage infrastructure and flood control measures. During the colonial era, local communities demonstrated resilience in the face of shifting governance and environmental constraints, as seen by this adaptation.

6. MODERN ERA (20TH CENTURY TO PRESENT)

In the contemporary period—twentieth century onwards—indigenous knowledge in Chennai merged with modern technology, especially on disaster management and urban master plans. Traditional practices such as mangrove conversation and elevated construction techniques began to form a part of the city's disaster management plans and master plans together with satellite imaging, GIS mapping, and digital early warning systems. For instance, in recognition of the ability of such features to lessen storm surges and floods, the Chennai Master Plan 2026 proposes steps for the preservation of coastal zones and the restoration of natural barriers. Programs for community-based disaster risk reduction have proven to be highly successful in preparing nearby communities by fusing traditional knowledge with contemporary abilities learned through instruction in communication technology and evacuation protocols. Quantitative data from a 2019 report by TNSDMA shows approximately 70% of coastal communities in Chennai have been covered under such programs, with the casualty figures due to disasters coming down by 30% in the last ten years. Further, Tamil Nadu has developed a web GIS-based system called TNSMART, in collaboration with ISRO, covering modules for hazard forecasting, disaster impact assessment, and response planning. As a result, Doppler radar observations and automatic weather stations have been integrated, improving real-time monitoring and enabling a quicker reaction to approaching calamities. Other advantages of this integration process are the community's resiliency and cultural preservation. The drawbacks include the uneven use of traditional knowledge, the continued marginalization of indigenous voices in the planning process, and the constant need to revise plans to adapt them to new dangers. These difficulties highlight how crucial it is to keep the community involved and employ both traditional and contemporary methods to minimize the effects of coastal disasters in Chennai.

7. CHALLENGES

There exist considerable challenges in Chennai to disaster risk management across social, demographic, and physical domains, particularly considering rapid urbanization and current physical settlements in coastal regions. The population density of the city is about 26,000 persons per square kilometer, adding to the vulnerability, for the more populated area, the lesser prepared it is to tackle flooding and other disasters. Coupled with Chennai's flat terrain and the resultant poor drainage, which can handle only about 50% of peak rainfall, there is a tendency for flooding. Indeed, more than 40% of Tamil Nadu's rainfall comes from the northeast monsoon, which makes this problem more serious. The extent to which the 2015 floods have been affecting more than 4 million people and causing more than 470 fatalities makes this city a very serious concern to climate-related emergencies. The rapid and often unregulated urbanization physically results in the degradation of such natural barrier systems—including mangroves and wetlands, which acted as buffers in Chennai against coastal hazards. The 2020 CMDA report estimates that more than 30% of such new constructions within these regions are in high-risk zones, hence very considerably increasing the city's vulnerability to flooding and storm surges. These developments have overstretched the existing infrastructure; the drainage and sewage system of the city, designed several decades ago, is incapable of tackling the increased runoff from these paved surfaces, resulting in frequent waterlogging and enhancing the effect of coastal disasters. Further, indiscriminate urbanization has resulted in the filling up of water bodies and construction over the natural drainage channels, which added to the complexity of disaster management operations. Despite initiatives such as the Chennai Master Plan 2026, that focuses on restoring natural barriers and improved drainage systems, challenges persist over the enforcement of building regulations and community participation in disaster preparedness. Quantitative data from the Tamil Nadu State Disaster Management Authority indicates that, despite 70% of coastal communities having participated in disaster risk reduction programs, erratic application of practices and continuing marginalization of indigenous knowledge mar effective disaster management in the region.

8. CONCLUSION

A multilevel approach is now required to bring Chennai's disaster risk management up to the mark. This will involve integrating the indigenous knowledge into the formal frameworks of disaster management and adding community voices into the planning process. Strengthening resilience through educational programmes about the preparedness of disasters, coupled with advanced technologies like GIS mapping and satellite imaging combining with traditional practices, is the way forward. The TNSMART web GIS-based system in Tamil Nadu has emerged as an exemplary model approach toward real-time hazard forecasting and response. More than 250,579 users could send distress alerts and get flood risk advisories through the system. Further, in addressing the challenges of urbanization, strict enforcement of building codes should be implemented as the population density of around 26,000 people per square kilometer in Chennai overstates the risks of flooding due to deficient drainage systems that can accommodate only around 50% of peak rainfall, and restorations must be made to natural drainage systems in order to address the challenge of flooding as the 2015 floods affected more than 4 million individuals and resulted in more than 470 deaths. The Tamil Nadu State Disaster Management Authority has further underlined the necessity for ongoing revisions to the disaster management plan. The process of monitoring and adapting to the hazards of climate change is ongoing. Chennai won't be able to have a strong framework of disaster management that is resilient, sustainable, and sensitive to the welfare of coastal populations until it is successful in fostering partnership between indigenous groups, government agencies, and technological specialists.

9. REFERENCES

4. The impact of the 2004 Indian Ocean tsunami on economic sectors. (2020). International Journal of Disaster Risk Reduction, 47, 101642. https://doi.org/10.1016/j.ijdrr.2020.101642

5. Tsunami hazard mitigation: Lessons from the 2004 Indian Ocean tsunami. (2021). Natural Hazards Review, 22(4), 04021030. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000292

6. Advances in tsunami research: A review of the past sixty years. (2022). Journal of Geophysical Research: Oceans, 127(3), e2021JC017157. https://doi.org/10.1029/2021JC017157

7. The role of early warning systems in tsunami disaster management. (2023). Disaster Prevention and Management, 32(2), 300-314. https://doi.org/10.1108/DPM-12-2021-0456

8. Coastal community resilience: Strategies for disaster preparedness. (2020). Environmental Science & Policy, 112, 291-299. https://doi.org/10.1016/j.envsci.2020.06.018

9. The socio-economic impacts of tsunamis: A case study of the 2004 Indian Ocean tsunami. (2021). International Journal of Disaster Risk Reduction, 47, 101642. https://doi.org/10.1016/j.ijdrr.2020.101642

10. Coastal flooding: Causes, impacts, and solutions. National Ocean Service. https://oceanservice.noaa.gov/facts/coastal-flooding.html

11. Coastal flooding and sea level rise. Climate Central. https://www.climatecentral.org/what-we-do/our-programs/coastal-flooding-and-sea-level-rise

12. Coastal flooding: Preparing for the future. (2020, September 23). FEMA. https://www.fema.gov/emergency-managers/risk-management/coastal-flooding

13. Coastal flooding and sea level rise: A growing threat. (2021, June 15). Union of Concerned Scientists. https://www.ucsusa.org/resources/coastal-flooding-sea-level-rise

14. Coastal flooding: Causes, impacts, and solutions. (2022, March 22). World Wildlife Fund. https://www.worldwildlife.org/threats/coastal-flooding

15. Coastal flooding and resilience. U.S. Environmental Protection Agency. https://www.epa.gov/arc-x/coastal-flooding-and-resilience

16. Coastal flooding and climate change. (2019, November 5). National Resources Defense Council. https://www.nrdc.org/stories/coastal-flooding-and-climate-change

17. Coastal flooding and adaptation. (2021, April 15). European Environment Agency. https://www.eea.europa.eu/themes/water/european-waters/coastal-and-marine-environment/coastal-flooding-and-adaptation

18. Coastal flooding and resilience: Lessons from the past, strategies for the future. (2020, October 28). National Academies of Sciences, Engineering, and Medicine. https://www.nationalacademies.org/our-work/coastal-flooding-and-resilience-lessons-from-the-past-strategies-for-the-future

19. Coastal flooding and sea level rise: Adapting to the new normal. (2018, September 12). World Bank. https://www.worldbank.org/en/news/feature/2018/09/12/coastal-flooding-and-sea-level-rise-adapting-to-the-new-normal

20. Traditional ecological knowledge in flood management: A case from Nigeria. (2022). Journal of Environmental Management, 302, 114021. https://doi.org/10.1016/j.jenvman.2021.114021

21. Integrating local knowledge in urban planning for flood resilience. (2023). Urban Planning, 8(1), 1-12. https://doi.org/10.17645/up.v8i1.5432

22. The importance of mangroves in coastal flood protection. (2021). Marine Ecology Progress Series, 669, 1-15. https://doi.org/10.3354/meps13730

23. Climate change and its impact on coastal flooding: A global perspective. (2022). Climate Dynamics, 58, 1-20. https://doi.org/10.1007/s00382-022-06015-1

24. Community-based disaster risk reduction: Engaging local populations in flood management. (2020). Disaster Management and Human Health Risk VI, 1-12. https://doi.org/10.2495/DMAN200011

25. Karthik, A. (2021, December 15). *Chennai's floods: the city has learned nothing from the past – here's what it can do. The Conversation*. http://theconversation.com/chennais-floods-the-city-has-learned-nothing-from-the-past-heres-what-it-can-do-172254

26. Subramanian, T. S., Noorani, A. G., SUBRAMANIAN recently, T. S., Chattopadhyay, S. S., Venkatesan, V., Sekhsaria, P., Ramnarayan, G., Gandhi, D., & Roy, V. (2005, January 14). Chennai's black Sunday. Frontline. https://frontline.thehindu.com/cover-story/article30203200.ece

27. Cyclone Vardah creates havoc in Tamil Nadu, thousands displaced from their homes. (2016, December 13). Firstpost. https://www.firstpost.com/india/cyclone-vardah-creates-havoc-in-tamil-nadu-thousands-displaced-from-their-homes-3153670.html

28. *Sea level rise and coastal flood risk maps -- a global screening tool by Climate Central*. Climatecentral.org. Retrieved August 19, 2024, from https://coastal.climatecentral.org/map/9/80.4083/13.0388/?theme=water_level&map_type=water_level_above_mhhw&basemap=cities&contiguous=true&elevation_model=best_available&refresh=true&water_level=4.7&water_unit=m

29. Minority Rights Group International. (2005). India's Dalits refused access to tsunami relief. ReliefWeb. Retrieved from https://reliefweb.int/report/india/indias-dalits-refused-access-tsunami-relief

30. Human Rights Watch. (2005). *After the deluge: India's reconstruction following the 2004 tsunami. Human Rights Watch.* Retrieved from https://www.hrw.org/report/2005/05/25/after-deluge/indias-reconstruction-following-2004-tsunami

31. People's Watch. (2005). *After the tsunami: Human rights of vulnerable populations*. Retrieved from https://www.preventionweb.net/files/715_9451.pdf

32. Berkeley Law. (2005). *After the tsunami: Human rights of vulnerable populations*. Retrieved from https://www.law.berkeley.edu/files/tsunami_full.pdf

33. UN Women. (2022). *Indian Ocean tsunami through the gender lens*. Retrieved from https://wrd.unwomen.org/sites/default/files/2022-03/pincha-indianoceantsunamithroughthegender-lens.pdf

34. Inter-Agency Standing Committee. (2015). *Guidelines for integrating gender-based violence interventions in humanitarian action: Reducing risk, promoting resilience and aiding recovery*. Retrieved from https://sheltercluster.s3.eu-central-1.amazonaws.com/public/docs/2015-iasc-gender-based-violence-guidelines_lo-res.pdf

35. United Nations Children's Fund. (2016). *The state of the world's children 2016: A fair chance for every child. UNICEF*. Retrieved from https://www.unicef.org/reports/state-worlds-children-2016

36. Basnet Bista, S., Standing, K., Parker, S., & Sharma, S. (2016). *Violence against women and girls in humanitarian crisis: Learning from the 2015 Nepal earthquake. ReliefWeb*. Retrieved from https://reliefweb.int/report/nepal/violence-against-women-and-girls-humanitarian-crisis-learning-2015-nepal-earthquake

37. Listo, R. (2018). *Preventing violence against women and girls in refugee and displaced person camps: Is energy access the solution? ScienceDirect*. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S2214629618300963

38. HelpAge India. (2005). *The impact of the tsunami on older people in India: A report on the situation of older people in the tsunami-affected areas of Tamil Nadu*. Retrieved from https://www.helpageindia.org/our-work/welfare-development/disaster-management/

39. UN Women. (2015). *Gender and disaster risk reduction: A guide for practitioners*. Retrieved from https://wrd.unwomen.org/sites/default/files/2022-03/pincha-indianoceantsunamithroughthegender-lens.pdf

40. National Disaster Management Authority. (2016). *A report on the Tamil Nadu floods*. Retrieved from https://ndma.gov.in/sites/default/files/PDF/Reports/TAMIL-NADU-FLOODS-english.pdf

41. International Labour Organization. (2016). *The impact of the Chennai floods on informal workers: A survey report*. Retrieved from https://www.ilo.org/wcmsp5/groups/public/---asia/---ro-bangkok/---ilo-delhi/documents/publication/wcms_496453.pdf

42. Madras Institute of Development Studies. (2016). *Economic impact of the 2015 floods in Chennai: A study of recovery patterns*. Retrieved from https://www.mids.ac.in/publications/economic-impact-chennai-floods.pdf

43. HelpAge India. (2016). *Older people in the 2015 Chennai floods: A study on the impact and recovery*. Retrieved from https://www.helpageindia.org/our-work/disaster-management/chennai-floods/

44. Care Earth Trust. (2016). *Urban flooding and its impact on low-income communities in Chennai: Lessons from the 2015 floods*. Retrieved from https://www.careearthtrust.org/urban-flooding-chennai-2015.pdf

45. Government of Tamil Nadu. (2016). Report on the impact of the December 2015 floods in Chennai: Damage assessment and recovery. Retrieved from https://www.tn.gov.in/tnfloods2015/impact-report.pdf

46. Chennai Corporation. (2016). Chennai floods 2015: A report on the recovery and rehabilitation efforts. Retrieved from https://www.chennaicorp.gov.in/chennaifloods2015/report.pdf

47. International Labour Organization. (2016). The impact of flooding on urban infrastructure and livelihoods in Chennai: A study. Retrieved from https://www.ilo.org/wcmsp5/groups/public/---asia/---ro-bangkok/---ilo-delhi/documents/publication/wcms_496453.pdf

48. Varshney, V., Ghai, R., Kumar, V., Varshney, B., Ghai, B., Kumar, B., Nitnaware, B., Nitnaware, H., Sajwan, B., Sajwan, R., Chauhan, B., Chauhan, S., & Narain, S. (2019). *Down To Earth brings to you latest news, opinion and blogs on environment and science from India and south Asia. Follow us for information on water, waste, climate change and energy among other topics*. Down To Earth. Retrieved August 19, 2024, from https://www.downtoearth.org.in/

49. V Bhagya Subhashini. (2023). Decoding Chennai's floods: Understanding the challenges before finding sustainable solutions. Swarajya. Retrieved from https://swarajyamag.com/infrastructure/decoding-chennais-floods-understanding-the-challenges-before-finding-sustainable-solutions

50. Confederation of Indian Industry. (2016). *Impact of the 2015 Chennai floods on small and medium enterprises*. Retrieved from https://www.cii.in/PolicyAdvocacyDetails.aspx?id=103

51. Tamil Nadu Small and Tiny Industries Association. (2016). *Survey report on the impact of Chennai floods on SMEs*. Retrieved from https://www.tanstia.org/survey-reports/2016/chennai-floods-impact

52. United Nations Development Programme. (2005). *Impact of the Indian Ocean tsunami on the fisheries sector in Tamil Nadu*. Retrieved from https://www.undp.org/content/dam/india/docs/tsunami_fisheries.pdf

53. World Weather Attribution. (2016). *Chennai floods, December 2015: Economic impact assessment*. Retrieved from https://www.worldweatherattribution.org/chennai-floods-december-2015/

54. Care Earth Trust. (2016). *Economic impacts of the Chennai floods on coastal communities: A case study*. Retrieved from https://www.careearthtrust.org/economic-impacts-chennai-floods

55. Kamala Devi, S. (2023). *A study of Vardah cyclone and its impacts in Tamil Nadu*. International Journal of Creative Research Thoughts (IJCRT), 11(10). Retrieved from https://ijcrt.org/papers/IJCRT2310591.pdf

56. TERI. (2017). *Impact assessment study of Cyclone Vardah on Chennai, on East Coast of Tamil Nadu, India*. TIDEE, 16(1). Retrieved from https://bookstore.teri.res.in/e_issue_text_1.php?oj_id=348&sector=849

57. Indian Institute for Human Settlements. (2017). *Long-term implications of humanitarian responses*. Retrieved from https://core.ac.uk/download/pdf/195778139.pdf

58. Tamil Nadu Health Department. (2016). *Health impact assessment of the 2015 floods in Chennai*. Retrieved from https://www.tnhealth.tn.gov.in/health-impact-assessment-2015-floods.pdf

59. UNICEF. (2016). *Chennai floods: Impact on children and education*. Retrieved from https://www.unicef.org/india/reports/chennai-floods-impact-children-and-education

60. Begley, V. (1992). *The archaeological site of Arikamedu: An Indo-Roman trading post in South India*. In *Journal of Ancient India* (Vol. 2). Retrieved from https://doi.org/10.1016/j.jai.1992.01.001

61. Francq, C. (2020). *The Information Centre of Arikamedu – An ancient port on the eastern sea coast of South India*. DHARMA project. Retrieved from https://doi.org/10.58079/nkfa

62. UNESCO. *Did you know? The Port Trade Centre of Arikamedu and Roman Exchange in the Indian Subcontinent*. Retrieved from https://en.unesco.org/silkroad/content/did-you-know-port-trade-centre-arikamedu-and-roman-exchange-indian-subcontinent

63. Indian Vagabond. (2016). *Arikamedu – The lost Roman trading port of India*. Retrieved from https://indianvagabond.com/2016/09/16/arikamedu-the-lost-roman-trading-port-of-india/

64. Wheeler, R. E. M. (1946). *Arikamedu: An Indo-Roman trading station on the east coast of India*. *Journal of Ancient India*, 2, 1-18. Retrieved from https://www.jstor.org/stable/44136767

65. Satyanarayana Murthy, R. N., Srikonda, R., & Kasinath, I. V. (2022). *Traditional water management systems of India*. Journal of the International Society for the Study of Vernacular Settlements, 9(2). Retrieved from https://isvshome.com/pdf/ISVS_9-2/ISVS9.2.5Satyanarayana.pdf

66. Sunkur, R., Kantamaneni, K., Bokhoree, C., & Ravan, S. (2023). Mangroves' role in supporting ecosystem-based techniques to reduce disaster risk and adapt to climate change: A review. *Journal of Sea Research*, *196*(102449), 102449. https://doi.org/10.1016/j.seares.2023.102449

67. Rathi, A. (2019). *Water conservation techniques in ancient and medieval India*. International Journal of Research in Social Sciences, 9(6). Retrieved from https://www.ijmra.us/project%20doc/2019/IJRSS_JUNE2019/IJRSSjune%282%2919.pdf

68. C.P.R. Environmental Education Centre. (2002). *Sacred tanks of South India*. Retrieved from https://www.cprindia.org/publications/working-papers/sacred-tanks-of-south-india
69. Rahman, M. (2018). *The process of urbanization in colonial India (1800-1947 A.D.)*. International Journal of Research and Analytical Reviews, 5(3), 33-39. Retrieved from http://ijrar.com/upload_issue/ijrar_issue_1586.pdf

70. Ahuja, R. (2001). *Urbanization and the changing landscape of Madras: 1850-1950*. In *Urban Studies* (Vol. 38, No. 12). Retrieved from https://core.ac.uk/download/pdf/195778139.pdf

71. Chennai Metropolitan Development Authority. (2008). *Second Master Plan for Chennai Metropolitan Area 2026*. Retrieved from https://www.cmdachennai.gov.in/Volume1_English_PDF/Vol1_Chapter00_Introduction.pdf

72. Tamil Nadu State Disaster Management Authority. (2019). *Disaster risk reduction in coastal communities: A report on community-based programs in Tamil Nadu*. Retrieved from https://tnsdma.tn.gov.in/DRR_Report_2019.pdf

73. World Bank. (2020). *Building resilience in Chennai: A comprehensive strategy for disaster risk management*. Retrieved from https://www.worldbank.org/en/news/feature/2020/05/01/building-resilience-in-chennai

74. ISRO. (2021). *TNSMART: A web GIS-based system for disaster management in Tamil Nadu*. Retrieved from https://www.isro.gov.in/tnsmart

75. India Infrastructure Report. (2021). *Urban resilience and disaster risk management in Chennai: Lessons learned and future directions*. Retrieved from https://www.indiainfrastructure.com/urban-resilience-chennai

76. Revi, A. (2008). *Climate change risk: An adaptation and mitigation agenda for Indian cities*. Environment and Urbanization, 20(1), 207-229. https://doi.org/10.1177/0956247808089157

77. Arabindoo, P. (2016). *Unprecedented natures? An inquiry into the Abu Dhabi floods of 2015*. City, 20(5), 704-717. https://doi.org/10.1080/13604813.2016.1223336

78. Jain, G., Wagner, A., Ainsworth, G., Okoro, U., & Bhatia, S. (2017). *Barriers and enablers to climate adaptation: Evidence from Mumbai*. International Journal of Urban Sustainable Development, 9(2), 210-227. https://doi.org/10.1080/19463138.2017.1322039

79. Chandran, R. (2019). *Chennai's water crisis highlights risk of growing thirst in Indian cities*. Reuters. Retrieved from https://www.reuters.com/article/us-india-water-chennai-idUSKCN1TQ0JN

80. Revi, A., Satterthwaite, D. E., Aragón-Durand, F., Corfee-Morlot, J., Kiunsi, R. B. R., Pelling, M., & Sverdlik. (2014). Urban areas. In *Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 535–612). Cambridge University Press.

Assessing the importance of coastal resilience in Environmental Vulnerability of Coastal City of Kochi, Kerala

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Abstract
Coastal cities are more exposed to disasters that affect their environmental assets because of their geographical position. The primary objective of this research is to provide a thorough methodology for assessing the environmental susceptibility of Kochi, a coastal city located in Kerala, India. Kochi, like to several coastal towns, is affected by inundation, surges caused by storms, and socio-environmental difficulties resulting from its geographic location. These hazards are aggravated by the existence of more vulnerable areas within these cities.

The study aims to analyse the city's distinct features and environmental factors. With the long coastline being the most important of all environmental assets of the city, shoreline change using the Digital Shoreline Analysis System (DSAS) tool, and the physical susceptibility of the area to environmental hazards will be the backbone of this study.
The study proposes a multi-pronged approach that integrates various methodologies and tools. An evaluation of the Kochi shoreline, including its historical changes and projected future changes, provides a definitive understanding of the relevance of the scenario for Kochi. Furthermore, the proposed Vulnerability Index will be used to evaluate the total susceptibility of Kochi's coastal regions to threats like as sea-level rise, accretion, and erosion. In addition, the research will assess the possibility for groundwater recharge using Multi-Criteria Decision Making (MCDM), taking into account aspects such as groundwater contamination and the intrusion of saltwater caused by proximity to the shore. These are used to arrive at most vulnerable areas and arrive at recommendations to decrease large scale destruction and damage of the socio- environmental concerns involved.

The research uses the Environmental Vulnerability Index (EVI) for analysing storm surge inundation and shoreline alteration to analyse the coastal resilience of Kochi, Kerala. These evaluations include the level of exposure, vulnerability, and ability to adapt to hazards, with a focus on how they affect population and urban growth. This research aims to assess the impact on the communities of Kochi by combining existing studies on social vulnerability, shoreline dynamics, and adaptation strategies. The project seeks to enhance Kochi's preparation and resilience against environmental issues by integrating coastal vulnerability assessment, adaption strategies and shoreline change analysis.
Keywords: Shoreline change, coastline, environmental vulnerability

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1. INTRODUCTION

Coastal cities are more exposed to environmental vulnerability because of their geographical position particularly those exacerbated by climate change. They encounter a plethora of dangers, such as intense inundation, storms surges, and increasing river currents. These occurrences have the potential to cause severe destruction to coastal areas, resulting in substantial damage to infrastructure and disruption of people's means of making a living. The importance of coastal resilience in this context cannot be overstated, as it encompasses the ability of both natural and human systems to withstand and recover from these disturbances. This paper aims to provide a methodology for assessing the environmental vulnerability of Kochi, a coastal city located in Kerala, India. Kochi, like to several coastal towns, has environmental assets and disadvantages such as inundation, surges caused by storms, and socioenvironmental difficulties resulting from its geographic location. These hazards are aggravated by the existence of vulnerable areas and ecological variables.

To comprehend the evolving vulnerability of coastal communities to natural hazards amidst the increasing population and economic growth in urban areas, it is important to investigate the differential impacts across diverse socioeconomic contexts. As a result, a growing number of coastal communities are engaging in vulnerability assessments to gain a comprehensive understanding of both human and natural system resilience and adaptive capacities.

However, vulnerability is a contested term as the relationships between the components of vulnerability are often unclear, overlapping or poorly understood. There are different approaches and methods for the selection and aggregation of indicators that are understood to increase or decrease the environmental vulnerability of a region. This paper discusses the approach in understanding environmental vulnerability with the context of the coastal assets of the city. Studies suggest that the vulnerability studies evolved from research under geography and natural hazards which are important and continue to be used in decision making.

Traditionally, physical scientists have adopted a hazard-centric approach to vulnerability assessment, defining it primarily in terms of exposure to physical threats (outcome vulnerability). Although socioeconomic factors have been considered within this framework, their influence has often been secondary to the physical hazard. In contrast, social scientists have tended to prioritize the intrinsic characteristics of populations and urban systems that render them susceptible to harm from shocks or stresses. A Systematic Review of Coastal Vulnerability Mapping However, recent advancements in the general vulnerability assessment literature have led to a convergence of these methods, recognizing the interconnectedness of several factors in determining vulnerability that are of social, economic, cultural, and biophysical nature.

While the coastal regions seem to be distinct unit for various analyses due to geographically clear spatial boundaries and a well-defined set of hazards, this perception may lead to overlooking the need for a multifaceted approach making the delineation of the coastal zone more complex than initially anticipated in terms of the socio-economic and temporal effects that the hazards may have on the region. This paper aims to delve into a specific methodological approach to address the vulnerability assessment of a coastal city such as Kochi taking into account its environmental assets, disadvantages and the guiding socio-economic factors governing development and expansion in Kochi.

1.1 Study Area

The study area is situated in the central part of Kerala, in Ernakulam district bordered by the districts of Thrissur on the north, Idukki on the east and south-east, Kottayam and Alappuzha on the south, and the Lakshadweep Sea on the west. The study area consists of the entire Kochi Municipal Corporation and 11 Coastal Gram Panchayats. The coastal gram panchayats include Elamkunnapuzha, Njarackal, Nayarambalam, Edavanakkad, Pallipuram, Kuzhupilly, Mulavukkad, chellanam, Kumbalangi and a very small part of Cheranallur with a total area of 23030 hectares.

Kochi is one of the fastest growing agglomerations in the state of Kerala; this is evidenced by the growth of the geographical area from 330 sq. km to 440 sq. km between 2001-11. This is indicative that the peri urban region of Kochi, will likely undergo significant structural changes with the transition of rural areas in to urban. These developments are primarily guided by the demand generated by various commercial establishments and industrial townships.

According to the (Census of India 2011 Kerala Series-33 Part XII-B District Census Handbook Ernakulam, 2011) out of total population, 38% is working population. Under which we have 74% of male working population and rest are females. Trade and transportation sectors make up Kochi's largest industry, employing 33.49% of all city workers. Miscellaneous Store Retailers, which account for 16.86% of the city's employment, is a good example. The same is true of professional and business services (27.68%), which are strongly represented in sectors like administrative and support services (15.41%). Kochi's labor force consists of about 970.9 thousand workers.

In recent years due to many large-scale development projects, especially in the construction sector and information technology, substantial employment opportunities are generated in Kochi, which is a positive factor for migration. However, sharp increases in land values and scarcity of developable land prevent lower and middle-income group families from buying land within the city for residential purposes. This has made a good percentage of people opt for residences on the city's outskirts of which a majority of the area lie along the coastal stretch of the city. This pushed forward several infrastructure developments in these areas improving the transportation through road, rail and water routes.

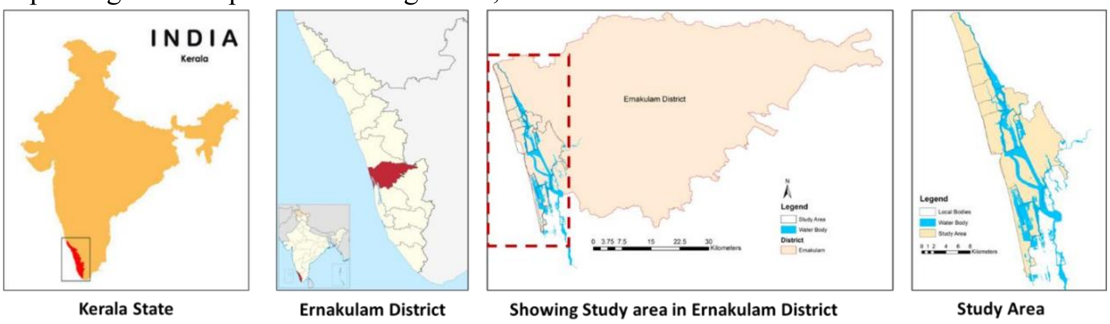

Figure 1: Location of study area

The study area consists of 11 fishing villages with a population of 70,000 fishermen according to the
2011 census. Edavanakkad and Chellanam has the highest population of Fishermen. Njarakkal and Elamkunnapuzha are the areas where the housing conditions are poorer, having more than 50% of semipucca houses. Data sourced from the (*KSCADC*, n.d.) of the socio-economic condition of fishermen community depicts that 60 % of the population are indulged in Inland fishing and nearly 18% of the fishermen housing are classified as Kutcha houses. Fishermen are subject to vulnerabilities of different types. Climate change, migration of fishes and change in fishing techniques makes the fishing a seasonal activity. This results in a highly fluctuating income for the community.

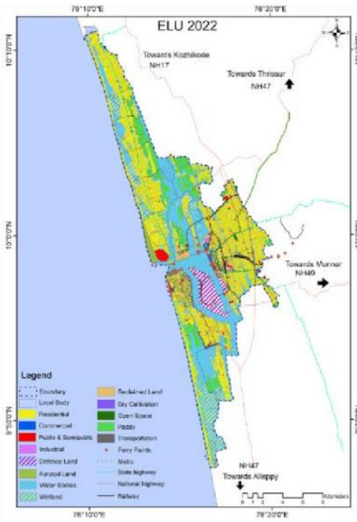

Figure 2: Fishermen population density

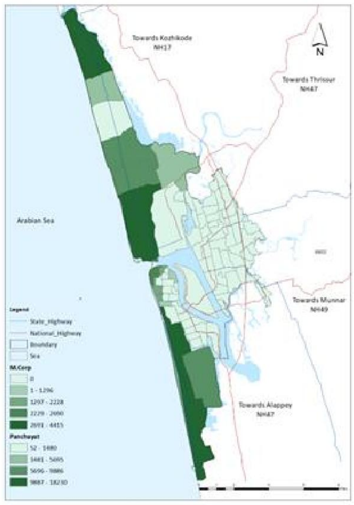

Figure 3: showing BPL population

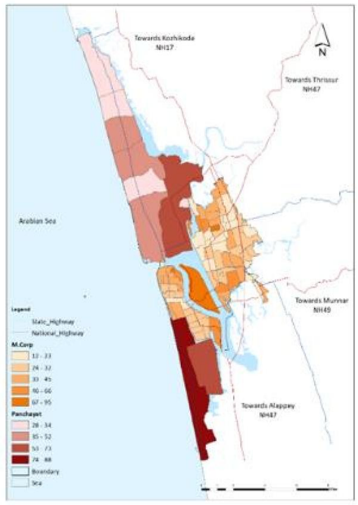

Figure 4: Population density

1.2 Urban Dynamics and Environmental Vulnerability (Literature Study)

With the long coastline being the most important of all environmental assets of the city, shoreline change using the Digital Shoreline Analysis System (DSAS) tool, and the physical susceptibility of the area to environmental hazards will be the backbone of this study. This analysis underscores the need for a comprehensive approach to managing the city's growth and expansion.

Vulnerability fundamentally depends on the capacity of socio-ecological systems to absorb disturbances while maintaining their essential functions and structures (Masselink & Lazarus, 2019). In the case of Kochi, this is affected by a multitude of factors, including urbanization, pollution, and the degradation of natural coastal ecosystems. The integration of technological innovations into coastal planning can significantly enhance resilience and decrease vulnerability by facilitating better resource management and disaster preparedness. According to (Huang et al., 2021) the deployment of spatial data and modelling techniques can help in assessing vulnerabilities and planning effective responses to potential hazards. Such data-driven approaches enable local authorities to make informed decisions regarding land use, infrastructure development, and conservation efforts.

Rapid urbanization significantly impacts coastal ecosystems, leading to increased vulnerability to environmental hazards. As cities expand, they often encroach upon natural buffers such as wetlands and mangroves, which play critical roles in mitigating flood risks and maintaining biodiversity (Pasquali & Marucci, 2021). For instance, highlight the effects of urban and economic development on coastal zone management, emphasizing the need for a comprehensive understanding of dynamics to address coastal erosion effectively (Pasquali & Marucci, 2021). This urban expansion not only exacerbates the risk of flooding and erosion but also leads to habitat loss and increased pollution, further threatening the resilience of coastal ecosystems (Cantasano et al., 2017). Moreover, the impacts of coastal reclamation and anthropogenic activities on natural wetlands underscore the need for a balanced approach to urban planning (Ma et al., 2019). emphasize that understanding the connections between human activities and ecological loss is crucial for developing effective planning initiatives.

The vulnerability of coastal cities is further exacerbated by climate change, which introduces additional risks such as sea-level rise and increased storm intensity. Studies indicate that urbanization in coastal areas often correlates with heightened disaster risk, as seen in the case of small towns in Central Java, Indonesia, where flooding and drought have become more prevalent due to rapid urban growth (Setyono et al., 2018). This trend necessitates the implementation of adaptive strategies that enhance community resilience and reduce exposure to climate-related hazards.

While some studies focus on a single specific hazard to study in a region, others consider multiple hazards and attempted to describe cumulative exposure with respect to the place. Measuring environmental vulnerability, particularly in coastal areas, requires a multifaceted approach that incorporates various parameters, with shoreline change being a critical factor. Shoreline change reflects the dynamic interactions between land and sea, influenced by natural processes such as erosion, sediment deposition, and human activities. This assessment explores methodologies for measuring environmental vulnerability with a focus on shoreline change, drawing on relevant literature.

Shoreline change can be quantitatively assessed using various indicators that reflect the physical and ecological conditions of coastal areas. For instance, the use of remote sensing technologies and Geographic Information Systems (GIS) allows for precise monitoring of shoreline movement over time. These technologies can capture changes in coastal morphology, enabling researchers to analyze patterns of erosion and accretion (Rumson et al., 2019). By integrating these data with socio-economic indicators, researchers can develop comprehensive vulnerability assessments that account for both environmental and human factors (Nguyen et al., 2016). The Digital Shoreline Analysis System (DSAS) is a powerful tool that facilitates this assessment by providing a systematic approach to measuring and analyzing shoreline changes over time. This paper discusses the importance of using the DSAS tool in quantifying environmental vulnerability through shoreline change analysis.

There are several advantages of using GIS for vulnerability assessment is its ability to integrate diverse datasets, including topographical, hydrological, socio-economic, and environmental information. This integration allows for a comprehensive analysis of the factors contributing to vulnerability in coastal areas. For instance, utilized GIS methodology to determine regional vulnerability to natural disasters, integrating environmental, socio-economic, and disaster information to create vulnerability maps that aid in tsunami mitigation planning (Hidayah et al., 2022). Such maps are invaluable for identifying high-risk areas and prioritizing interventions. the vulnerability of coastal areas by considering factors such as geomorphology, sea-level rise, and population density (Zhu et al., 2018). By employing GIS to calculate and visualize these indices, decision-makers can identify areas most at risk and allocate resources effectively. The work of on the Niger Delta exemplifies this approach, where GIS was used to combine inundation and erosion layers with population data to determine the population at risk from flooding (Musa et al., 2014).
One effective method for assessing environmental vulnerability is the development of vulnerability indices that incorporate shoreline change as a key parameter. For example,

propose a flood vulnerability index that integrates various indicators, including shoreline change, to identify the most vulnerable coastal cities and inform adaptation measures (Balica et al., 2012). This index can be adapted to include specific metrics related to shoreline dynamics, such as erosion rates and the extent of coastal habitat loss, providing a more nuanced understanding of vulnerability.

2. Methodology and Datasets

The study proposes a multi-pronged approach that integrates various methodologies and tools. An evaluation of the Kochi shoreline, including its historical changes and projected future changes, provides a definitive understanding of the relevance of the scenario for Kochi. Furthermore, the proposed Vulnerability Index will be used to evaluate the total susceptibility of Kochi's coastal regions to threats like sea-level rise, accretion, and erosion. In addition, the research will assess the possibility for groundwater recharge using Multi-Criteria Decision Making (MCDM), considering aspects such as groundwater contamination and the intrusion of saltwater caused by proximity to the shore.

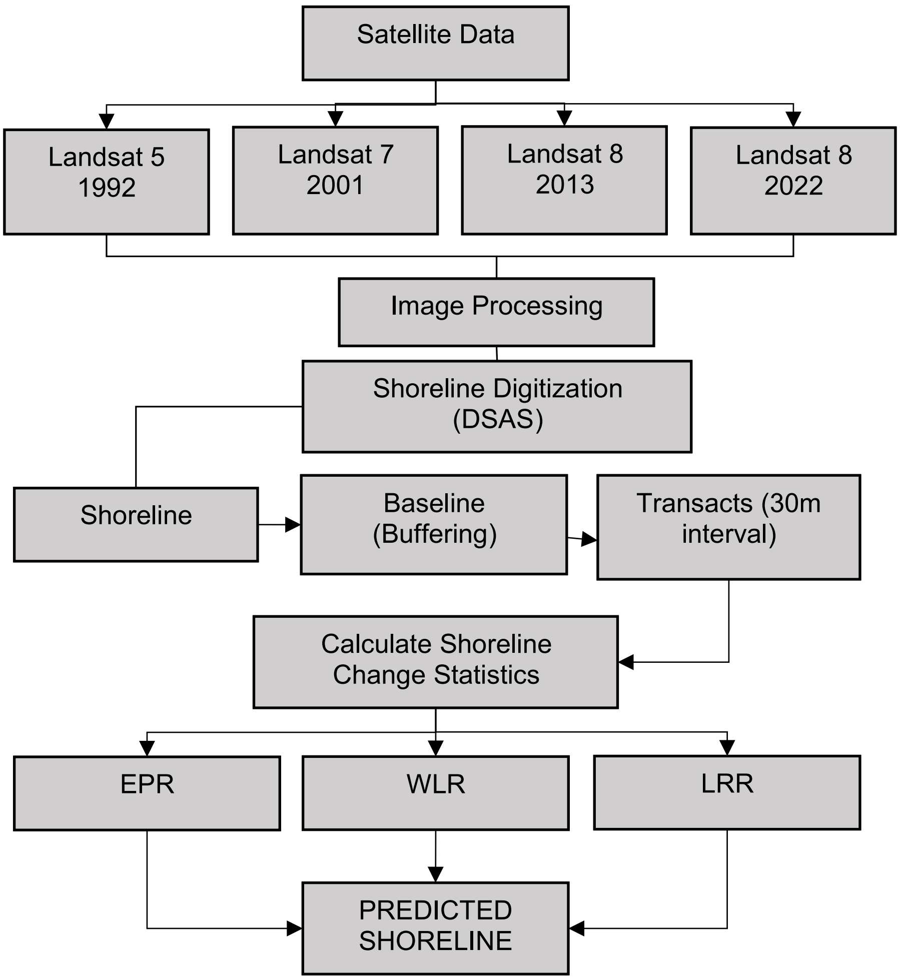

Figure 6: Methodology to assess shoreline change

The flowchart provides an organized approach to evaluating shoreline alterations, which is an essential component in figuring out how vulnerable coastal areas like Kochi are to environmental hazards. In order to examine long-term shoreline patterns, the procedure starts with gathering historical satellite data from several Landsat missions (Landsat 5 in 1992, Landsat 7 in 2001, and Landsat 8 in 2013 and 2022). The Digital coastline Analysis System (DSAS) is used to digitize and map the coastline throughout various time periods once the satellite photos have been processed for accuracy. In order to measure shoreline movement, a baseline is created using buffering techniques, and transects are drawn from the baseline at regular intervals (such as 30 meters). Shoreline changes are quantified using a number of statistical metrics, including End Point Rate (EPR), Weighted Linear Regression (WLR), and Linear Regression Rate (LRR), which are then used to forecast shoreline locations in the future. Planning mitigation techniques and evaluating future environmental concerns depend on this projection. This methodology's emphasis on shoreline change analysis draws attention to its important function in assessing environmental vulnerability in coastal zones, offering vital insights into the effects of coastal dynamics, and guiding the development of successful coastal zone management plans.

It is essential to select appropriate parameters that can effectively capture the dynamics of the shoreline and the factors influencing its stability. Geomorphological features can influence how the shoreline responds to wave action and sea-level rise. (Kumar et al., 2019) emphasized the importance of geomorphology and wave characteristics in their study of coastal vulnerability mapping. Similarly, understanding the socio-economic context of coastal communities is essential for assessing vulnerability. Factors such as population density, economic reliance on coastal resources, and community preparedness can influence how communities respond to shoreline changes. et al. developed a vulnerability index that integrates socio-economic indicators, demonstrating the importance of this parameter in understanding overall vulnerability as seen in (Liu, 2023).

3. Approach to Environmental Vulnerability Assessment

The region of Kochi is particularly vulnerable to environmental vulnerability due to its location in a coastal zone and its distinctive brackish water habitat. One of the most crucial aspects of any coastal zone management is the evaluation of environmental vulnerability across this vast region of 321 square kilometres. The environment is often more susceptible since the changes in environmental indicators are having negative effects. This research evaluates the environmental risk of 74 wards of Kochi Corporation and 11 Panchayats.

The concept of vulnerability, as defined by the Intergovernmental Panel on Climate Change (*AR6 Synthesis Report: Climate Change 2023 — IPCC*, n.d.) is a function of exposure, sensitivity, and adaptive capacity. This framework is essential for understanding how different systems, communities, and ecosystems respond to climate-related hazards, particularly in coastal areas. The term "exposure" describes a system that a natural disaster has an impact on. The creation of vulnerability indices should be done at smaller scales and in a context-specific manner. Vulnerability = Exposure × Sensitivity−Adaptive Capacity. High exposure to climatic threats, high system sensitivity, and inadequate adaptation capacity are all considered instances of high vulnerability. Remote sensing (RS) and Geographic Information Systems (GIS) have developed into effective tools in recent years for evaluating the environment at the macro or micro spatial scale. A few key characteristics of RS and GIS include the ability to create new data by fusing together already-existing datasets and a geographical reference scheme. Studies addressing the evaluation of regional environmental vulnerability are scarce, despite the fact that RS and GIS technology has become a widely

utilised instrument to analyse regional ecological risk, environmental deterioration, and landscape changes.
The environment is impacted by a number of natural and human indicators. It is essential and critical to employ relevant indicators when evaluating environmental vulnerability. First, in order to analyse environmental sensitivity in the coastal region of Kochi, ten indicators were selected based on the literature research and taking into account the soil type, anthropogenic situation, geographic position, and climate. It should be underlined that only the most significant and conspicuous indicators were considered, and that this list was not exhaustive.

The flowchart depicts an evaluation of the three critical environmental vulnerability factors: exposure, sensitivity, and adaptive capacity. The Exposure component indicates the degree to which the system is exposed to hazards and may include components such as environmental pollution. The Sensitivity component concentrate on how vulnerable the system is to harm, taking into account things like human health and environmental conditions. Adaptive Capacity evaluates the capacity to adjust to these risks by taking socioeconomic aspects into account. All of these inputs come together to form the indices for the Ecological Vulnerability Assessment, a key process where the inputs are combined and potentially weighted using techniques such as the Analytic Hierarchy Process (AHP). An ecological vulnerability, which provides vital information for environmental management and decision-making, is the process' end product. It categorises the vulnerability levels. The relationship between these variables and how they help determine and comprehend environmental vulnerability is graphically shown in the flowchart.

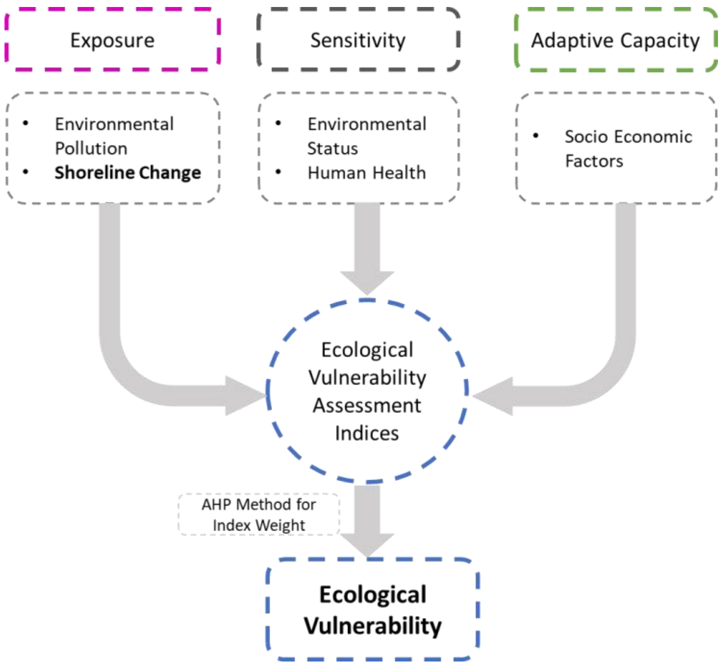

Figure 7: Methodology of Ecological Vulnerability

This analysis includes 10 pertinent indicators after examining the literature, including soil type, average temperature, vegetation change, population density, population change, road density, surface salinity, cumulative dry day (CDD), cumulative wet day (CWD), and groundwater level. The AHP was given to determine the weight for each indicator, and the data were then standardised into a single dimension. The created environmental vulnerability map is divided into five categories, each having a range of vulnerabilities from very low to very high, with intervals of 0-1.5, 1.5-1.75, 1.75-2, 2-2.25, and >2.25, respectively. The results of an environmental vulnerability assessment can provide useful direction for long-term environmental management, particularly in the management of coastal zones. With the aid of environmental indicator data and the PCA approach, the development framework may be evaluated at various geographical and temporal scales in the coastal zone. The **Table 1** shows the respective weights arrived at, for each parameter.

Table 1: Showing weightages for each indicator

Indicators	**Weight**
Soil	0.120301
NDVI change	0.091370
Average max temperature	0.052774
Dry season GW level	0.096398
Salinity	0.097947
CDD	0.131289
CWD	0.070529
Population density	0.119253
Population density change	0.112745
Road density	0.107393

4. Results and Discussion

The analysis of the shoreline changes yielded interesting results. For efficient understanding of the change in shoreline, the area of study was divided into six transects or zones and understood separately. In each zone, the accretion and erosion of the shoreline was quantified for a period of 30 years from 1992 to 2022 as represented in **Figure 8**. Zone 3 shows the highest levels of erosion and the highest levels of accretion in the entire coastline under study. The study reveals significant changes in the coastal landscape of Kochi over the past three decades, with erosion and accretion observed in certain areas. The Environmental Vulnerability Index (EVI) categorizes coastal areas into five levels: very low, low, moderate, high, and very high vulnerability. High vulnerability areas, such as Chellanam and Edavanakkad, are characterized by socio-economic reliance on fishing, poor housing conditions, and limited adaptive capacity. Moderate vulnerability areas, like Kochi City and Kumbalangi, are driven by urban development pressures and ecological degradation. Low vulnerability areas, like mangrove restoration projects and coastal defenses, show effectiveness in enhancing coastal resilience. Groundwater recharge potential is also highlighted, with the Multi-Criteria Decision Making (MCDM) analysis highlighting the need for protective measures. The socio-economic assessment highlights the complex interplay between environmental vulnerability and community resilience, with areas with a high concentration of fishing communities facing economic instability and inadequate housing. Recommendations for enhancing coastal resilience include integrated coastal zone management, restoration of natural barriers, infrastructure resilience, and community engagement and education.

4.1 Shoreline Change Analysis

The ability of DSAS to analyze long-term shoreline changes is particularly valuable in the context of climate change and increasing human pressures on coastal ecosystems. highlighted the successful application of DSAS in assessing the effects of natural and anthropogenic factors on shoreline morphology in the Gulf of Cagliari, Italy (Biondo et al., 2020).

By analyzing historical shoreline positions, researchers can identify trends in erosion and accretion, which are critical for predicting future changes and assessing environmental vulnerability. This predictive capacity is vital for coastal management, as it allows for the development of strategies to mitigate risks associated with shoreline change.

In this scenario, the entire study area is divided into six zones to understand the erosion and accretion rate in detail. The linear regression rate for six zones.

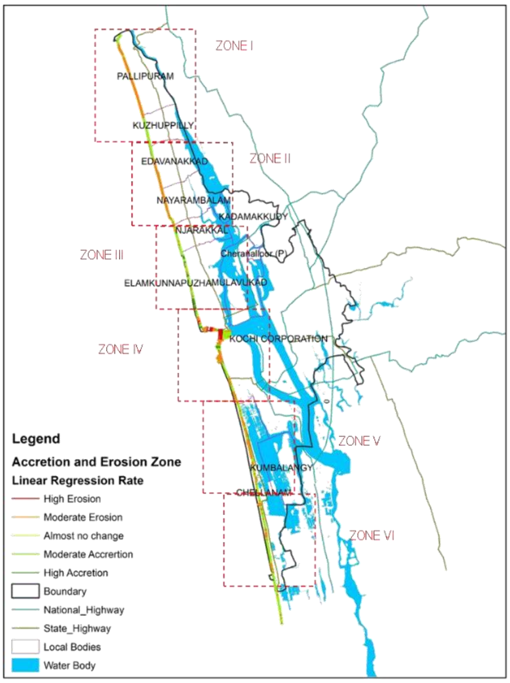

Figure 8: Accretion and Erosion zones of coastline.

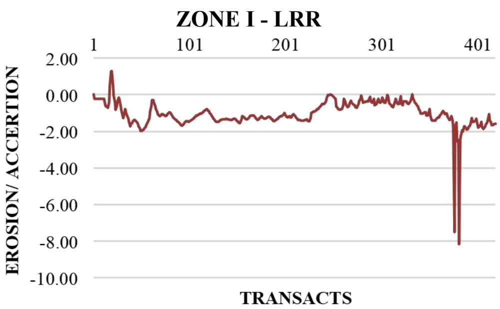

Figure 9: Showing erosion and accretion rate in zone I

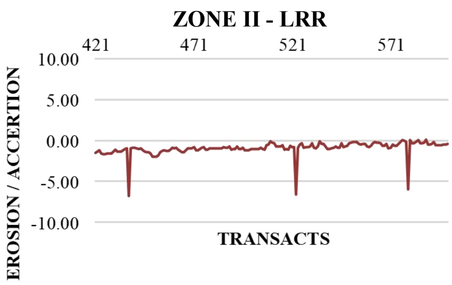

Figure 10: Showing erosion and accretion rate in zone I I

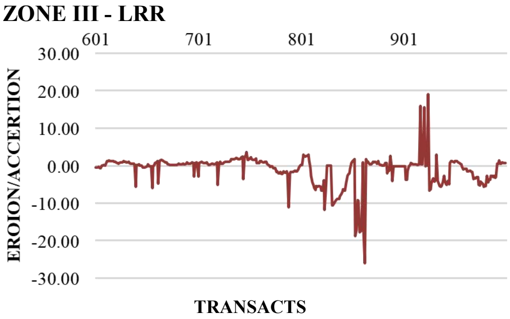

Figure 11: Showing erosion and accretion rate in zone III

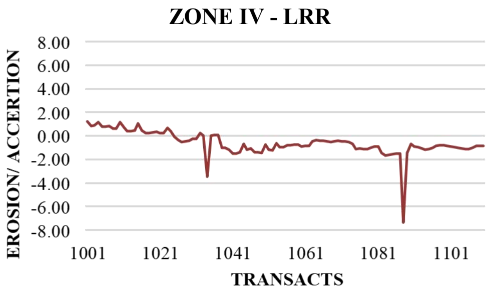

Figure 12: Showing erosion and accretion rate in zone IV

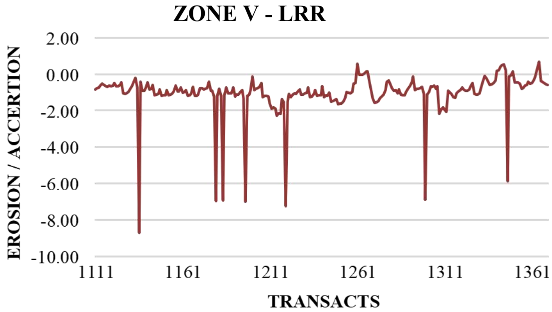

Figure 13: Showing erosion and accretion rate in zone V

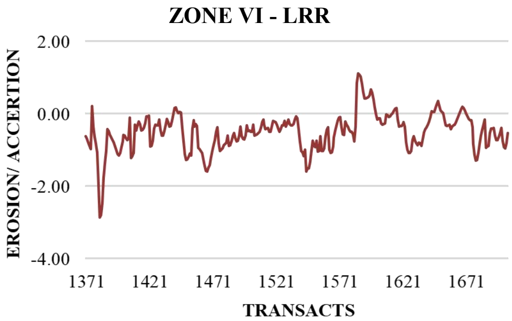

Figure 14: Showing erosion and accretion rate in zone VI

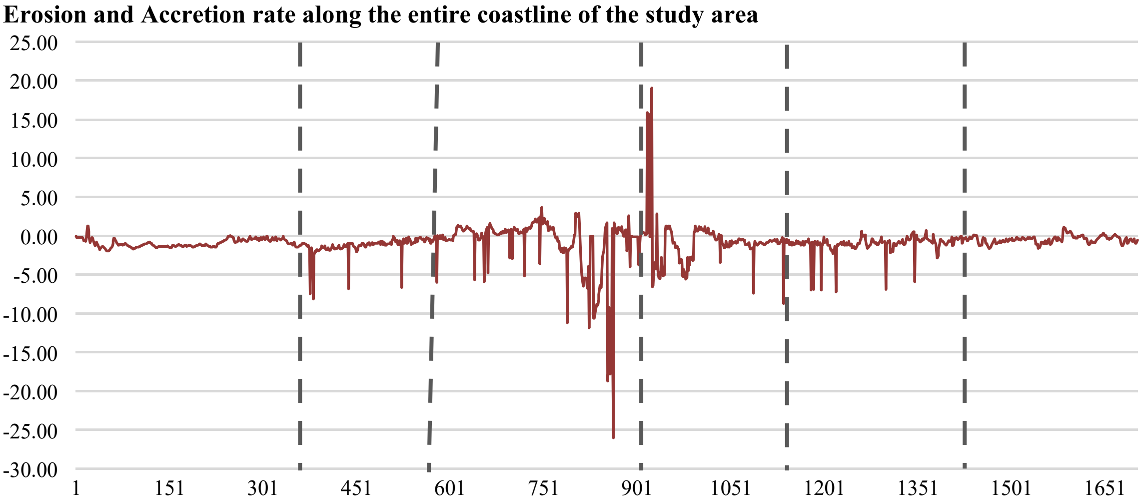

Figure 15: Erosion and Accretion rate along the entire coastline of the study area

4.2 Environmental Vulnerability

Five vulnerability categories interval of their gathered data make up the created map for each particular indication. Moreover, the environmental vulnerability map is divided into five classes of vulnerabilities, with very low, low, medium, high, and very high vulnerabilities.

Spatial Distribution of Indicators

Surface soil is essential for the development of vegetation and plants as well as for preventing topsoil erosion. Erosion is halted by the soil's compacted characteristics. The ability of soil to store more water can help to enhance the land. According to our investigation, clayey soil and sandy soil is found the most. Due to the region's importance for agriculture, the soil quality is good for the environment.

The loss of biodiversity and environmental deterioration are both halted by vegetation. Saline intrusion and sea level rise brought on by climate change are anticipated to have a negative effect on the current vegetation type. The current eco-environmental behaviour is hampered by the fast vegetation change. Vegetation cover between 2001 and 2011 was used to measure NDVI changes. Our study shows that most of the region has seen moderate to significant vegetation change over the course of an 11-year period in grasslands and moderately dense. While the western section of the territory exhibits a rise in vegetation, the eastern part of the area exhibits a loss in vegetation, this could be due to the rise in CBD. For the evaluation of environmental vulnerability, this is particularly concerning.

Because there isn't enough access to fresh surface water in the coastal area, groundwater has been disappearing at an alarming rate. The surface water cannot be used for irrigation or domestic purposes due to a significant salt intrusion. Groundwater depletion is mostly caused by population stress and demand. Emphasis on long-term groundwater depletion should be made, where there is more urbanisation and human density.

Kochi’s crops are susceptible to rising temperatures. The crops produce less when temperatures are high. The total temperature in this nation has increased as a result of the effects of climate change.

A cumulative dry day (CDD) is the total of all of the dry days in a given year. The environment will ultimately become more susceptible as a result of the rising temperature and CDD. If the CDD rises, the soil loses sufficient moisture and becomes more susceptible to saline intrusion.

The total of all of a year's consecutive rainy days is known as a Cumulative Wet Day (CWD). The environment is placed at danger when CDD rates rise and CWD levels fall. Without sufficient rainfall, surface water dries up, which is followed by decreased recharge, increased groundwater pumping for drinking and irrigation, and scorching weather. Due to the insufficient supply of freshwater from upstream, the salt level rises.

Salinity levels rise when seawater intrusion causes freshwater to become more salinized. When the freshwater flow in the upstream area decreases, this gets severe. Aquaculture, irrigation, and other water-related occupations all depend heavily on surface water. Salinity prevents it from being used for many things. Freshwater crops like rice would suffer as a result of this. In comparison to the study area, the southern region has high amount of saltwater intrusion.

Road density is taken into account when evaluating environmental vulnerability since traffic congestion causes pollutants on the roadways, such as petrol and fuel emissions. Road density is high in the CBD, areas further to CBD have low road density. High population density, urbanisation, coastal development, and a rise in tourism are all followed by a high road density.

Many types of pollution may be produced by human development and urbanisation, including the discharge of domestic garbage, unauthorised building, and automobile emissions. Due to urbanisation, property that was formerly utilised for other purposes needs to be converted to residential land. In the urban region, there is a high population density.

In most areas of the Southern zone, population density is observed to be low the salinity, this could be due to unavailability of fresh water in that region. Just a few significant cities with thriving industries and economic growth have high densities. The unchecked population expansion has a detrimental effect on the ecosystem.

The population change in the Southwest area between 2001 and 2011 has been computed. The majority of the area has seen medium to high population change. The high saline level in many areas of this region is the cause of the alterations. This may be a sign that the environment has changed to make it difficult for humans to survive. Because of the negative effects of salinity and the difficulties in making a living, people have occasionally moved to large cities and other locations.

Figure 16: Showing soil type

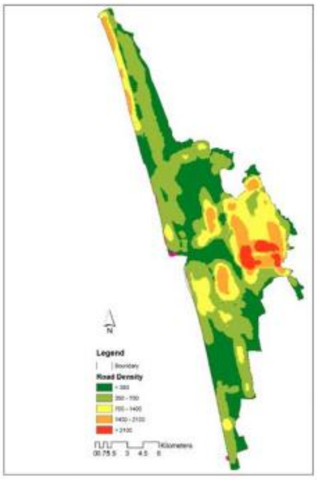

Figure 18: Showing Road density

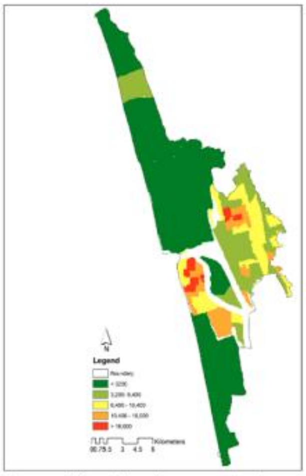

Figure 20: showing population density

Figure 17: showing change in NDVI

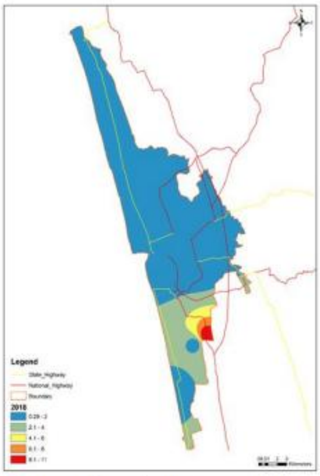

Figure 19: showing average ground water depth

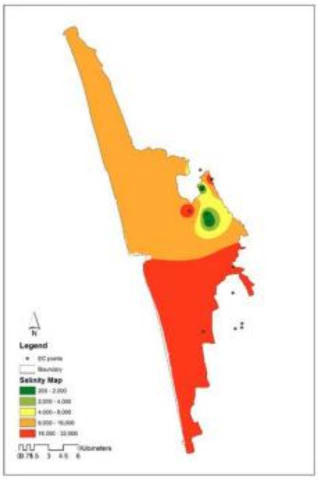

Figure 21: showing salinity

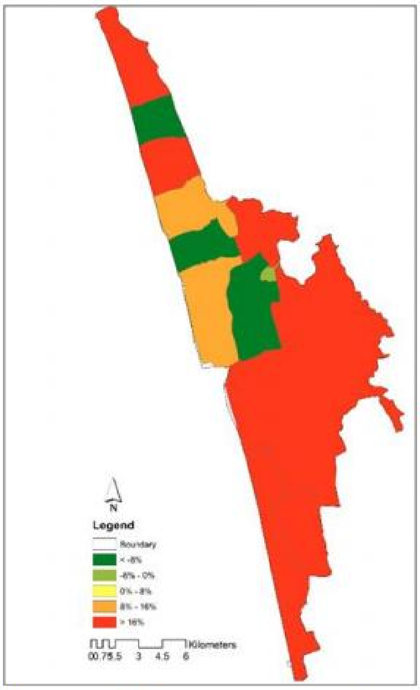

Figure 22: Showing change in population density

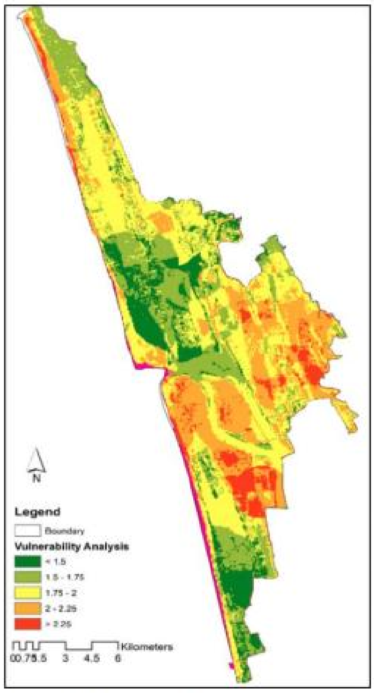

Figure 23: Spatial distribution of environmental vulnerability

5. Observation

The Net Shoreline Movement shows overall 865.29 meters of negative distance and 655.1 as positive distance, it shows approximately 81% of the shore is showing erosion and 19% of the shore is showing accretion.

EPR is calculated by dividing the distance of shoreline movement by the time elapsed between the oldest and the most recent shoreline.

EPR= NSM/ (time between oldest and most recent shoreline)

The average rate of the shore as per End point rate is -0.91m/year, which shows erosion. The maximum erosion value is -28.85 meters and accretion value is 21.84 meters.

Table 2: showing condition of shoreline in the study area

S. NO	LOCATION	CONDITION OF SHORE
1	Zone I	Moderate Erosion
2	Zone II	Moderate Erosion
3	Zone III	Moderate Accretion
4	Zone IV	Moderate/High erosion
5	Zone V	Moderate Erosion
6	Zone VI	Moderate Accretion

6. Conclusion

Kochi is more environmentally fragile due to its geological characteristics. It has a large population and long coastline. People must struggle greatly to live close to the coast due to the small amount of useable terrain. Ten variables were taken into account in this study to determine how vulnerable the regional ecosystem is. The AHP is used with GIS to calculate the weights of ten indicators. These strategies allow us to combine varied spatial information better than other conventional ways. The findings indicate that the moderate to high environmental sensitivity zone covers more than half of the territory. The situation is really concerning. Monitoring the state of a few chosen indicators is necessary to reduce vulnerability in the South-East area. These analysis underscores the need for a comprehensive approach to managing the city's growth and expansion.

A contemporary method for understanding environmental vulnerability is the framework presented in this study. This may be used at various geographical and temporal scales while taking into account pertinent indicators for a particular location. The analysis also includes certain restrictions. Due to the lack of recent data, the socio-economic data was primarily from 2011. The findings presented the trend using the available data.

7. References and Citation

AR6 Synthesis Report: Climate Change 2023 — IPCC. (n.d.). Retrieved September 19, 2024, from https://www.ipcc.ch/report/sixth-assessment-report-cycle/

Balica, S., Wright, N., & Meulen, F. v. d. (2012). A Flood Vulnerability Index for Coastal Cities and Its Use in Assessing Climate Change Impacts. *Natural Hazards*, *64*(1), 73–105. https://doi.org/10.1007/s11069-012-0234-1

Biondo, M., Buosi, C., Trogu, D., Mansfield, H., Vacchi, M., Ibba, A., Porta, M., Ruju, A., & Muro, S. D. (2020). Natural vs. Anthropic Influence on the Multidecadal Shoreline Changes of

Mediterranean Urban Beaches: Lessons From the Gulf of Cagliari (Sardinia). *Water*, *12*(12), 3578. https://doi.org/10.3390/w12123578

Cantasano, N., Pellicone, G., & Ietto, F. (2017). Integrated Coastal Zone Management in Italy: A Gap Between Science and Policy. *Journal of Coastal Conservation*, *21*(3), 317–325. https://doi.org/10.1007/s11852-016-0479-z

Census of India 2011 KERALA SERIES-33 PART XII-B DISTRICT CENSUS HANDBOOK ERNAKULAM VILLAGE AND TOWN WISE PRIMARY CENSUS ABSTRACT (PCA) DIRECTORATE OF CENSUS OPERATIONS KERALA. (n.d.).

Hidayah, Z., Rohmah, N. N., & Wardhani, M. K. (2022). Coastal Vulnerability Study on Potential Impact of Tsunami and Community Resilience in Pacitan Bay East Java. *Forum Geografi*, *36*(1). https://doi.org/10.23917/forgeo.v36i1.17160

Huang, X., Song, Y., & Hu, X. (2021). Deploying Spatial Data for Coastal Community Resilience: A Review From the Managerial Perspective. *International Journal of Environmental Research and*

Public Health, *18*(2), 830. https://doi.org/10.3390/ijerph18020830

KSCADC. (n.d.). Retrieved September 19, 2024, from https://www.keralacoast.org/coastalmanagement.php

Kumar, B. S., Balukkarasu, A., & Tamilarasan, K. (2019). Coastal Vulnerability Mapping Using Remote Sensing and GIS Techniques in Tuticorin Coast of Tamil Nadu, India. *Journal of Geography Environment and Earth Science International*, 1–12. https://doi.org/10.9734/jgeesi/2019/v20i230100

Liu, X. (2023). Comprehensive Assessment of Vulnerability to Storm Surges in Coastal China:

Towards a Prefecture-Level Cities Perspective. *Remote Sensing*, *15*(19), 4828. https://doi.org/10.3390/rs15194828

Ma, T., Li, X., Bai, J., & Cui, B. (2019). Impacts of Coastal Reclamation on Natural Wetlands in Large River Deltas in China. *Chinese Geographical Science*, *29*(4), 640–651. https://doi.org/10.1007/s11769-019-1049-8

Masselink, G., & Lazarus, E. D. (2019). Defining Coastal Resilience. *Water*, *11*(12), 2587. https://doi.org/10.3390/w11122587

Musa, Z. N., Popescu, I., & Mynett, A. E. (2014). The Niger Delta's Vulnerability to River Floods Due to Sea Level Rise. *Natural Hazards and Earth System Science*, *14*(12), 3317–3329.
https://doi.org/10.5194/nhess-14-3317-2014
Nguyen, T. T. X., Bonetti, J., Rogers, K., & Woodroffe, C. D. (2016). Indicator-Based Assessment of Climate-Change Impacts on Coasts: A Review of Concepts, Methodological Approaches and Vulnerability Indices. *Ocean & Coastal Management*, *123*, 18–43.
https://doi.org/10.1016/j.ocecoaman.2015.11.022
Pasquali, D., & Marucci, A. (2021). The Effects of Urban and Economic Development on Coastal Zone Management. *Sustainability*, *13*(11), 6071. https://doi.org/10.3390/su13116071
Rumson, A. G., Hallett, S. R., & Brewer, T. (2019). The Application of Data Innovations to Geomorphological Impact Analyses in Coastal Areas: An East Anglia, UK, Case Study. *Ocean & Coastal Management*, *181*, 104875. https://doi.org/10.1016/j.ocecoaman.2019.104875
Setyono, J. S., Handayani, W., Rudiarto, I., & Esariti, L. (2018). Resilience Concept in Indonesian Small Town Development and Planning: A Case of Lasem, Central Java. *E3s Web of Conferences*, *68*, 01027. https://doi.org/10.1051/e3sconf/20186801027
Zhu, Z., Cai, F., Chen, S.-L., Gu, D., Feng, A., Cao, C., Qi, H., & Chen, Y. (2018). Coastal Vulnerability to Erosion Using a Multi-Criteria Index: A Case Study of the Xiamen Coast. *Sustainability*, *11*(1), 93. https://doi.org/10.3390/su11010093

Impact Prediction using Cyclone-Risk Identification Framework - A Case of Thane Cyclone 2011, Tamil Nadu Coast

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Abstract

Cyclone is a Natural Hazard which is capable of causing mass destruction to human livelihood and properties. According to National Disaster Management Authority of India, the Indian subcontinent is one of the worst affected regions in the world in terms of Cyclones and on an average, five to six tropical cyclones form every year, of which two or three could be severe. Considering the severity and frequency of the Disaster caused by Cyclones, this study attempts to build a Framework to compute the areas affected by Cyclones before the impact through Weather Forecast data, which can then be used for Disaster Response Measures. In this study, Parameters of the Cyclone Thane of 2011 is taken to compute the areas affected by Storm Surge and Fluvial Floods through tools such as ADCIRC, HEC-HMS, HEC-RAS.
Storm Surge caused by the Cyclone was estimated with the datasets such as the Tidal Database, Bathymetry Data, Cyclone Parameters such as Cyclone Track, Windspeed, etc. Fluvial Flooding caused by Cyclonic Rain was estimated with the datasets such as Digital Elevation Map (DEM), Rainfall Data, Soil Type Data, Land Use Land Cover (LULC) map. This assists in identifying and prioritizing the settlements which are in severe need of disaster relief measures. This study attempts to incorporate the datasets and tools required to estimate the hazards into a Framework which can estimate the Extent and the Time of the Impact of the Cyclonic Hazards such as Storm Surge and Fluvial Floods. Through this Framework, forecasted Cyclone parameters can be utilized to estimate the affected areas beforehand which can be vital is saving lives and livelihood of the people.

Keywords: Cyclone; Disaster Response; Storm Surge**;** Fluvial Floods.

1. INTRODUCTION

Cyclones are among the most devastating natural disasters, characterized by powerful rotating winds around a low-pressure centre. These storms can cause widespread destruction through intense winds, heavy rainfall, storm surges, and flooding. Coastal areas are particularly vulnerable, often experiencing severe damage to infrastructure, homes, and agriculture. The aftermath of a cyclone can lead to significant loss of life, displacement of communities, and long-term economic impacts. Effective disaster preparedness and response are crucial to mitigating the severe consequences of cyclones, which are becoming more frequent and intense due to climate change. India, located in South Asia and bordered by the Bay of Bengal, the Indian Ocean, and the Arabian Sea, is particularly vulnerable to tropical cyclones. The country experiences two to four cyclones annually, most of which make landfall along the east coast, particularly affecting the states of West Bengal, Odisha, Andhra Pradesh, and

Tamil Nadu. The west coast is less frequently hit, but states like Kerala, Karnataka, Maharashtra, Gujarat, and Goa are still at risk.

Tamil Nadu, located on India's southeastern coast, is highly vulnerable to cyclones, especially in its northern regions. The state faces frequent tropical cyclones due to its proximity to the Bay of Bengal, where these storms often form. The rising trend in the magnitude of cyclones hitting Tamil Nadu underscores the need for a more effective and dynamic disaster response framework to manage and mitigate the impacts of these storms. The existing disaster response measures in Tamil Nadu have shown significant gaps, as highlighted by the challenges faced during the Chennai floods and the Gaja cyclone. In these events, the lack of swift rescue and relief operations left many stranded, and communication breakdowns exacerbated the difficulties in carrying out rescue missions. These incidents highlight the urgent need to improve disaster response strategies to optimize resource use and save lives.

To address these challenges, there is a need for an advanced Impact Prediction and Cyclone-Risk Identification Framework. Such a framework would enable better prediction of cyclone impacts, allowing for more targeted and efficient disaster response measures. By identifying high-risk areas and potential impacts in advance, authorities can allocate resources more effectively, ensure quicker and more organized evacuations, and reduce the overall damage caused by cyclones. This proactive approach is crucial as the intensity and frequency of cyclones continue to rise, particularly in vulnerable regions like Tamil Nadu. Implementing such a framework would not only enhance the resilience of affected communities but also minimize the economic and social disruptions caused by these devastating natural disasters.

2. MATERIALS AND METHODS

Existing Framework for Disaster Risk Identifications of the Study Area were researched before developing the Cyclone-Risk Identification Framework for Impact Prediction. It was noticed that the existing Framework contains existing Vulnerable Areas and the Impact Predication is based on the atmospheric conditions on these vulnerable areas. Various studies regarding Storm Surge Estimation and Fluvial Flood estimation were researched in order to develop Cyclone-Risk Identification Framework as these weren’t included in the Existing Framework. Numerous studies have been conducted to estimate storm surges and fluvial floods using various advanced models. The ADCIRC (ADvanced CIRCulation) model is frequently employed to simulate storm surges, as it captures the time-varying water levels during extreme weather events like cyclones. This model uses detailed shoreline geometry and an unstructured mesh to represent complex coastal topographies, ensuring precise predictions. In parallel, hydrological models like HEC-HMS (Hydrologic Engineering Center's Hydrologic Modeling System) and hydraulic models such as HEC-RAS (River Analysis System) are widely used for simulating fluvial floods. These models consider land elevation, precipitation, land use, and soil type data to calculate runoff and map floodplains. By integrating these models, it is possible to generate comprehensive cyclone risk assessments that are essential for disaster planning, mitigation strategies, and effective emergency response, particularly in regions prone to both storm surges and riverine flooding.

2.1 Existing Framework for Impact Prediction

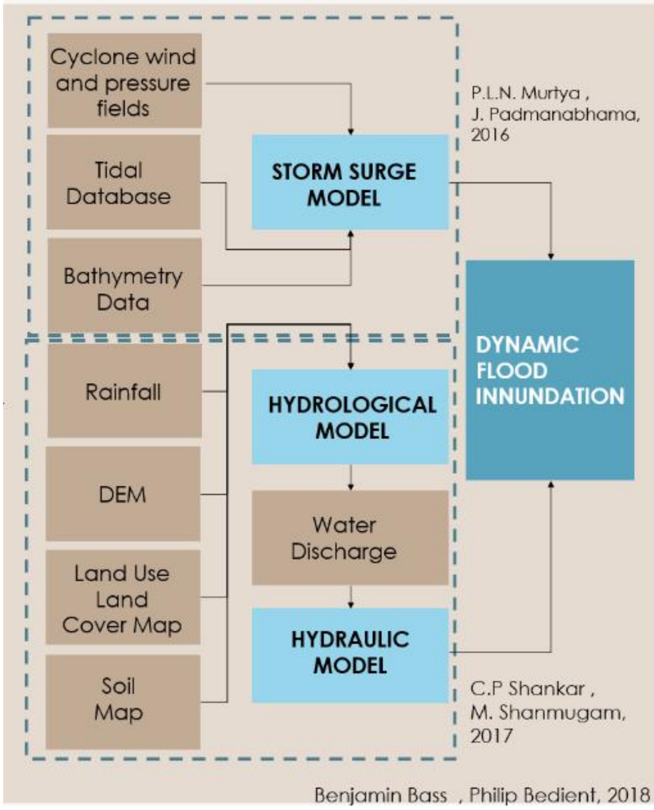


Figure 1: Existing Literatures for Storm Surge and Fluvial Flood Impact Estimations.

The 2021 Cuddalore District Disaster Management Plan is a comprehensive guide aimed at enhancing emergency management and disaster preparedness in the region. It provides detailed protocols for cyclone preparedness, type of response measures, location of the cyclone shelters, and dispatch of relief goods. This plan is structured around the guidelines set by the National Institute of Disaster and aligns with the Sendai Framework Project's principles of disaster risk reduction. A key emphasis of the plan is on the empowerment of local communities, promoting self-help and the active involvement of local groups in the relief process. By fostering community resilience and ensuring swift, organized responses in grassroot level, the plan aspires to minimize the impact of disasters and facilitate quicker recovery. (Cuddalore District Disaster Management Plan, 2021)

Tamil Nadu, with its extensive coastline and dense population of over 72 million, is highly vulnerable to a range of both non-seasonal and seasonal hazards. More than half of the state’s population resides in coastal areas, making them particularly susceptible to natural disasters such as cyclones, floods, and tsunamis. These hazards annually disrupt the lives of thousands, exacerbating the state’s socioeconomic challenges by affecting livelihoods, damaging infrastructure, and straining resources. In response to these significant risks, the Tamil Nadu Government has partnered with the Regional Integrated Multi-Hazard Early Warning System (RIMES) to create the TNSMART Application. This innovative tool is designed to enhance the state's disaster management capabilities by providing real-time monitoring of hazard risks. TNSMART is meticulously aligned with the four priority areas of the Sendai Framework for Disaster Risk Reduction: understanding disaster risk, strengthening disaster risk governance, investing in disaster risk reduction, and enhancing disaster preparedness. By integrating these principles, the application empowers the government to make informed decisions, improve governance structures and ensure that communities are better prepared for disasters. TNSMART is equipped with advanced features that include Hazard Forecasting and Impact Forecasting, utilizing weather forecast data and information on existing vulnerable locations. It integrates a GIS-based database containing comprehensive data such as administrative boundaries (state, district, division, taluk, revenue village), hamlet locations, land use patterns, and vulnerable areas. Additionally, it maps critical elements like water bodies (rivers, lakes, tanks), Digital Elevation Models, transportation networks (roads, railways), and vital infrastructure such as dams, mines, hospitals, and relief centres. This extensive data supports precise and effective disaster management and response efforts. Ultimately, TNSMART represents a critical step forward in safeguarding the lives and well-being of Tamil Nadu's residents by proactively managing disaster risks. (TNSMART Report, 2018)

2.2 Storm Surge Modelling

Coastal areas are affected by a complex interplay of physical processes, including tides, storm surges, waves, and ocean currents during Cyclonic Landfall. Understanding the interactions between these forces is crucial for predicting the impact caused by Cyclone in the region. Storm surges, which are significant rises in sea level caused by cyclones, are particularly challenging to model and predict due to their dependence on multiple factors. These factors include the cyclone's track, wind intensity, the timing of tides, and the slope of the shoreline. To model storm surges, a combination of sophisticated models is employed. The Weather Research and Forecasting (WRF) Model is used to predict the cyclone's track, providing crucial data on the storm's path and intensity. The Dynamic Holland Model simulates the wind fields associated with the cyclone, which play a significant role in generating storm surges. The Simulating WAves Nearshore (SWAN) Model is utilized to simulate the behavior of tides during the cyclone, offering insights into the interaction between tidal movements and the storm surge. Finally, the ADvanced CIRCulation (ADCIRC) Model calculates the time-varying water levels during storm surge events. This model uses detailed geometry data of the shoreline with an unstructured mesh to represent the complex topography of coastal areas, ensuring precise storm surge predictions. (Bhaskaran et al., 2013)

A Coupled Wave and Hydrodynamic Model, combining SWAN (Simulating WAves Nearshore) and ADCIRC (ADvanced CIRCulation) with the Holland Symmetric Wind Model, is essential for computing storm surges. These models simulate the interactions between waves, wind, and ocean circulation during storm events. The resulting storm surge predictions are invaluable for disaster planning, mitigation strategies, and emergency response efforts. However, the accuracy of these models heavily relies on the resolution of the unstructured mesh used to represent the ocean's geometry. Higher-resolution meshes provide more precise simulations, leading to better-informed decision-making in disaster management. (Deb & Ferreira, 2016)

2.3 Hydrological and Hydraulic Modelling

Land elevation, precipitation, land use, and soil type data are critical components in calculating runoff through hydrological models like HEC-HMS. This model simulates the rainfall-runoff process, with the runoff data being essential for hydraulic models like HEC-RAS, which map the floodplain of a region. The SCS Curve Number, derived from soil type and land use data, plays a key role in estimating runoff, reflecting how different surfaces respond to precipitation. By incorporating forecasted precipitation into these models, it is possible to generate pre-flood inundation maps, providing valuable insights into potential flood areas before an event occurs. These maps enhance the flood warning system, allowing for timely and accurate warnings that can help protect lives and property by enabling proactive measures and effective emergency response planning. (Balbhadra Thakur et al., 2017). Joint flood risk for cyclones can be assessed by integrating storm surge models like ADCIRC with hydrological and hydraulic models such as HEC-HMS and HEC-RAS. This approach combines predictions of storm surge impacts with calculations of runoff and floodplain mapping, providing a comprehensive evaluation of flood risks. This integration enhances disaster preparedness and response by offering a more complete understanding of potential flooding scenarios. (Benjamin Bass & Philip Bedient, 2018)

3. METHODOLOGY

The following methodology outlines the steps undertaken in assessing the hazards caused by Thane cyclone in Tamil Nadu. The process involved a comprehensive review of literatures for existing disaster management practices of the Study Area, estimation of cyclone-induced hazards, and the application of modeling techniques to understand storm surge and fluvial flooding.

3.1 Study Area

Cuddalore District, situated along Tamil Nadu's eastern coastline, is notably vulnerable to tropical cyclones due to its geographical and topographical characteristics. Bordered by the Bay of Bengal to the east, Cuddalore is one of the most cyclone-affected districts in Tamil Nadu. Its low-lying terrain, combined with a catchment area encompassing nearly 40% of the state, significantly increases its susceptibility to cyclonic events. Even when cyclones do not make direct landfall in Cuddalore, the intense rainfall generated in the broader catchment area often leads to severe fluvial flooding within the district. The district features a 68 km coastline and is crisscrossed by five major rivers: the Thenpennaiyar, Gadilam, Uppanar, Vellar, and Kollidam rivers. These rivers contribute to both the flood risk and the overall hydrological dynamics of the region. The district's vulnerability is further highlighted in a 2018 National Disaster Management Authority (NDMA) report on the Gaja Cyclone. The report categorizes the cyclone proneness of various Indian districts, with Cuddalore emerging as one of the most susceptible to tropical cyclones. Key factors contributing to this vulnerability include the frequency and intensity of cyclones, wind speeds, and the potential for maximum storm surges and precipitation. The scope of this study focuses on three specific administrative taluks within Cuddalore District, which are identified as particularly prone to cyclonic activity in the District Disaster Management Plan. These taluks are Cuddalore Taluk, Bhuvanagiri Taluk, and Chidambaram Taluk. By concentrating on these cyclone-prone areas, the study aims utilize the Cyclone-Risk Identification Framework with parameters of the Thane Cyclone of 2011 to predict the Impact of the Hazards such as Storm Surge and Fluvial Floods.

3.2 Existing Impact Prediction Framework

The State of Tamil Nadu employs a specialized tool for disaster management, known as the Tamil Nadu System for Multi-Hazard Potential Impact Assessment, Alert, Emergency Response Planning, and Tracking (TNSMART), to support existing disaster response measures.

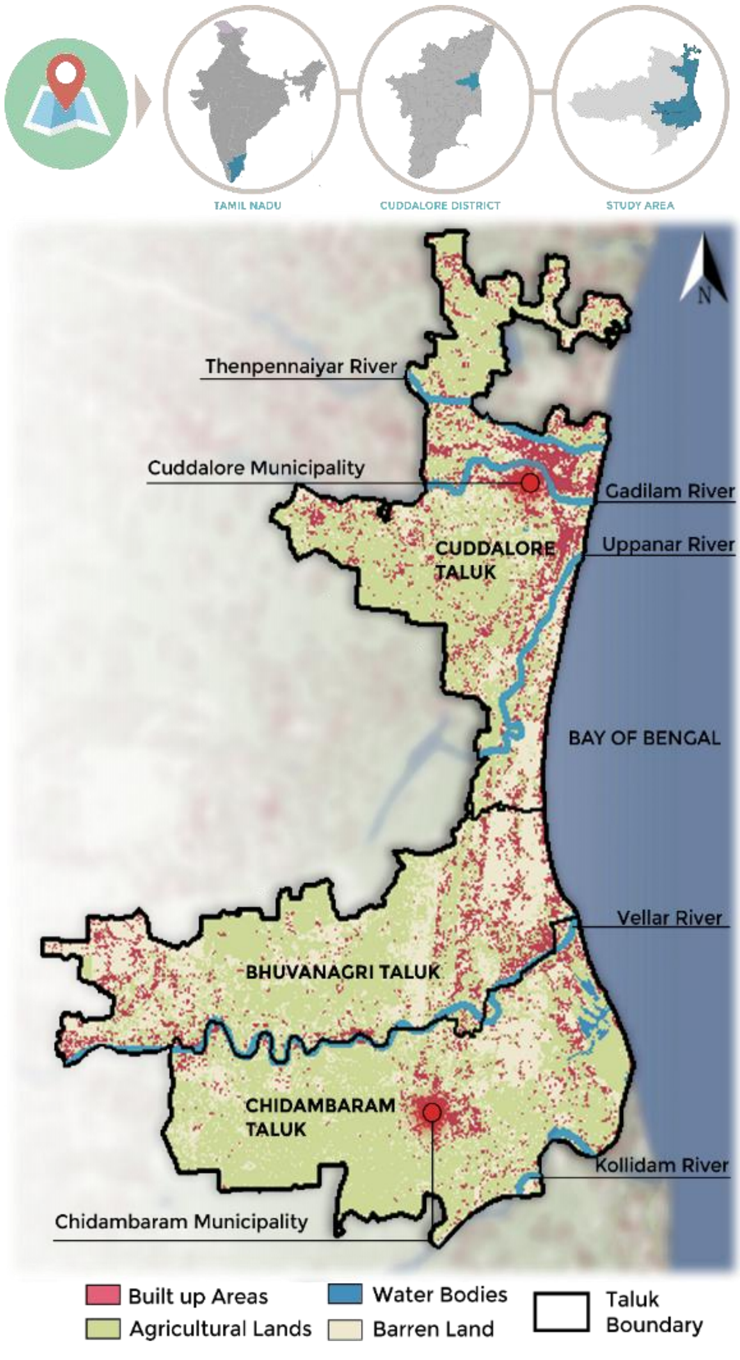


Figure 2: Study Area.

TNSMART is a sophisticated decision support tool designed specifically for disaster response planning in Tamil Nadu, developed by the Regional Integrated Multi-Hazard Early Warning

System (RIMES). This tool supports the state's disaster management framework by integrating various data sources and models to enhance response effectiveness. The framework for existing disaster response measures, was developed in Figure 3, based of the TNSMART report authored by Dr. Korlapati Satyagopal IAS, Mr. Itesh Dash, and Dr. Jothiganesh Shanmugasundaram, outlines how TNSMART operates.

TNSMART leverages weather forecast data from several authoritative sources, including the Indian Meteorological Department (IMD), the European Centre for Medium-Range Weather Forecasts (ECMWF), and the RIMES Experimental Weather Research Forecasting Model, along with an Ensemble Model. This comprehensive data integration allows for accurate and timely predictions of weather-related hazards.

A critical component of TNSMART's functionality involves the mapping of flood-inundated areas through ground surveys. These surveys identify vulnerable locations and their specific

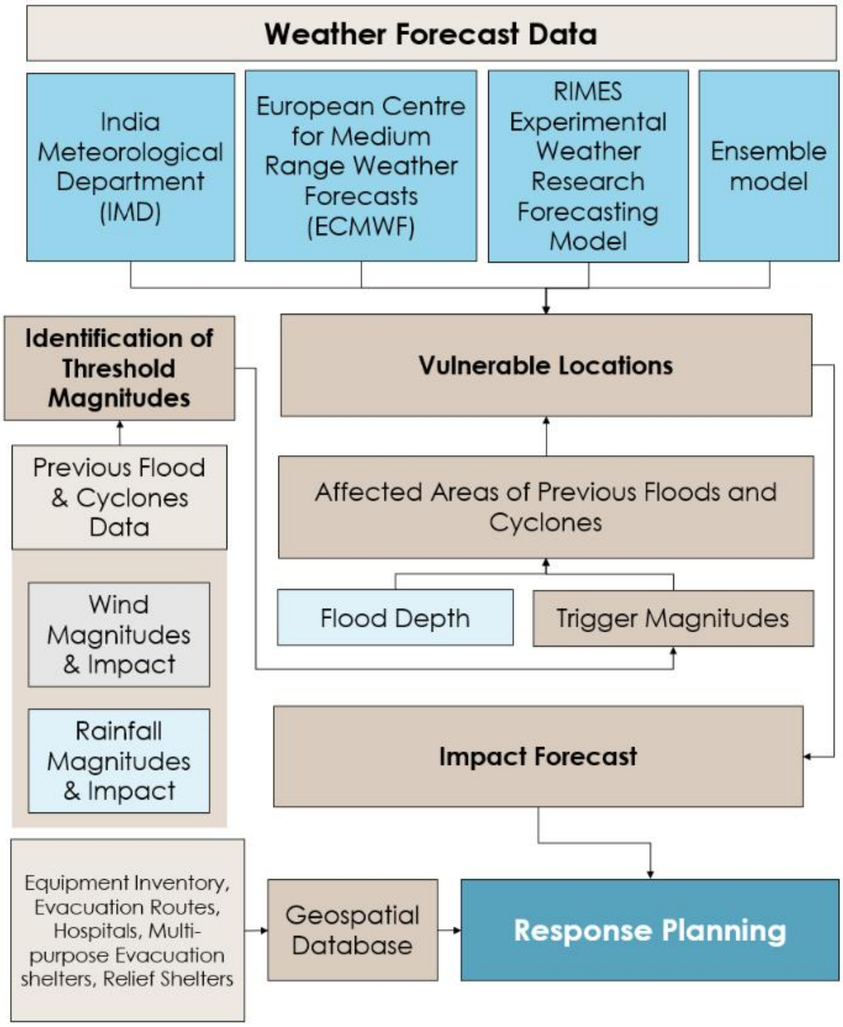


Figure 3: Framework of TNSMART.

flood depths, which are then used to establish "Trigger Magnitudes." A Trigger Magnitude represents the level of a hazard at which a particular area becomes significantly impacted. This threshold is determined based on historical data from previous floods and cyclones, which helps in predicting the impact of similar future events. The identification of these vulnerable areas and their corresponding Trigger Magnitudes enables detailed impact assessments. These assessments are carried out by analysing the dynamic results generated by weather forecast systems. The forecasts provide valuable insights into potential flood and cyclone impacts, allowing for more informed and proactive response planning. Based on these impact forecasts, the Tamil Nadu Government can formulate and implement response strategies tailored to the anticipated severity of hazards. This systematic approach ensures that disaster response efforts are well-coordinated and effective, enhancing the state's ability to manage and mitigate the impacts of natural disasters.

3.3 Scope for Improvement

Although there already an Impact Prediction Framework exists, which addresses the Dynamicity of a Disaster, there are room for enhancement in several areas.

- First, the framework does not account for topography, catchment areas, and river geometry, which are crucial factors influencing fluvial floods.
- Second, it lacks consideration of storm surges, which depend on cyclone track, wind speed, tidal height, and regional bathymetry.

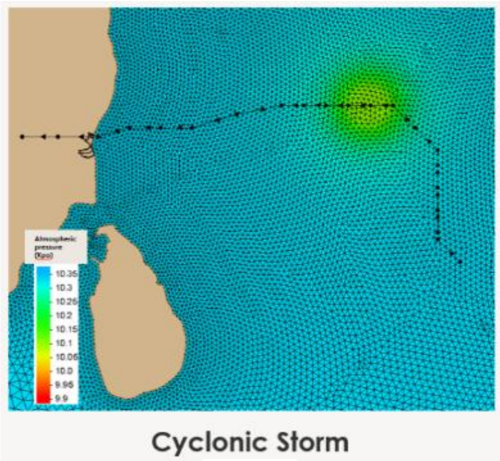
Additionally, the framework may produce inaccurate Trigger Magnitudes for fluvial floods because it focuses on rainfall magnitude at vulnerable points rather than the broader catchment areas. Improving these aspects could lead to a more comprehensive and accurate disaster Impact prediction and response system.

3.4 Cyclone Impact Prediction Methodology

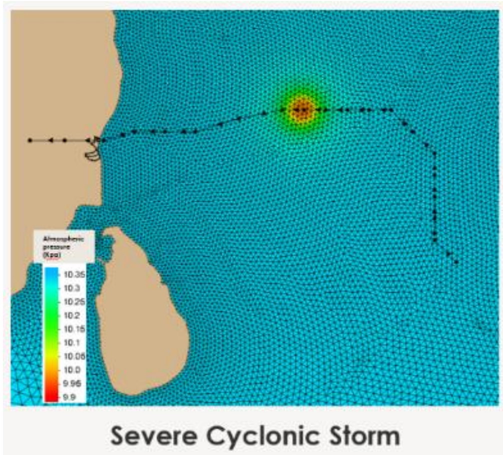
The Cyclone-Risk Identification Framework was utilized to predict the Impact of the Thane Cyclone of 2011 for the Study Area. The 2011 Thane Cyclone was selected as the reference for this study due to its severe and far-reaching impacts on the Cuddalore district. According to officials from the District Disaster Management Authority (DDMA), Thane Cyclone caused extensive devastation, making it one of the most significant natural disasters to hit the region.

Thane, a Very Severe Cyclonic Storm, was the most powerful tropical cyclone in the Bay of Bengal during 2011. The storm originated from a tropical disturbance that formed in the monsoon trough to the west of Indonesia. Over the course of several days, this disturbance gradually intensified as it tracked northwestward. By December 25, it had strengthened enough to be officially classified as a depression. The following day, the system was designated as Cyclonic Storm Thane. Thane continued to gain strength, and by December 28, it had developed into a Very Severe Cyclonic Storm, packing powerful winds and heavy rainfall as it approached the southeastern coast of India.

On December 30, 2011, Cyclone Thane made landfall in the Cuddalore district of Tamil Nadu, unleashing widespread devastation. The cyclone's impact was catastrophic, particularly in Cuddalore, which bore the brunt of the storm's fury. The cyclone's strong winds and torrential rains destroyed homes, fishing boats, crops, and livestock, severely affecting the livelihoods of thousands of people. According to official reports, the cyclone claimed the lives of 40 people and 271 animals. The damage to infrastructure was extensive, with over 400 trees uprooted along the Cuddalore-Chidambaram roads, effectively halting vehicular traffic and complicating rescue and relief efforts.



(a)



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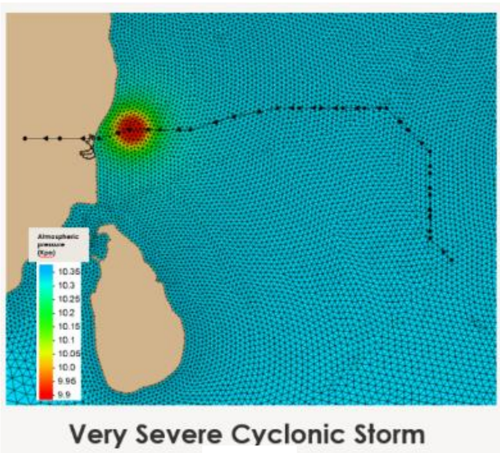


(c)

Figure 4: Stages of Thane Cyclone generated in SMS Software (a) Cyclone Thane at 27th December 0:00 AM (b) Cyclone Thane at 28th December 6:00 PM (c) Cyclone Thane at 30th December 4:30 AM

The Neyveli Lignite Corporation, a major power producer in the region, also suffered significant setbacks as its mines were submerged, disrupting electricity production. The cyclone's impact was so severe that it posed considerable challenges for the National Disaster Response Force and Fire and Rescue Services. The damaged roadways made it difficult for them to reach the cyclone-affected fishing hamlets, where the need for assistance was most urgent. In Cuddalore, agricultural lands were inundated, settlements were destroyed, fishing boats were wrecked, electrical poles were knocked down, and transportation facilities were crippled. The widespread destruction caused by Cyclone Thane underscored the region's vulnerability to severe weather events and highlighted the need for robust disaster preparedness and response mechanisms.

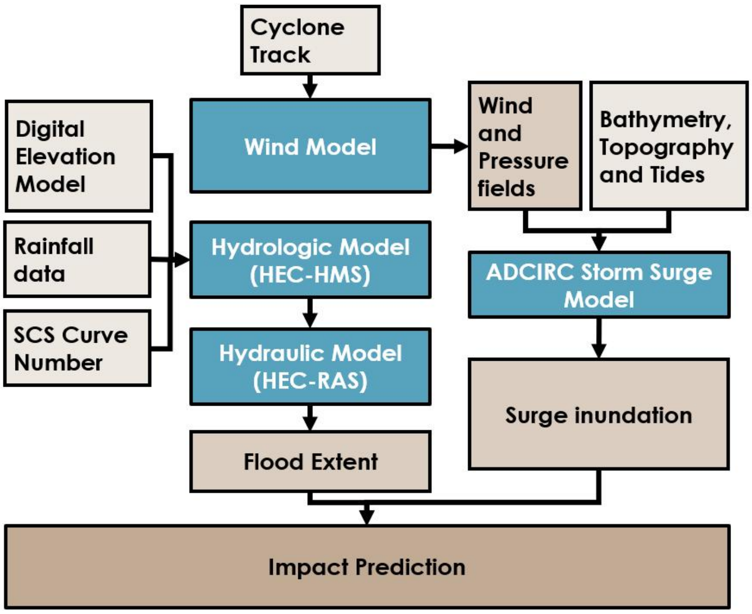


Figure 5: Cyclone Risk Identification Framework

To assess the impact of hazards caused by the cyclone, an estimation was conducted, focusing on storm surges and fluvial flooding. The Advanced Circulation Model (ADCIRC) was widely used in various studies to estimate storm surge inundation, incorporating a wind model, a 3D mesh, and tidal data. This approach allowed for precise estimation of storm surges during the cyclone. For fluvial flooding, hydrological and hydraulic models were employed, utilizing existing rainfall data from the cyclone. However, a rainfall model that estimates rainfall based on cyclone parameters was not used. The modelling effectively determined the fluvial flood inundation caused by the rivers during the cyclone.

4. FINDINGS

The results after utilizing the Cyclone-Risk Identification Framework on the Thane Cyclone of 2011 are as follows.

4.1 Storm Surge Modelling

Storm surge refers to the abnormal rise in sea level that occurs when a tropical cyclone or other intense storm forces ocean water to surge over the coast, exceeding the predicted astronomical tide levels. This phenomenon, according to the Indian National Centre for Ocean Information Services (INCOIS), is primarily driven by the meteorological forces associated with tropical cyclones and hurricanes. The strong winds generated by these storms push large volumes of ocean water towards the shore, creating a surge that can inundate coastal areas. While the low pressure at the center of the storm (the eye) does contribute to the surge, its effect is relatively minor compared to the influence of wind. Several factors influence the magnitude of a storm surge. These include the size and extent of the storm's wind field (especially the radius of maximum winds), the storm's strength and speed, its central pressure, its track and landfall location, as well as the coastal elevation and the shape and features of

the coastline. All of these elements interact to determine the height and impact of the storm surge, making accurate prediction a complex task.
In this study, the ADvanced CIRCulation (ADCIRC) model was used to estimate the storm surge generated by Cyclone Thane. ADCIRC is a sophisticated numerical model designed to simulate the movement of oceanic, coastal, and estuarine waters. It was developed by Dr. R.A. Luettich, Jr. from the University of North Carolina at Chapel Hill's Institute of Marine Sciences and Dr. J.J. Westerink from the University of Notre Dame's Department of Civil Engineering and Geological Sciences. The model is widely used in the field of coastal engineering and oceanography to predict storm surges and other hydrodynamic phenomena. For this study, the Holland Symmetric Cyclone Wind Model was employed to simulate the wind fields associated with Cyclone Thane. This model was provided with various parameters, including the cyclone's track, maximum sustained wind speed, radius of maximum winds, and minimum sea level pressure at each point along the cyclone's path. These inputs allowed the model to accurately represent the wind conditions that contributed to the storm surge.

The simulation also required the creation of a detailed 3D mesh of the Bay of Bengal, which was generated using the Surface Water Modelling Software (SMS). The mesh incorporated bathymetric data, which provides information on the underwater topography, and tidal constituents, which describe the tidal patterns in the region. The Le Provost Tidal Database, an inbuilt database within SMS, was used in conjunction with the Harmonica tool to generate tide levels based on sinusoidal equations corresponding to the given time period. This allowed

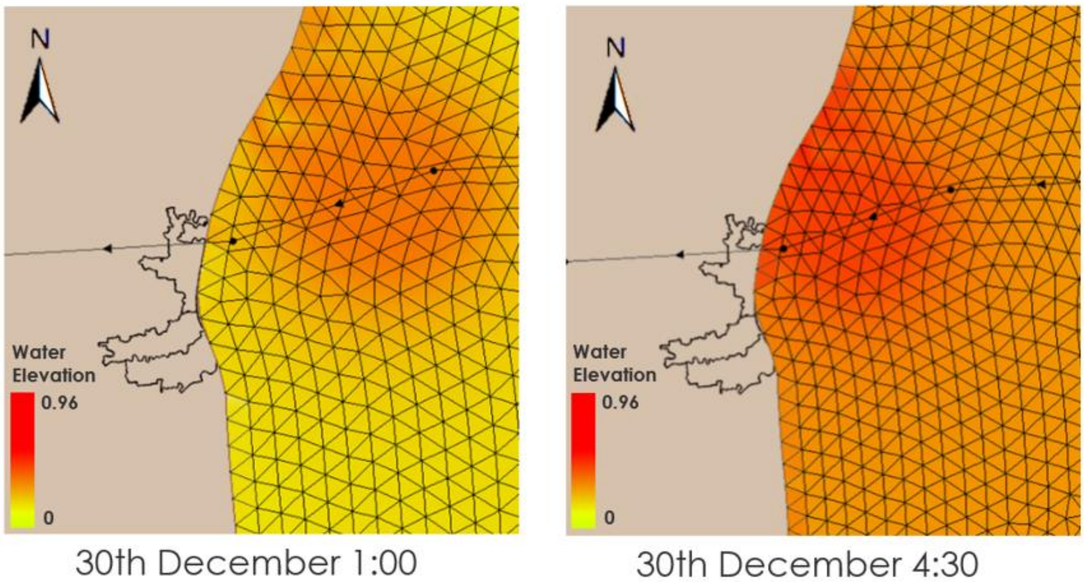


Figure 6: Water Elevation at 30th December 1:00 IST and 30th December 4:30 IST.

for the representation of tidal conditions during the cyclone's passage.

Once all the data were integrated, the ADCIRC model generated water elevation maps, which are shown in Figure 6. The results indicated that the maximum storm surge during Cyclone Thane occurred at approximately 4:30 IST on December 30, 2011, with a surge height of 0.56 meters. The model predicted that only certain fishing hamlets near the shore would experience inundation, highlighting the localized nature of the storm surge impact. The results from the

ADCIRC model were visualized using ArcMap, a geographic information system (GIS) tool. Digital Elevation Model (DEM) data was utilized in the Raster Calculator tool within ArcMap to identify the areas likely to be inundated by the storm surge.

4.2 Hydrological Modelling

Cyclones bring about intense rainfall during landfall, leading to the overflow of river waters into nearby settlements—a phenomenon known as fluvial flooding. Accurately estimating fluvial floods requires understanding the dynamic water discharge in each river, which necessitates detailed hydrological modeling. This modeling process is essential for determining the dynamic quantity of water flowing within a river system, which, in turn, helps to estimate the areas likely to be inundated through subsequent hydraulic modeling.

The hydrological modeling process involves two key components: the Basin Model and the Meteorological Model. The Basin Model represents the watershed boundaries and incorporates permeability values, which are crucial for estimating surface water runoff. The permeability of the soil and the characteristics of the land use within the watershed determine how much rainfall infiltrates the ground versus how much becomes surface runoff. In this study, the Soil Conservation Service (SCS) Curve Number method was employed to estimate surface water runoff for the study area. This method is widely used in hydrological studies because it provides a reliable estimate of runoff based on soil type, land use, and land cover conditions.

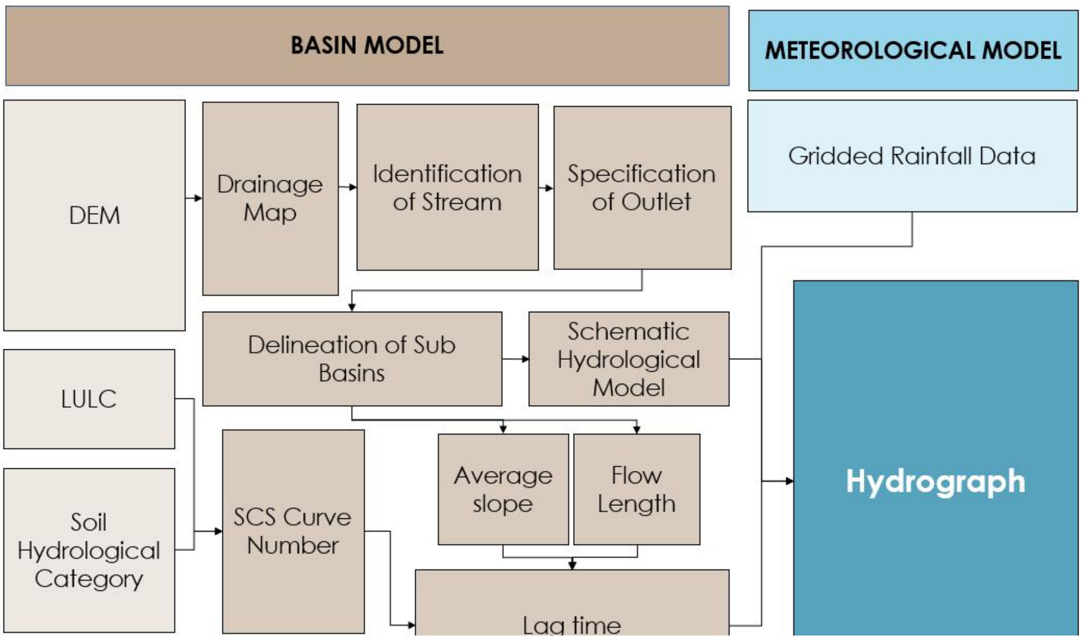


Figure 7: Methodology for Hydrological Modelling.

For the Meteorological Model, rainfall data is a critical input. Yearly gridded rainfall data with a spatial resolution of 0.25 x 0.25 degrees, provided by the India Meteorological Department (IMD) Pune, was used in the hydrological model to determine runoff. This data allows for a detailed representation of the spatial and temporal distribution of rainfall, which is essential for understanding the dynamic nature of flooding in human settlements. The

Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) was utilized to perform the hydrological modeling. This software is well-suited for simulating the rainfall-runoff process, providing insights into how different land and climate factors contribute to flooding.

The study area contains 5 rivers and four major river basins: the Pennaiyar River Basin, the Paravanar River Basin, the Vellar River Basin, and the Kauvery River Basin. Due to the vast area covered by these basins, only parts of each were considered in the analysis to maintain computational efficiency. The SCS Curve Number method, as used in various hydrological studies, was applied to estimate surface runoff within these basins. The Curve Number is a dimensionless value that represents the percentage of rainfall that will result in runoff, taking into account the soil type, land use, and land cover characteristics.

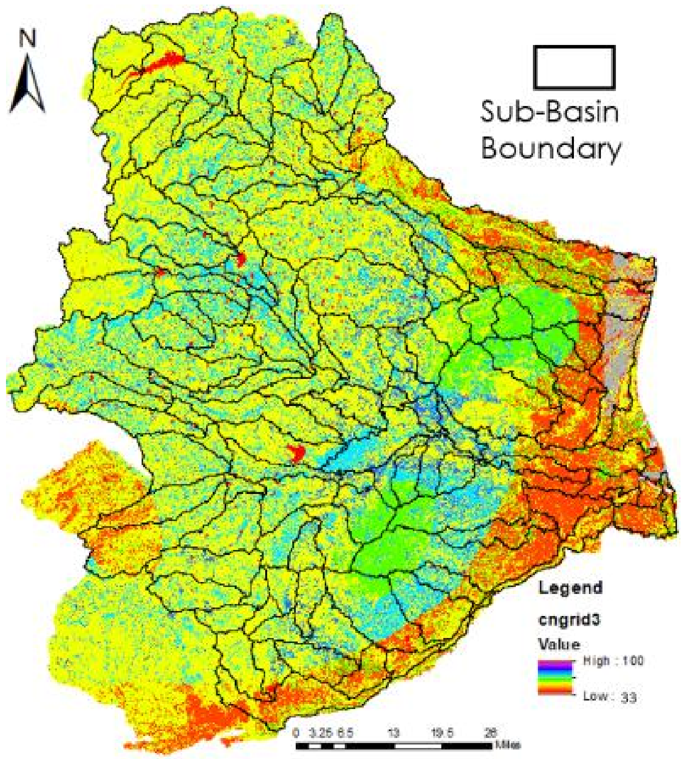


Figure 8: SCS Curve Number Map.

To generate the Curve Number raster, the Geo-HEC HMS plugin in ArcMap was employed. This tool allowed for the integration of soil hydrograph categories and land use land cover (LULC) data. For this purpose, six Digital Elevation Model (DEM) images were mosaicked to delineate sub-basins within the larger river basins, ensuring more accurate hydrographs in the modeling process. Additionally, LULC data was generated through supervised classification at the same scale, for SCS Curve Number calculations for each sub-basin. An important parameter in hydrological modeling is the lag time, which is the time difference between the peak rainfall and the peak discharge of river water. Lag time is influenced by the river flow length within the sub-basin, the average slope of the terrain, and the SCS Curve

Number. Calculation of lag time is crucial for predicting the timing of flood peaks and for designing effective disaster response strategy.

The study focuses on five significant rivers within the Cuddalore District—Thenpennaiyar, Gadilam, Uppanar, Vellar, and Kollidam—each of which plays a crucial role in the region's hydrology and flood dynamics. These rivers flow into the Bay of Bengal and are part of larger river basins, influencing the flood patterns in the district, especially during cyclonic events. The Thenpennaiyar River, part of the Pennaiyar River Basin, discharges into the Bay of Bengal in the northern part of the Cuddalore District. The study considered 24 sub-basins within the river's catchment area, covering 203.12 km². The analysis revealed a peak flow of 649.5 cubic meters per second. The average Curve Number (CN), a critical parameter in estimating runoff, was calculated to be 88.27 for these sub-basins. The hydrograph for the Thenpennaiyar River is depicted in Figure 9. The Gadilam River, also within the Pennaiyar River Basin, flows through the Cuddalore Municipality before reaching the Bay of Bengal. The study area included 11 sub-basins, spanning 128.36 km². The peak flow was determined to be 158.5 cubic meters per second, with an average Curve Number of 85.93. The hydrograph for the Gadilam River is shown in Figure 10. The Uppanar River, part of the Paravanar River Basin, discharges into the Bay of Bengal in the northern part of the Cuddalore District. For this river, 7 sub-basins were analyzed, covering an area of 75.12 km². The peak flow was found to be 216.8 cubic meters per second, and the average Curve Number was 82.55. The hydrograph for the Uppanar River is provided in Figure 11. The Vellar River flows through the Vellar River Basin, traversing the Salem, Perambalur, and Cuddalore districts before emptying into the Bay of Bengal at Parangipettai. The study considered 54 sub-basins within the Vellar River catchment area, covering 434.02 km². The peak flow was calculated at 842 cubic meters per second. The hydrograph for the Vellar River is illustrated in Fig. Figure 12. Finally, the Kollidam River, part of the Kaveri River Basin, flows into the Bay of Bengal at the southernmost point of the Cuddalore District. This river is the northern distributary of the Kaveri River as it passes through the Thanjavur delta. The study included 31 sub-basins, covering an area of 234.92 km². The peak flow for the Kollidam River was the highest among the studied rivers, at 999 cubic meters per second. The hydrograph for the Kollidam River is depicted in Figure 13.

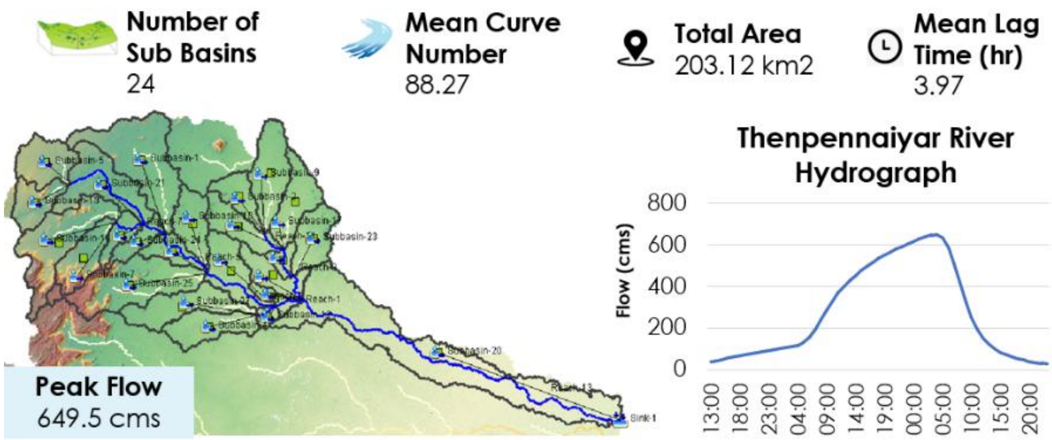


Figure 9: Thenpennaiyar River Sub-basins and its Hydrograph.

4.3 Hydraulic Modelling

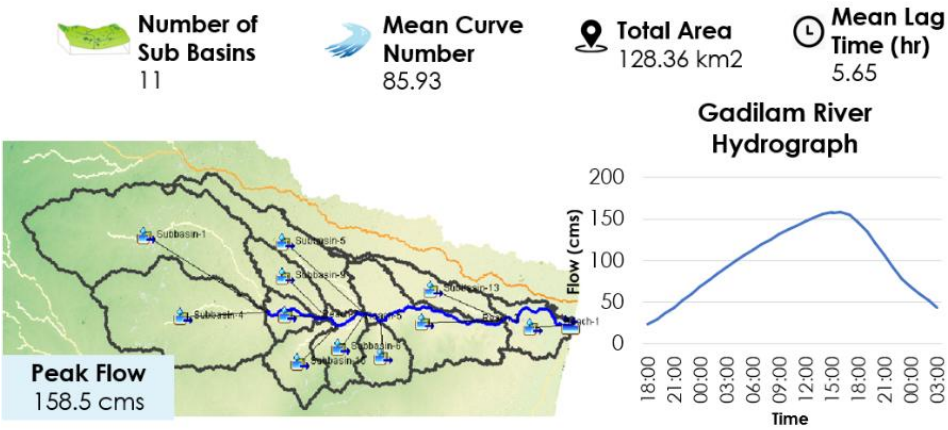


Figure 10: Gadilam River Sub-basins and its Hydrograph.

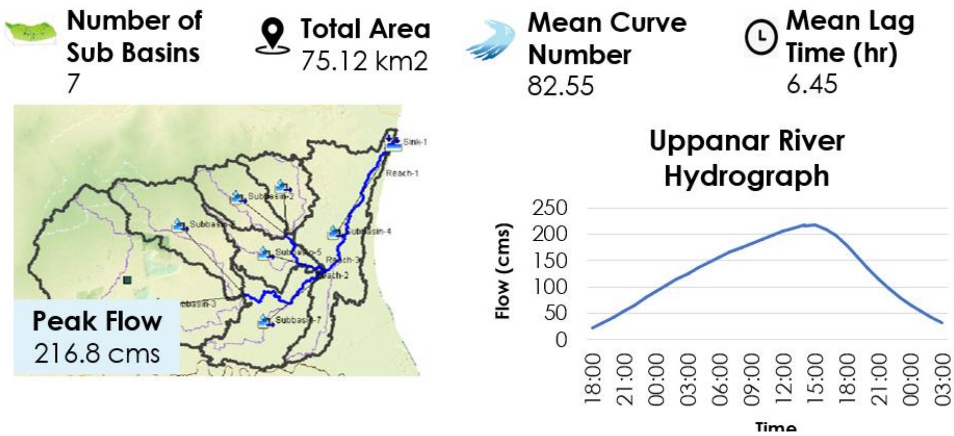


Figure 11: Uppanar River Sub-basins and its Hydrograph.

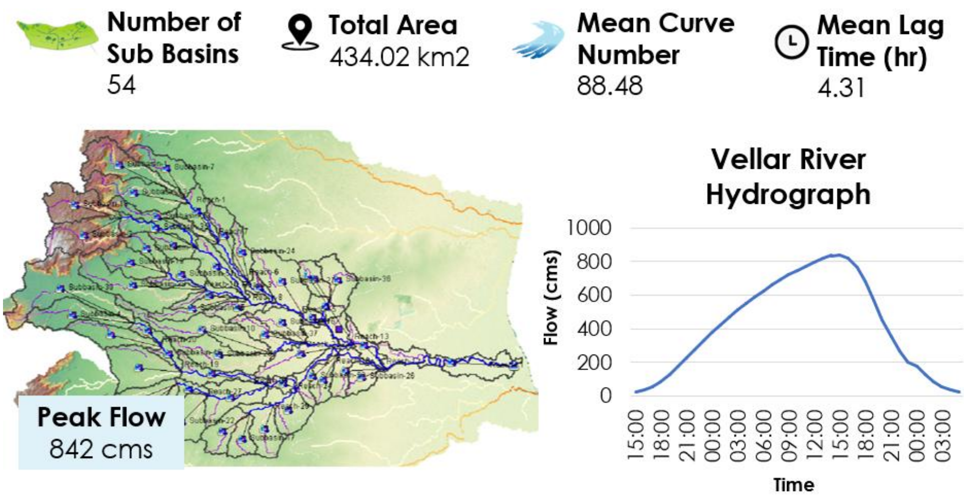


Figure 12: Vellar River Sub-basins and its Hydrograph.

To simulate the flooding caused by rivers during Cyclone Thane in the study area, a Hydraulic Model was employed, which required data of river geometry and water discharge. The river geometry was defined using a 2D mesh and a Digital Elevation Model (DEM), while the water discharge data was derived from hydrological modelling and represented as hydrographs. The hydraulic modelling was conducted using HEC-RAS, a robust tool for simulating river flow and floodplain inundation. The first step in the hydraulic modelling process was to create 2D meshes for each of the five rivers studied—Thenpennaiyar, Gadilam, Uppanar, Vellar, and Kollidam. These meshes are essential for conducting unsteady flow analysis, which helps identify potential inundated areas. The choice of mesh size is critical; a larger mesh covers more area but requires extensive computational resources, while a smaller mesh might miss critical inundation zones. Through trial and error, an optimal mesh size was determined, balancing computational efficiency and coverage accuracy. Although modelling the entire length of each river was impractical, the focus was placed on sections near settlements to derive actionable results.

The Thenpennaiyar River was the first to experience water discharge in the study area due to the storm caused by Cyclone Thane. This river overflowed into adjacent settlements, reaching peak inundation at 4:00 IST on December 31st, nearly 24 hours after the cyclone made landfall. The Thenpennaiyar River was the first to cause flooding in the study area, inundating neighbouring settlements. Despite being part of the same basin as the Thenpennaiyar, the Gadilam River reached its peak inundation 12 hours later, around 16:00 IST on December 31st. This delay could be attributed to the basin’s slope or the specific rainfall pattern during the storm. Although the Gadilam River inundated a larger area than the Thenpennaiyar, much of the flooded region consisted of vacant land, reducing the impact on human settlements. The Uppanar River reached its peak flow before the Gadilam River, contributing to the inundation of a housing colony near the ocean. This river caused the second round of flooding in the study area, following the Thenpennaiyar River. The peak inundation occurred at 14:00 IST on December 31st, and the Uppanar River caused significant damage to populated areas, especially in comparison to the Gadilam River. Despite having the largest catchment area of the rivers studied, the Vellar River did not significantly impact settlements. The excess water primarily flowed through vacant lands, with peak inundation observed at 15:00 IST on December 31st. This minimized the river's overall impact on human settlements. The Kollidam River experienced the latest peak inundation at 17:00 IST on December 31st. As a result, disaster relief operations could prioritize other rivers before addressing the Kollidam.

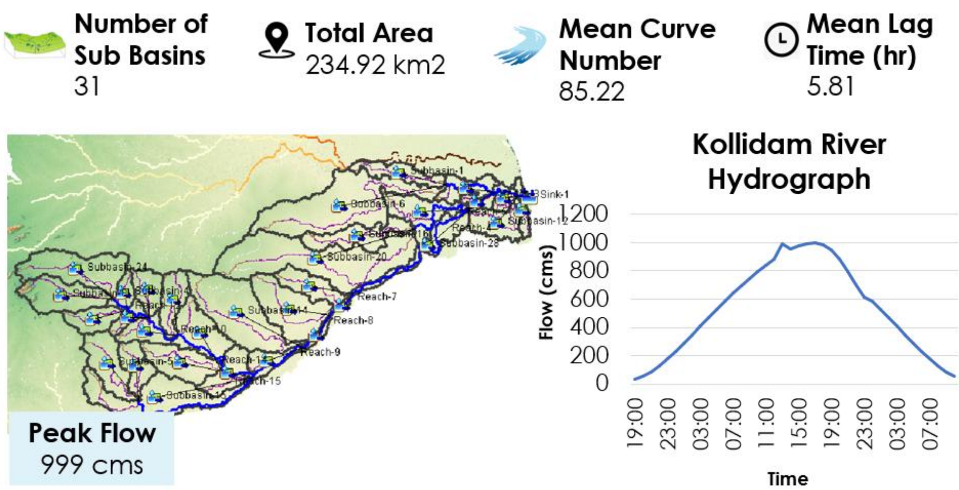
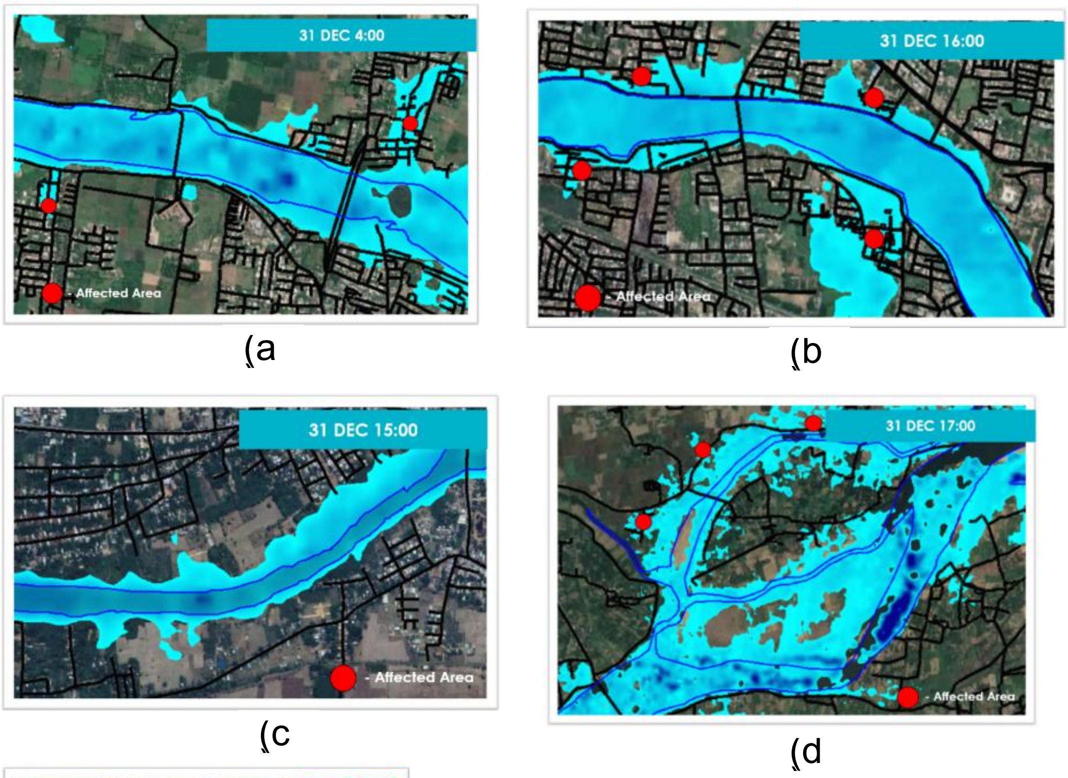


Figure 13: Kollidam River Sub-basins and its Hydrograph.

The study focused on the northern banks of the Kollidam River, which fall under the jurisdiction of Cuddalore District.



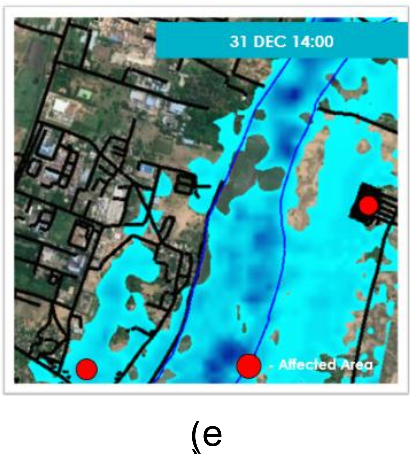


Figure 14: Peak River inundation caused by the 5 rivers and corresponding affected Settlements of the Study Area. (a) Thenpennaiyar River (b) Gadilam River (c) Vellar River (d) Kollidam River (e)

5. DISCUSSIONS

The study presents a Cyclone Risk Identification framework designed to assess the risks posed by tropical cyclones, based on key atmospheric and cyclone parameters. By focusing on the Cuddalore Coast as a case study, the framework's practical applications in cyclone disaster management are demonstrated. The framework's primary utility lies in its ability to work with forecasted cyclone parameters, enabling the prediction of potential impacts before the cyclone makes landfall. This predictive capability allows authorities to identify high-risk areas, plan evacuations, and allocate resources more effectively, ensuring a more coordinated and timely disaster response.

In addition to impact predictions, the framework facilitates the integration of route optimization algorithms, which are crucial for disaster response operations. These algorithms help determine the most efficient evacuation routes and supply chains, reducing the time and effort needed to reach affected areas. Moreover, the analysis of road networks within this framework can identify critical nodes that are vulnerable during disasters. By pinpointing these critical points, infrastructure can be reinforced to be disaster-resilient, enhancing overall preparedness and minimizing potential disruptions during emergency response efforts. This approach not only optimizes immediate disaster management but also contributes to long-term infrastructure resilience.

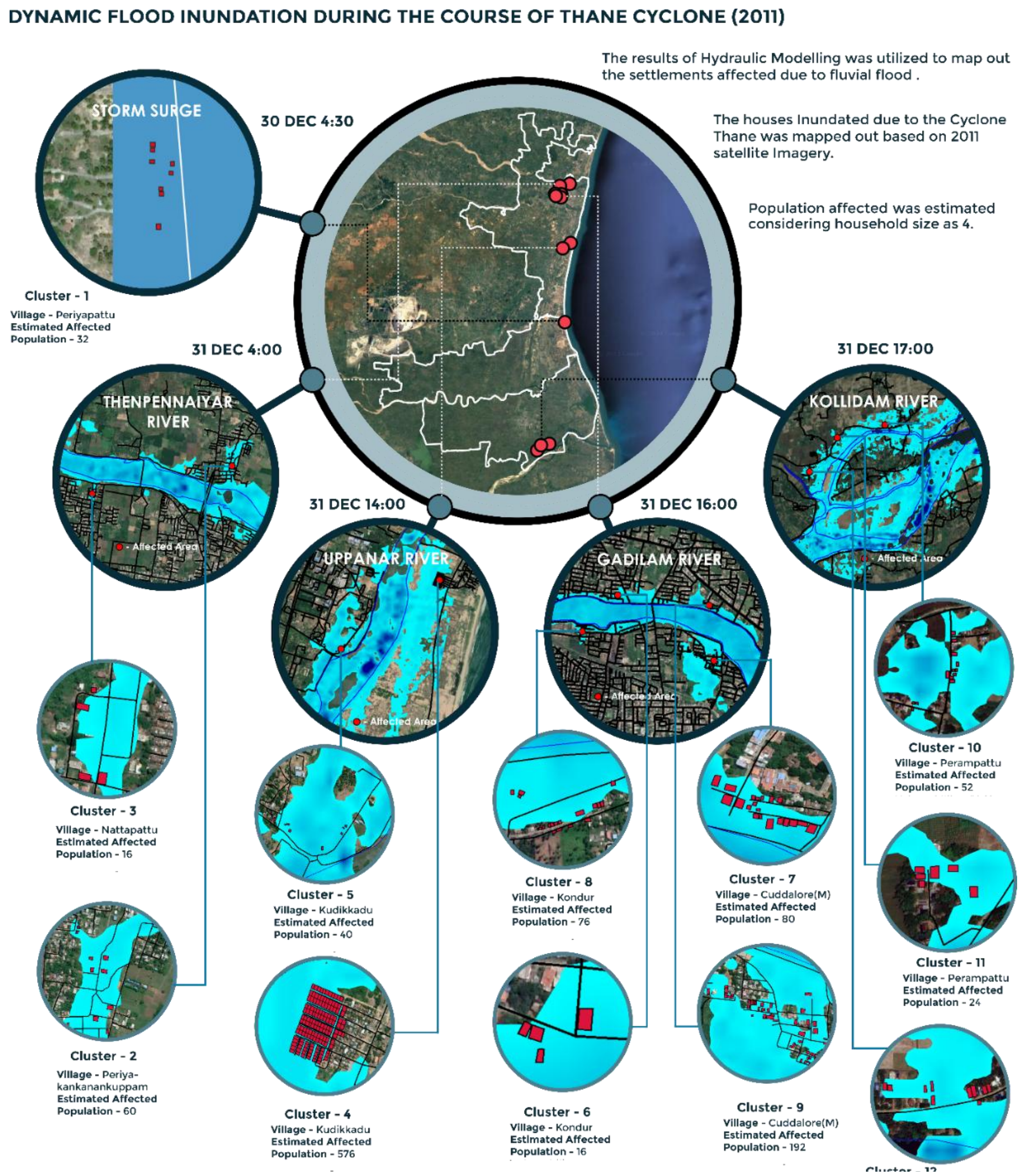


Figure 15: Flood Inundation and Affected Population estimated based on Thane Cyclone (2011)

To further enhance the accuracy of the framework, the study suggests integrating a Digital Surface Model (DSM) into the hydraulic modelling process and Storm Surge Estimation. A

DSM provides detailed information on the elevation of the Earth's surface, including buildings and other structures, which can significantly improve the precision of flood simulations. Additionally, incorporating the effects of various artificial structures into the hydrological modelling will allow for a more accurate estimation of water flow during a cyclone event. This refined modelling approach will lead to better predictions of inundation areas and the overall impact of the cyclone, allowing for more targeted and effective disaster response strategies.

6. REFERENCES

- Bass, B., & Bedient, P. (2018). Surrogate modeling of joint flood risk across coastal watersheds. Journal of Hydrology, 558, 159-173.
- Bhaskaran, P. K., Nayak, S., Bonthu, S. R., Murty, P. L. N., & Sen, D. (2013). Performance and validation of a coupled parallel ADCIRC–SWAN model for THANE cyclone in the Bay of Bengal. *Environmental Fluid Mechanics*, *13*, 601-623.
- Commissionerate of Revenue Administration and Disaster Management, Government of Tamil Nadu & Regional Integrated Multi-hazard Early Warning System. (2019). Commissionerate of Revenue Administration and Disaster Management, A web-GIS based decision support system for strengthening disaster management. Pathumthani, Thailand : RIMES
- Deb, M., & Ferreira, C. M. (2018). Simulation of cyclone-induced storm surges in the low-lying delta of Bangladesh using coupled hydrodynamic and wave model (SWAN+ ADCIRC). Journal of Flood Risk Management, 11, S750-S765.
- Government of Tamil Nadu. (2021). DISTRICT DISASTER MANAGEMENT PLAN of Cuddalore.
- Joyce, J., Chang, N. B., Harji, R., Ruppert, T., & Singhofen, P. (2018). Cascade impact of hurricane movement, storm tidal surge, sea level rise and precipitation variability on flood assessment in a coastal urban watershed. Climate Dynamics, 51, 383-409.
- Murty, P. L. N., Padmanabham, J., Kumar, T. S., Kumar, N. K., Chandra, V. R., Shenoi, S. S. C., & Mohapatra, M. (2017). Real-time storm surge and inundation forecast for very severe cyclonic storm 'Hudhud'. Ocean Engineering, 131, 25-35.

- Natarajan, S., & Radhakrishnan, N. (2019). Simulation of extreme event-based rainfall–runoff process of an urban catchment area using HEC-HMS. Modeling Earth Systems and Environment, 5, 1867-1881.
- Priya, A., & Mani, N. D. (2015). Cyclone prone areas in Tamil Nadu State—a geospatial approach. Int J Eng Res Technol, 4(2), 693-696.
- Punithavathi, J., Tamilenthi, S., & Baskaran, R. (2012). A study of thane cyclone and its impacts in Tamil Nadu, India using geographic information system. Arch Appl Sci Res, 4(1), 685-695.
- Rao, A. D., Jain, I., & Venkatesan, R. (2010). Estimation of extreme water levels due to cyclonic storms: a case study for Kalpakkam coast. The International Journal of Ocean and Climate Systems, 1(1), 1-14.
- Rao, V. R., Subramanian, B. R., Mohan, R., Kannan, R., Mageswaran, T., Arumugam, T., & Rajan, B. (2013). Storm surge vulnerability along Chennai–Cuddalore coast due to a severe cyclone THANE. Natural hazards, 68, 453-465.
- Saravanan, S., Jennifer, J., Singh, L., & Abijith, D. (2018). Cyclone vulnerability assessment of cuddalore coast in Tamil Nadu, India using remote sensing, and GIS. In MATEC Web of Conferences (Vol. 229, p. 02022). EDP Sciences.
- Saxena, S., Geethalakshmi, V., & Lakshmanan, A. (2013). Development of habitation vulnerability assessment framework for coastal hazards: Cuddalore coast in Tamil Nadu, India—A case study. Weather and Climate Extremes, 2, 48-57.
- Shankar, C. P., Shanmugam, M., Pradeep, C., & Thirumalaivasan, D. (2018). Flood modeling for a part of Adyar river basin using HEC-HMS and HEC-RAS for the December 2015 floods. Ecol Environ Conserv, 24, S260-S263.
- Silva-Araya, W. F., Santiago-Collazo, F. L., Gonzalez-Lopez, J., & Maldonado-Maldonado, J. (2018). Dynamic modeling of surface runoff and storm surge during hurricane and tropical storm events. Hydrology, 5(1), 13.
- Thakur, B., Parajuli, R., Kalra, A., Ahmad, S., & Gupta, R. (2017, May). Coupling HEC-RAS and HEC-HMS in precipitation runoff modelling and evaluating flood plain inundation map. In World Environmental and Water Resources Congress 2017 (pp. 240-251).

- Wang, N., Hou, Y., Mo, D., & Li, J. (2021). Hazard assessment of storm surges and concomitant waves in Shandong Peninsula based on long-term numerical simulations. Ocean & Coastal Management, 213, 105888.
- Wang, S., Mu, L., Yao, Z., Gao, J., Zhao, E., & Wang, L. (2021). Assessing and zoning of typhoon storm surge risk with a geographic information system (GIS) technique: a case study of the coastal area of Huizhou. Natural Hazards and Earth System Sciences, 21(1), 439-462.

Enhancing Economic Resilience and Conservation of Coastal Confluence Zone through Ecosystem Service Valuation and Livelihood Dependency in South Goa

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Abstract

Coastal confluence zones (CCZ), where rivers meet the ocean, are important ecological areas because the mixing of freshwater and saltwater creates a unique environment that supports the development of diverse species of flora and fauna, making it essential to maintain the ecosystem of these estuary zones. In Goa, the growth of the tourism sector has led to densely populated coastal areas. At the confluence, rising fishing and tourism activities have made the population increasingly dependent on ecosystem services. Hence, the study aims to conduct ecosystem service valuation and livelihood dependency analysis to enhance economic resilience and ensure the conservation of ecological areas at the Coastal Confluence Zone by developing management guidelines. Four rivers in South Goa namely Sal, Saleri, Talpona, and Galgibag were selected and weighted overlay was performed using parameters (intertidal zones, salinity, contours, mangroves, khazan land, proximity to the high tide line, and fishing settlements) to delineate CCZ for each river. The changes in LULC from 2003 to 2023 inferred a decrease in forest land, barren land, and wasteland but an increase in the area of agricultural land. Ecosystem services - provisioning, regulating, supporting, and cultural - were evaluated for economic value using Rs/ha to calculate the total economic value for all the CCZs. It was observed that regulating services contribute the most, while cultural services contribute the least. Two main occupations, tourism, and fishing, were identified, with livelihood dependency on tourism increasing in most CCZs over the past decade, except in Sal CCZ, where reliance on fisheries is growing. Livelihood performance analysis was done for natural, physical, social, financial, and human assets through various indicators where it was seen most CCZs are performing good for natural assets but poor for social, financial, and human assets. The outcome proposes management guidelines for ecosystem services, the development of a framework to conduct ecosystem service valuation and livelihood dependency, protection of turtle nesting areas, climate-smart plantation and groundwater recharging for enhanced ecosystem services, and recommendations for fisheries based on asset indicators requiring attention.

Keywords: Coast; Confluence; Eco-system services; Livelihood dependency

1. INTRODUCTION

A Coastal Confluence Zone (CCZ) is a coastal area where different water bodies, such as rivers, creeks, backwaters, or even other estuaries, converge at sea. This convergence can involve the mixing of freshwater from multiple sources with brackish or saline waters, leading to complex hydrological dynamics influenced by tides and varying salinity levels. Unlike estuaries, which specifically involve the mixing of freshwater and seawater, a CCZ can include a broader range

of water body interactions, the surrounding land use, and other factors. These zones can support unique habitats and species, often with high biodiversity.
The analysis in this study depends upon the assessment of Ecosystem Services and Livelihood dependency. These aspects are interconnected as they all impact the well-being of the local community and environment. In highly sensitive regions, ecosystem services are more likely to be disrupted. For example, if a mangrove ecosystem is destroyed, it may no longer provide essential services like fisheries habitat or coastal protection, threatening livelihoods, including food security and climate regulation.

2. RESEARCH GAP

In Goa, the rapid development of the tourism industry has led to increasing population density in coastal areas, accompanied by the growth of buildings and recreational activities to accommodate tourists. This has resulted in a shift from traditional fishing occupations to tourism-related jobs, making the population heavily dependent on coastal ecosystem services. Despite the dynamic nature of Coastal Confluence Zones (CCZs), where sudden changes in sandbars occur during monsoon seasons due to heavy water flow, no existing plans or documents have adequately addressed the relationship between ecosystem services, and livelihood dependencies in these zones. This highlights a need for the development of CCZ management guidelines where eco-system service valuation is considered along with livelihood dependency such that the livelihoods of existing communities are sustained while balancing the development.

3. AIM AND RESEARCH OBJECTIVES

Aim: To conduct ecosystem service valuation and livelihood dependency analysis to enhance economic resilience and ensure the conservation of ecological area at Coastal Confluence Zone by developing management guidelines.
Objectives:

A. Objective 1**:** To identify the various ecosystem services present in the confluence zone & examine their economic value.

Sub-Objectives
1.1: To identify, measure, and quantify the provisioning services.
1.2: To identify, measure, and quantify the regulatory services.
1.3: To identify, measure, and quantify the supporting services.
1.4: To identify, measure, and quantify the cultural services.

B. Objective 2: To understand and analyze the dependency of the local livelihoods on the coastal confluence zone.
C. Objective 3: To develop management guidelines for the coastal confluence zone ensuring economic resilience and ecological conservation.

4. METHODOLOGY

The methodology began with a thorough review of existing literature to understand the coastal confluence zone (CCZ), the ecosystem services it offers, and methods for valuing them. This also involved assessing the livelihood dependency and understanding the four selected CCZs and their specific characteristics. Then, the case area was selected, and baseline studies were conducted to understand the demographics and social aspects. Land Use and Land Cover changes from 2003 to 2023 were analyzed. This was followed by delineation of the CCZ within the case area using weighted overlay analysis for the identified parameters to establish the boundaries. Following this, ecosystem services were evaluated, focusing on provisional, regulating, supporting, and cultural services. The livelihood dependency was analyzed by identifying the two main occupations in each CCZ and the population dependent on them. A sub-analysis assessed livelihood performance based on various assets: physical, natural, financial, social, and human. Parameters for ecosystem services and livelihood dependency were then selected to develop proposals and recommendations. Finally, the proposals included management guidelines for ecosystem services, fisheries, and tourism.

5. CASE AREA DESCRIPTION

Goa is a highly popular tourist destination, particularly known for its coastal tourism activities. The northern part of the state attracts the majority of tourists, while the southern region is increasingly gaining popularity among tourists due to its coastal attractions. This trend raises concerns about potential threats to the ecosystem services in South Goa, similar to those experienced in the coastal regions of North Goa. As a result, the ecosystem services at the CCZ of South Goa have been broadly evaluated and livelihood dependency has been studied.

Figure 1: Selected river confluences in South Goa

5.1. Observations Through Site Visits to Each of the CCZ

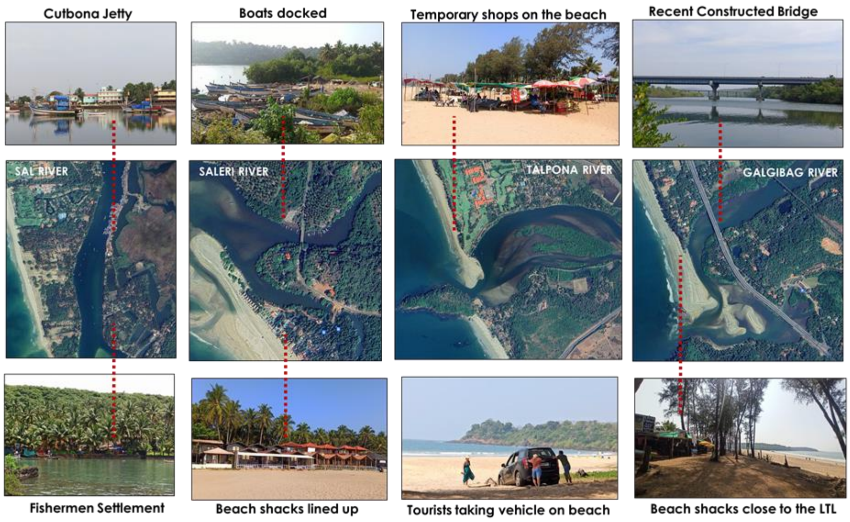


Figure 2: Pictures of the observations on the site during the site visit.

The Sal River CCZ in South Goa is home to the famous fishing jetty, with numerous boats crossing the river mouth daily. The area is surrounded by fishermen's settlements with small houses and abundant coconut plantations. In the vicinity of 1 km away from the river mouth, there are several resorts along Cavelossim Beach and Mobor Beach.

The Saleri River CCZ features boats docked closer to the fishermen's houses, along with kayaking and boat ride facilities near the river mouth. This CCZ also has numerous beach shacks, small resorts, and restaurants lined up at Agonda Beach, catering to the increasing tourism activity.

Moving on to the Talpona River CCZ, the northern side of the river mouth features temporary shops and sunbath chairs encroaching upon the intertidal area at Rajbag Beach. Resorts adjacent to the beach maintain a 200-meter buffer from the LTL, with open green spaces for recreation. On the southern side, there's a fishing jetty that also supports tourism activities like boat rides. A turtle nesting area is being monitored, where it is observed that tourists are driving vehicles on the beach, potentially affecting the ecosystem services.

Lastly, the Galgibag River CCZ is less developed compared to the other zones. The recent construction of a bridge connecting South Goa to the border of Karnataka is a notable development, located near the river mouth. Mangroves are observed around this bridge, and there are beach shacks close to the LTL, catering to tourists and fishermen alike.

5.2. Selection of Surrounding Villages of the CCZ Area

Four rivers in South Goa meet the sea, namely, Sal, Saleri, Talpona, and Galgibag. Surrounding the Sal River are the villages of Cavelossim, Velim, and Quitol. The Saleri River is flanked by the villages of Colva and Agonda. The Talpona River passes through Nagarcem-Palolem and Poinguinim, while the Galgibag River is bordered by the villages of Poinguinim and Loliem.

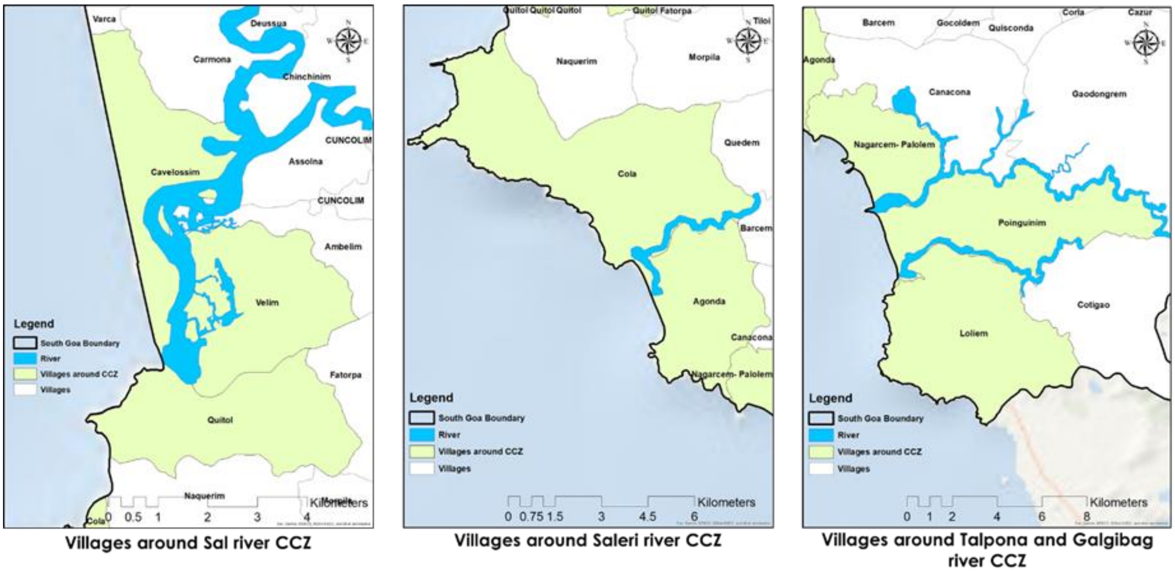


Figure 3: The selected four confluence zones with their surrounding villages

5.3. Land Use Land Cover of the Villages

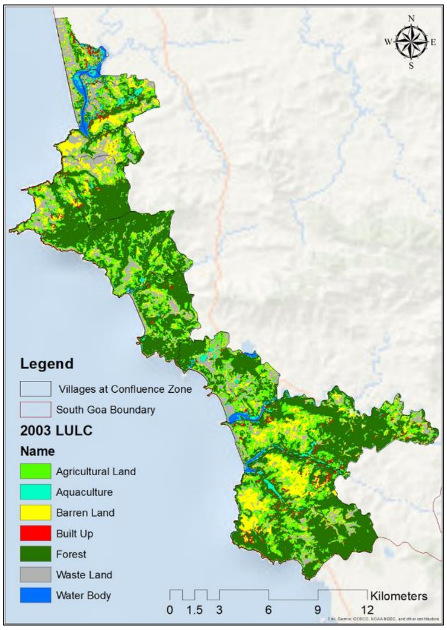


Figure 4: LULC 2003

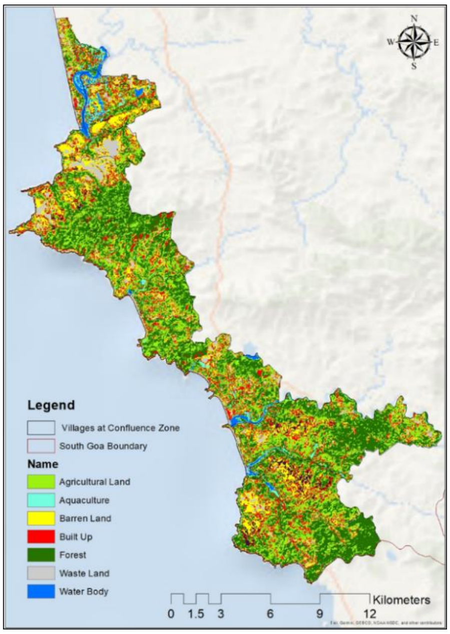


Figure **5:** LULC 2023

In 2003, the land use and land cover (LULC) map showed that agricultural land accounted for 23%, aquaculture 3%, barren land 13%, built-up areas 3%, forest 46%, wasteland 11%, and water bodies 2%. The majority of the land consisted of forest and agricultural land.

In 2023, the LULC map indicated that agricultural land had increased to 31%, aquaculture remained at 3%, barren land decreased to 9%, built-up areas rose to 18%, forest decreased to 33%, wasteland decreased to 4%, and water bodies remained at 2%.

5.4. Demographic Study of the Villages

The population of the surrounding villages is obtained from the Census of India and projection is done using arithmetic, geometric, and incremental methods. After comparing the 2011 estimations with the actual population, the Incremental Method was found to have the smallest difference, making it the best choice for projecting future populations in this context. The villages are classified based on their proximity to the river mouth, and population projection helps in forecasting the future size and structure of the population.

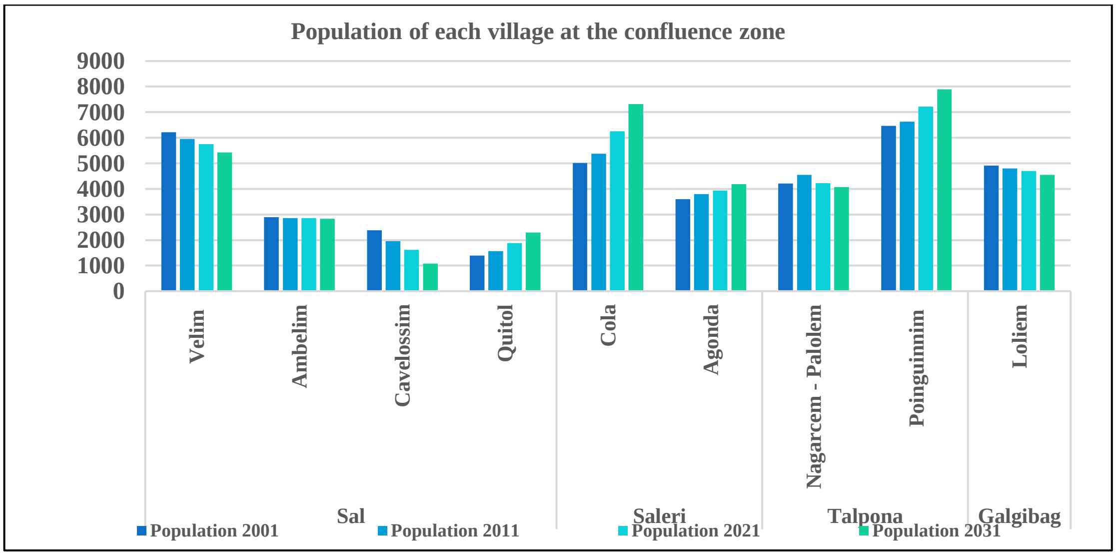


Figure 6: Population of each village at the confluence zone

The total population of the four selected CCZs shows that the villages at the Sal River have the highest population, while the villages at the Galgibag have the lowest. The population of Saleri and Talpona is increasing, but the population of Sal River and Galgibag is decreasing by 2031.

Table 1: Population Projection for all 4 CCZ

Confluence Zone	Population 2001	Population 2011	Population 2021	Population 2031
Sal	12879	12334	12116	11625
Saleri	8601	9183	10198	11504
Talpona	10671	11172	11446	11970
Galgibag	4910	4797	4703	4552

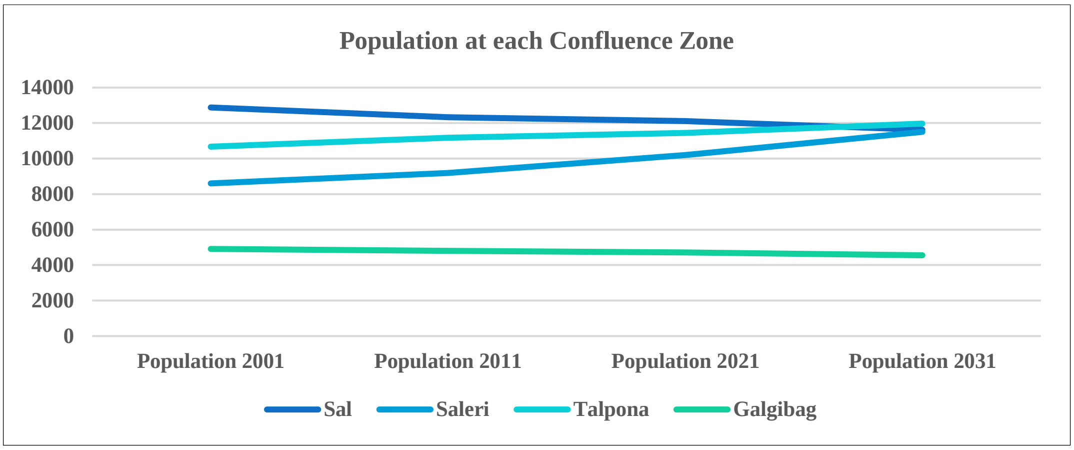


Figure 7: Population at each Confluence Zone

6. DELINEATION OF COASTAL CONFLUENCE ZONE FOR ALL FOUR RIVERS

When it comes to the Coastal Confluence Zone there is no specific delineation as we see in the case of forests, hilly areas, ghats, lakes, etc. To analyze the Coastal Confluence Zone (CCZ), it is essential to define the boundary of the study area. The features and characteristics of estuary zones were identified based on various literature papers and used as parameters to delineate the CCZ. For this purpose, based on various literature papers, the features and characteristics of estuary zones were identified (Auropremi, 2019; Baitalik, 2015; Biggs & Cronin, 1981; Nayak, 2021; Pradhan, 2016; Ramachandra, Rajinikanth, & Bharath, 2019; Scanes, Ferguson, & Potts, 2017; Singh et al., 2004; Thrush et al., 2014). The estuary zone experiences a sedimentation process, where river-carried sediments settle, along with intertidal flats. Tidal action and salinity levels, ranging from 5 parts per thousand (ppt), were considered. This salinity was observed to reach the contour line from 5 m to 15 m, marking the presence of mangroves and khazan land associated with salty water influence, a 1 km buffer from the High Tide Line, and the presence of fishermen's settlements near the mouth of the river was also considered as parameters. These parameters were mapped and transformed into data layers, with weights assigned to them. A weighted overlay analysis was performed to obtain the delineation of the CCZ.

Table 2: Delineation Parameters and weights

Delineation Parameters	Weights
Intertidal flats	38.3
Salinity (5ppm)	27.7
Contours (5 m to 15 m)	13.6

Mangroves	9.1
Khazan Land	6.3
1 km from HTL	3.1
Fishing Settlement	1.9

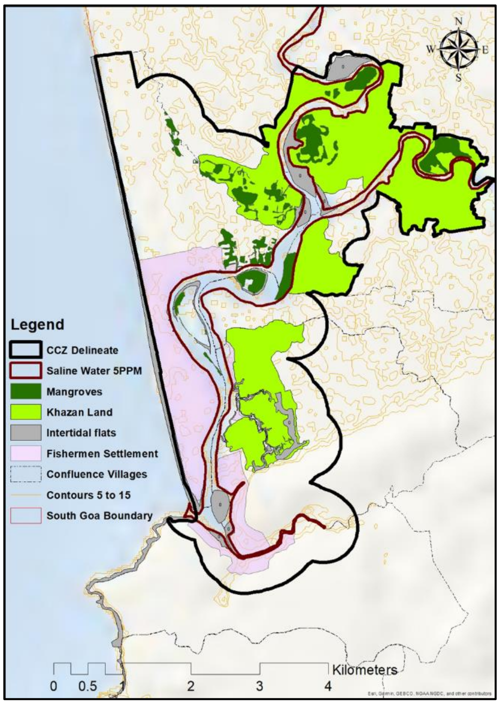


Figure 8: CCZ Delineation at Sal River

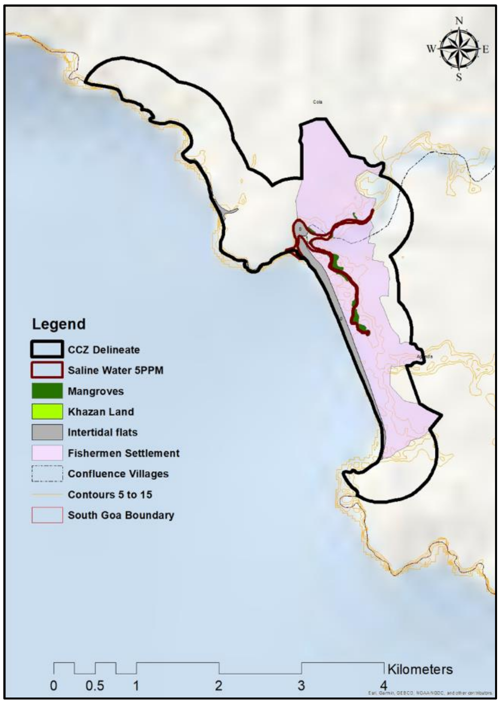


Figure 9: CCZ Delineation at Saleri River

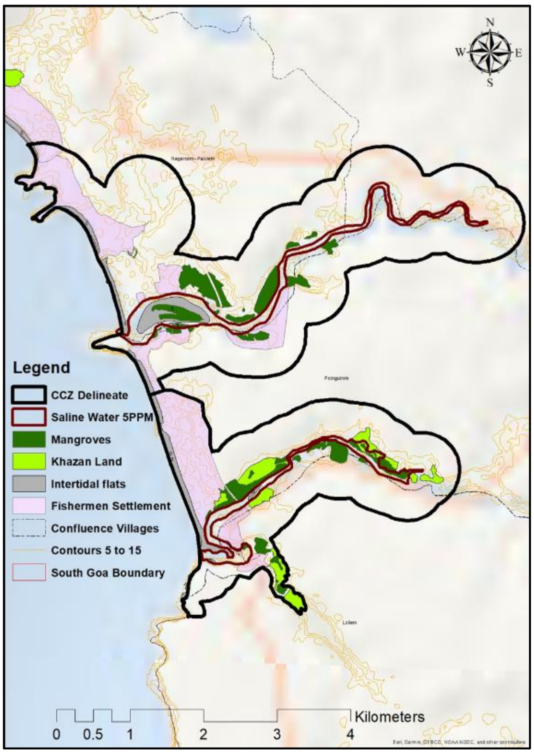


Figure 10: CCZ Delineation at Talpona and Galgibag River

7. RESULTS AND FINDINGS

7.1. Ecosystem Services Valuation

For performing the valuation, a literature review was done where the research paper - Ramachandra, T. V., Raj, R. K., & Aithal, B. H. (2019). Valuation of Aghanashini Estuarine Ecosystem Goods and Services. *Journal of Biodiversity*, *10*(1-2), 45-58. https://doi.org/10.31901/24566543.2019/10.1-2.093. Retrieved from https://www.researchgate.net/publication/338193800_Valuation_of_Aghanashini_Estuarine_Ecosystem_Goods_and_Services was followed.

The study involves using both direct and indirect valuation methods to evaluate the various benefits derived from the estuary. Data collection included gathering secondary information from government reports, research institutes, and academic studies, as well as conducting field surveys to collect primary data on fish resources, sand mining, and salt production, with valuable input from local communities.

For direct valuation, the study utilized the Market Valuation Technique to assess goods and services with clear market prices, such as fishing, agriculture, timber, and sand mining. For indirect valuation, the study presents economic values assigned to various indirect ecosystem services provided by estuaries, categorized under regulating services, supporting functions, and information functions. Each service, such as erosion control, flood control, and nutrient cycling, is valued based on data from different regions or countries using methods like damage cost avoided, replacement cost, and benefit transfer. These values are expressed in Indian Rupees (INR) per hectare, with references provided for the studies or reports that informed these estimates.

For indirect valuation, values from existing literature were adapted and converted into Indian Rupees (INR) per hectare to estimate the economic worth of the estuary's indirect services. These values were standardized and expressed in Indian Rupees (INR) per hectare, allowing for consistent comparison and aggregation across different areas of the estuary.

The study found that provisioning services contributed 22.7% of the total economic value while regulating and supporting services contributed 36.7% and 38.8%, respectively, and cultural services contributed 1.8%. The total economic value of the Aghanashini estuary was estimated at ₹24.03 billion per year, underscoring its significant role in supporting the local economy.

The values used for the indirect ecosystem services are adapted from published literature (Ramachandra et al. 2017a; Bann 2003; Barbier et al. 2011; Costanza et al. 1997; Costanza and Folke 1997; UNEP 2013; NEP/GEF 2007; TEEB 2011). The area covered by the services is considered, and the unit is multiplied by this area to calculate the total value of the service. This method is applied only for the indirect services that are regulatory, supporting, and cultural. The direct services are the provisional services for which the direct market values are considered. After the calculation of the values of all individual services, the Total Economic Value (TEV) is calculated.

Table 1: Economic values assigned to different indirect ecosystem services

Function	*Country/ Region*	*Technique used*	*Unit (rs/hectare)*	*References*
		Regulating Services		
Erosion control	Gujarat	Damage cost avoided	137606	Hirway and Goswami 2007; Prakash et al. 2010
Flood control	Srilanka	Replacement cost	158249.67	Barbier et al. 2011; Gunawardena and Rowan 2004; Sathirathai and Barbier 2001
Storm protection	Srilanka	Replacement cost	45000	Kathiresan and Narayanasamy 2005; de Groot and Vander Meer 2010
Nutrient retention	Orissa	Replacement cost	11034.5	Costanza et al. 1997; Costanza, and Folke 1997; de Groot and Vander Meer 2010
Disturbance regulation	Global	Benefit transfer	25515	Costanza et al. 1997; Costanza and Folke 1997; de Groot and Vander Meer 2010
Waste treatment	Global	Benefit transfer	301320	Costanza et al. 1997; Costanza and Folke 1997
Nutrient cycling	Global	Benefit transfer	949500	Barbier et al. 2011; Costanza et al. 1997; Costanza and Folke 1997; de Groot and Vander Meer 2010
Carbon sequestration	Ashtamudi estuary, Kerala	Damage cost-avoided	9110.2	Anoop et al. 2008; Barbier et al. 2011; Costanza et al. 1997; Costanza and Folke 1997; de Groot and Vander Meer 2010
Gas regulation	Global	Benefit transfer	9600	Barbier et al. 2011; Costanza et al. 1997; Costanza and Folke 1997; Fischlin et al. 2007
Climate regulation	Global	Be nefit transfer	4800	Barbier et al. 2011; Costanza et al. 1997; Costanza and Folke 1997; Fischlin et al. 2007
Oxygen provision	Global	Benefit transfer	5280	Barbier et al. 2011; Costanza et al. 1997; Costanza and Folke 1997; Fischlin et al. 2007
water regulation	Global	Benefit transfer	209088	Barbier et al. 2011; Fischlin et al. 2007
water supply	Global	Benefit transfer	145920	Barbier et al. 2011; Fischlin et al. 2007
Ground water recharging	Global	Benefit transfer	192000	de Groot and Vander Meer 2010; Fis-chlin et al. 2007; Barbier et al. 2011; Hassan et al. 2005; MEA 2005
Natural hazard mitigation	Global	Benefit transfer	9600	Ramachandra et al. 2002; Ramachandra and Rajinikanth 2003; UNEP 2013; UNEP/GEF 2007
		Supporting Functions (Sahyadri 2018)		
Habitat/refugia	Global	Benefit transfer	5895	Costanza et al. 1997; Costanza, Folke 1997; de Groot, Vander Meer 2010
Breeding ground and Nursery	Thailand	Benefit transfer	5271.3	Costanza et al. 1997; Costanza, Folke 1997; de Groot, Vander Meer, 2010
Biodiversity	Global	Benefit transfer	216000	Costanza et al. 1997; Costanza, Folke 1997; de Groot, Vander Meer 2010
		Information Functions (Sahyadr 2018)		
Recreation	Global	Benefit transfer	17145	Barbier et al. 2011; Costanza et al. 1997; Costanza and Folke 1997; de Groot and Vander Meer 2010
Cultural and artistic	Global	Benefit transfer	1305	Bann 2003; Barbier et al. 2011; Costan-za et al. 1997; Costanza and Folke 1997; UNEP 2013; NEP/GEF 2007; TEEB 2011
Aesthetic	Global	Benefit transfer	100	Barbier et al. 2011; Costanza et al. 1997; Costanza and Folke 1997
Science and Education	Kenya	Research funds	34660.35	Bann 2003; Barbier et al. 2011; Cos-tanza et al. 1997; Costanza and Folke 1997; UNEP 2013; NEP/ GEF 2007; TEEB 2011

Figure 11: Economic Valuation of Indirect Ecosystem Services Provided by Estuaries (Adapted from Ramachandra, Raj, & Aithal, 2019)

This method is used in this study to obtain the ecosystem service valuation of each of the services and find the Total Economic Values of each of the CCZ. The initial stage involved utilizing the Geographic Information System (GIS) to map the spatial distribution of various parameters within the area. This mapping facilitated an understanding of the relationship between the services and the diverse land uses present. Subsequently, comprehensive parameters were identified for each service. For instance, breeding grounds pertinent to supporting services were identified within areas encompassing agricultural land, rivers, forests, and intertidal flats. Similarly, for regulatory services such as flood control, areas comprising khazan, dunes, mangroves, intertidal flats, and rivers were considered. Furthermore, for cultural services like recreation, areas characterized by built-up, intertidal flats, and river were given due consideration. This approach was extended to all services to accurately calculate their valuation. The areas of land use have been considered from the 2023 LULC and GCZMP maps. The following table shows the areas (Land Use) used for each of the ecosystem services that is selected to calculate Total Economic value (TEV).

Table 3: Different areas of the CCZ used as per the parameters for Calculating TEV

Parameters	Sal (Ha)	Saleri (Ha)	Talpona (Ha)	Galgibag (Ha)	Areas Considered (Ha)
Total Area (Ha)	2253.00	604.58	1089.63	625.68	
Habitat	2253	604.58	1089.63	625.68	Entire CCZ
Breeding ground	1169.76	405.59	392.13	455.29	Agricultural Land, River, Intertidal Flats, Aqua Culture
Biodiversity	1004.90	379.20	353.62	399.12	Agricultural Land, River, Aqua Culture
Recreation	938.42	146.33	224.71	202.36	Built up, Intertidal Flat, River
Cultural	1263.41	488.26	454.67	500.48	Built-up, River Agricultural Land
Aesthetic	1428.27	514.66	493.18	556.64	Built, River, Intertidal Flats Agricultural Land
Education	1292.19	412.34	450.02	500.36	Sand Dunes, Intertidal Flats, River, Agricultural Land
Erosion Control	391.43	33.15	96.40	101.23	Sand Dunes, Mangroves, Intertidal Flats
Flood Control	1494.54	44.02	208.51	201.34	Khazan, Sand Dunes, Mangroves, Intertidal Flats, River
Storm Protection	802.33	44.02	181.55	146.08	Sand Dunes, Mangroves, Intertidal Flats, River
Nutrient Retention	1378.15	44.02	208.51	194.62	Khazan, Mangroves, Intertidal Flats, River
Carbon sequestration	918.77	6.75	84.84	100.33	Khazan, Sand Dunes, Mangroves
Waste treatment	2253	604.58	1089.63	625.68	Entire CCZ
Gas regulation	2253	604.58	1089.63	625.68	Entire CCZ
Climate regulation	2253	604.58	1089.63	625.68	Entire CCZ
Oxygen provision	490	368	268	354	Agricultural land (Khazan, Vegetation, Mangroves)
water regulation	1005	379	354	399	River, Aquaculture

Water Supply	1103	11	112	100	River
Ground water recharging	2253	604.58	1089.63	625.68	The entire CCZ except the built-up area
Natural hazard mitigation	2253	604.58	1089.63	625.68	Entire CCZ
Erosion	391.43	33.15	96.40	101.23	Sand Dunes, Mangroves, Intertidal Flats

The values for Rs/Ha are obtained by using the areas. The total valuation for each CCZ and the parameters used under each service are also indicated, along with the method used for deriving the value and the unit (Rs/Ha) for the respective parameter. The study relies on both secondary data and field surveys. For secondary data, the Information was gathered from government reports, research institutes, and academic studies, and a field survey was done for primary data collection through surveys focused on fish resources, agriculture, and salt production. This involved interactions with local communities to understand resource availability and usage. For Direct Valuation important services were identified through academic reports and filed surveys. For goods and services with clear market prices, the study used the Market Valuation Technique.

Table 4: Ecosystem Services Matrix for Economic Value of Each of the CCZ

	Parameters	**Sal**	**Saleri**	**Talpona**	**Galgibag**	**Unit (Rs/ Ha)**
Provisional Services	Fisheries (Revenue Rs/yr)	8,12,90,00,000	59,50,00,000	60,80,00,000	37,90,00,000	-
	Agriculture Products (Coconut Revenue Rs/Yr)	330225600	158310400	119351200	140995200	
	Salt (Revenue Rs/ Yr)	1050000	-	-	-	
	Total (Rs/ Yr)	**8460275600**	**753310400**	**727351200**	**519995200**	-
Regulating Services	Erosion control	53863458	4561198	13265175	13930225	137606
	Flood control	236509857	6965643	32996589	31861889	158250
	Storm protection	36104962	1980756	8169736	6573721	45000
	Nutrient retention	15207228	485703	2300800	2147527	11034.5

	Carbon sequestration	8370202	61509	772954	914001	9110.2
	Waste treatment	678873960	182172046	328327312	188529898	301320
	Gas regulation	21628800	5803968	10460448	6006528	9600
	Climate regulation	10814400	2901984	5230224	3003264	4800
	Oxygen provision	2586440	1944763	1417521	1870564	5280
	water regulation	210111721	79285390	73937681	83451931	209088
	water supply	160964891	1586150	16359091	14607567	145920
	Ground water recharging	432576000	116079360	209208960	120130560	192000
	Natural hazard mitigation	21628800	5803968	10460448	6006528	9600
	Total (Rs/ Yr.)	**1889240720**	**409632438**	**712906939**	**479034203**	
Supporting Services	Habitat	13281435	3563999	6423369	3688384	5895
	Breeding ground (Nesting)	6166154	2137994	2067060	2399947	5271.3
	Biodiversity	217057563	81906395	76381902	86210672	216000
	Total (Rs/ Yr.)	**236505153**	**87608388**	**84872331**	**92299003**	
Cultural Services	Recreation	16089184	2508838	3852705	3469541	17145
	Cultural	1648751	637182	593342	653121	1305
	Aesthetic	142827	51466	49318	55664	100
	Education	44787709	14291955	15597837	17342520	34660
	Total (Rs/ Yr.)	**62668473**	**17489440**	**20093202**	**21520846**	
	Total Economic Value (Rs/Yr.)	**10,64,86,89,946**	**1,26,80,40,666**	**1,54,52,23,672**	**1,11,28,49,252**	

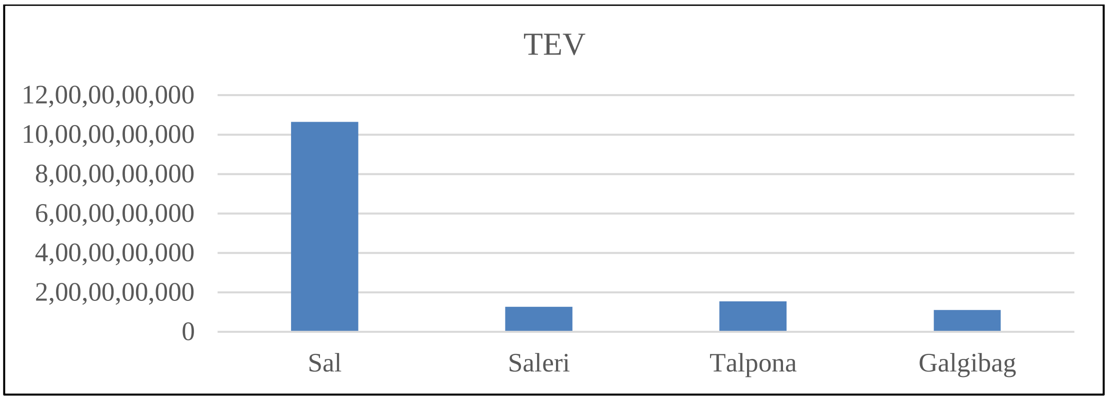
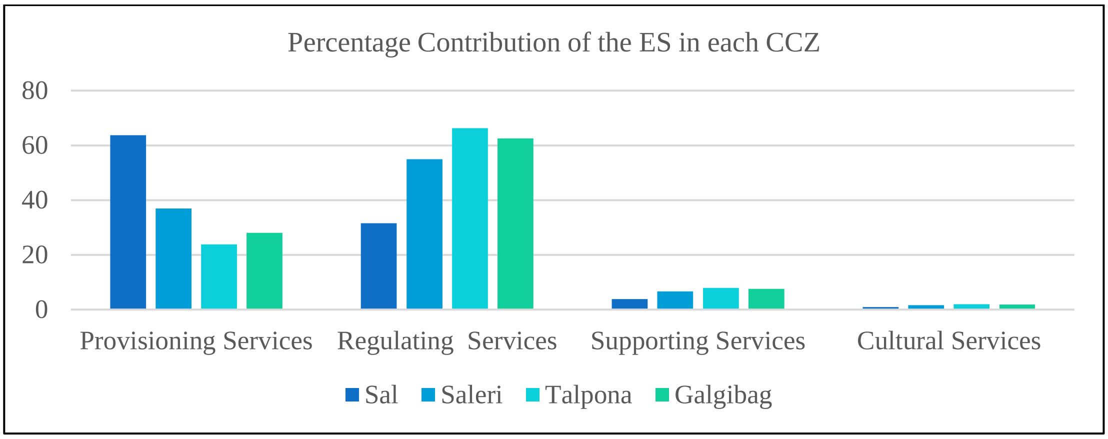


Figure 12: Total Economic Value of all four CCZ (Rs/ Year)



Percentage Contribution of the ecosystem services in each CCZ

Inference:

- The highest TEV is seen at the River Sal which is around INR 10 billion (Rs.10,64,86,89,946).
- It is seen that Cultural services give the least contribution in the TEV and Regulating services give the highest contribution.

8. LIVELIHOOD DEPENDENCY ANALYSIS

8.1. Analysing the identified two main occupations

In this analysis, the two main occupations were identified based on the site visit and primary survey. The two main occupations identified are Fisheries and Tourism. The dependency of the people of the CCZ in these occupations is analyzed.

8.1.1. Fisheries

The fishermen's settlements that fall in the selected four CCZs are identified based on GCZMP Maps and the fishermen's census conducted by the Directorate of Fisheries, Goa. The number of fishermen families and the fishermen population is taken based on data availability for the years 2005, 2010, and 2016.

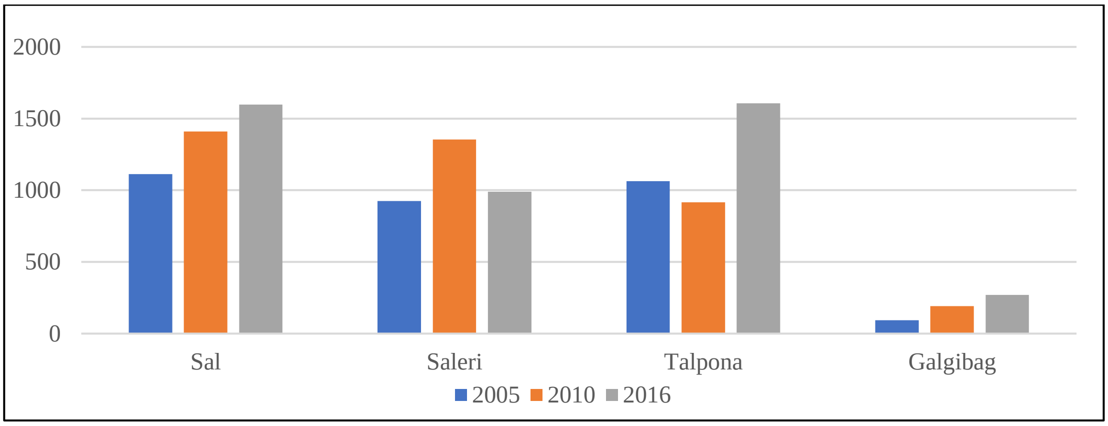


Figure 13: Fishermen Population at the CCZ Villages

Inference:

- Sal: The population depended on fisheries is seen increasing.
- Saleri: The population increased in 2010 and later on decreasing.
- Talpona: Population-dependent fisheries is increasing rapidly.
- Galgibag: Population is less compared to other CCZ but dependency on fisheries is increasing.

In Sal, the population dependent on fisheries has consistently increased over the observed years, indicating growing reliance on this sector. In Saleri, there is a noticeable increase in the population by 2010, but this trend reversed, showing a decline by 2016. Talpona experienced a rapid increase in population dependent on fisheries, particularly in 2016, suggesting a significant shift toward fisheries-based livelihoods. Meanwhile, Galgibag shows the lowest overall dependency, though it still exhibits a gradual increase over time.

8.1.2. Tourism

As per the Goa Tourism Policy 2020 by the Government of Goa, 40% of Goa's population is dependent on tourism directly and indirectly (2020). Out of this, it is observed that the majority of the tourists arrive at North Goa, and South Goa has fewer tourist comparatively. Therefore, assumptions were made for the year-wise distribution of tourism dependency: in 2021, 40% of the population is assumed to be dependent, with 25% in North Goa and 15% in South Goa. For 2011, the dependency is estimated at 30%, with 20% in North Goa and 10% in South Goa, and for 2001, it's estimated at 20%, with 15% in North Goa and 5% in South Goa. Further, the growth rate is calculated based on the year wise dependency from 2001 to 2011.

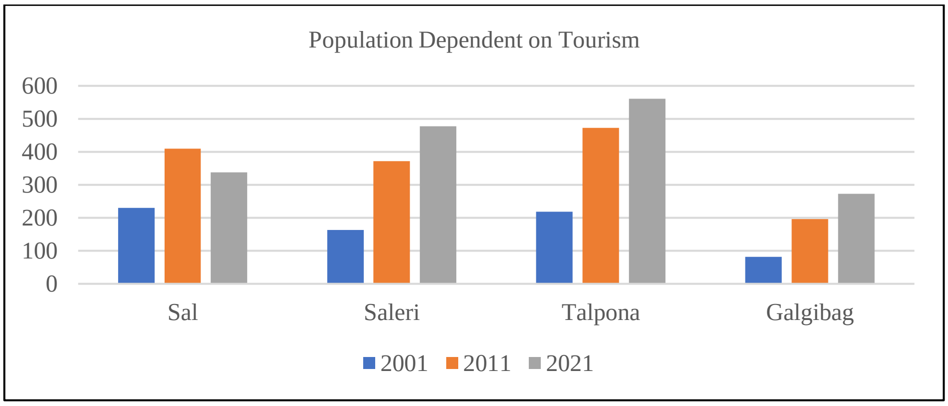


Figure 14: Population Dependent on tourism

Inference:

- Sal: Population depended on tourism is seen decreasing from 2001 to 2021.
- Saleri: Population dependency is drastically increased in 2011 and there is slow increase in the year 2021.
- Talpona: Population dependent is increasing rapidly from 2001 to 2011.
- Galgibag: Population dependency is less as compared to other CCZs but it is gradually increasing from 2001 to 2021.
- Overall, the population dependency on tourism is seen increasing at Saleri, Talpona and Galgibag CCZ. Whereas only in Sal CCZ it is decreasing.

In Sal, the population dependent on tourism has been decreasing from 2011 to 2021, indicating a reduced reliance on the tourism sector. Saleri shows a significant increase in tourism dependency from 2001 to 2011, followed by a slower rate of increase by 2021. Similarly, Talpona has experienced a steady and rapid rise in tourism-dependent population from 2001 to 2011, with a slower upward trend continuing to 2021. Galgibag, while showing the lowest overall dependency on tourism, has seen a gradual increase from 2011 to 2021.

8.2. Livelihood Performance

The livelihood performance analysis is a component of the livelihood dependency analysis. This analysis involves assessing various indicators related to Natural, Physical, Social, Financial, and Human Assets for both the fisheries and tourism sectors. To gather data, individuals involved in fishing and tourism activities at the CCZ were surveyed using both a Google form and a printed form to rate the indicators for each asset. Each asset was given an equal weightage of 20, making the total score 100. The scores for each asset were then recalculated to provide a score out of 20. The analysis of each asset's score is based on the scores given to each indicator within the asset.

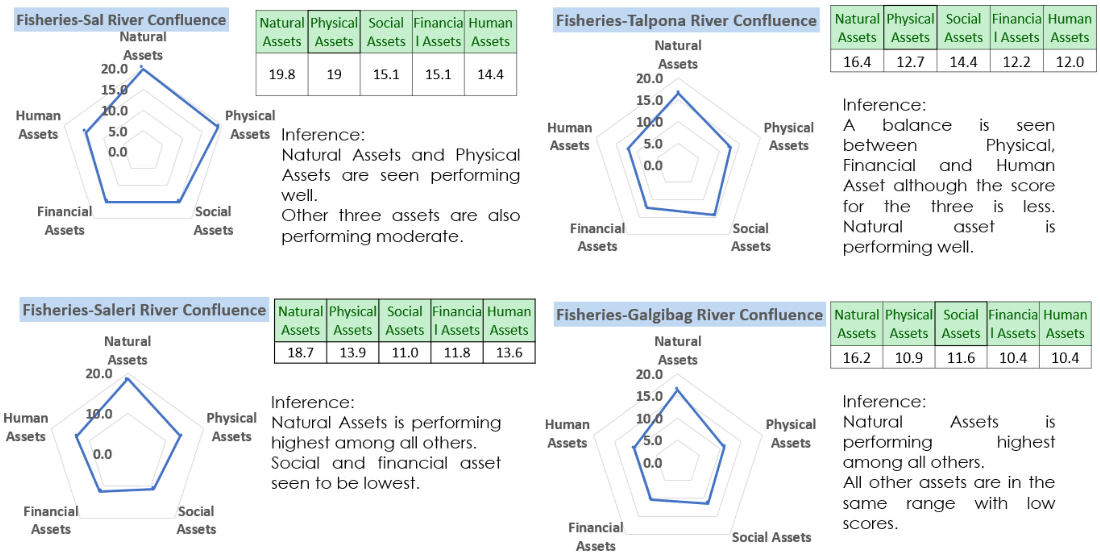
For the fisheries sector, the following indicators were chosen:

- Natural Assets: Accessibility to the beach area, accessibility to mangroves, and accessibility to the fishing area.
- Physical Assets: Accessibility to storage, accessibility to the road from CCZ, accessibility to the market area, availability of transport, and accessibility to the jetty.
- Social Assets: Assistance from NGOs, assistance from government schemes, availability of fishermen associations, ability to train fishermen, ability to perform cultural customs, and level of conflicts between fishermen and the government.
- Financial Assets: Income levels, availability of financial assistance, and other occupational opportunities.
- Human Assets: Education level, other skills, and availability of health programs/check-ups for fishermen.

For the tourism sector, the following indicators were chosen:

- Natural Assets: Accessibility to the beach area, accessibility to CCZ from the beach, accessibility to tourism activity, and accessibility to marine life.
- Physical Assets: Accessibility to the jetty from the road, accessibility to transportation from the beach, and accessibility to CCZ from the road.
- Social Assets: Availability of information about CCZ tourism (online/offline) and availability of tourism schemes.

- Financial Assets: Income levels of people in tourism, investment made to start tourism activity, maintenance of CCZ area, and other occupational opportunities.
- Human Assets: Education level, other skills, and availability of health programs/check-ups for people in tourism.



Fisheries-Sal River Confluence

Natural Assets	Physical Assets	Social Assets	Financial Assets	Human Assets
19.8	19	15.1	15.1	14.4

Fisheries-Talpona River Confluence

Natural Assets	Physical Assets	Social Assets	Financial Assets	Human Assets
16.4	12.7	14.4	12.2	12.0

Fisheries-Saleri River Confluence

Natural Assets	Physical Assets	Social Assets	Financial Assets	Human Assets
18.7	13.9	11.0	11.8	13.6

Fisheries-Galgibag River Confluence

Natural Assets	Physical Assets	Social Assets	Financial Assets	Human Assets
16.2	10.9	11.6	10.4	10.4

Figure 15: Asset Scores for Each CCZ, Based on Cumulative Indicator Scores Collected Through Surveys and Site Visits

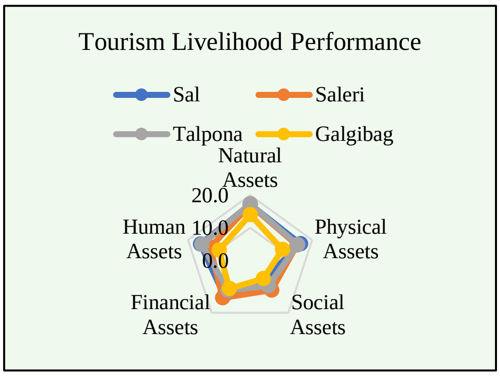


Figure 16: Tourism Livelihood Performance

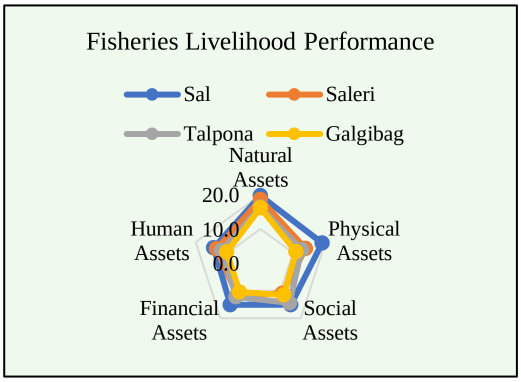


Figure 17: Fisheries Livelihood Performance

Inference:

- Fisheries: All the CCZ are performing well in Natural assets. CCZ at Sal River has scored highest in physical assets and Saleri in social assets. The lowest balance of score is seen in Galgibag.
- Tourism: All the CCZ are performing moderately well in natural, physical, and human assets. A balance of scores is seen in Saleri River CCZ. All CCZ are performing poor in social assets whereas Sal River CCZ is performing the least.

9. DISCUSSION

9.1. Discussion on ecosystem service valuation analysis

In the Sal CCZ, the total economic value is ₹10,64,86,89,946. Provisional services account for 79.44% of the total value. Regulating services contribute 17.74% while supporting and cultural services add 2.22% and 0.59%, respectively. For the Saleri CCZ, the total economic value is ₹1,26,80,40,666. Here, provisional services also play a significant role, contributing 59.41% of

TEV, regulating services account for 32.30%, while supporting services contribute 6.91%, and cultural services 1.38%. In the Talpona CCZ, with a total economic value of ₹1,54,52,23,672, provisional services contribute 47.07% of TEV. Regulating services have a substantial share of 46.15%. Supporting services account for 5.49%, and cultural services contribute 1.30%. In the Galgibag CCZ, the total economic value is ₹1,11,28,49,252. Provisional services make up 46.71% of TEV. Regulating services contribute 43.06%, while supporting services account for 8.29%. Cultural services add 1.93%.

Provisional Services dominate the economic value in all CCZ, especially at the Sal, where they account for nearly 79.44% of the total value. Regulating Services also play a significant role, particularly in the Talpona and Galgibag estuaries, contributing around 46.15% and 43.06% of their total economic values, respectively. Supporting Services make a modest contribution across all CCZs, ranging from 2.22% in Sal to 8.29% in Galgibag. Cultural Services account for the smallest share of the total economic value in all estuaries. The data emphasizes the importance of provisional and regulating services in estuarine ecosystems, with supporting and cultural services also playing a role, though to a lesser extent. It is crucial to balance these services to sustain the ecological and economic benefits of estuaries. The data illustrates that provisional services are the primary contributors to the economic value of all estuaries, especially in the Sal estuary. Regulating services are also crucial, particularly in the Talpona and Galgibag estuaries. While supporting and cultural services contribute smaller percentages, they are still important for these estuaries' overall ecological and economic sustainability.

9.1.1. Selection of Ecosystem Services for Proposals

The proposals for ecosystem services undergo a selection process based on the ranking of parameters for each of the four ecosystem services, as depicted in the graphs. It's important to note that proposals for one ecosystem service are interconnected to all other services and contribute to the enhancement of the entire ecosystem.

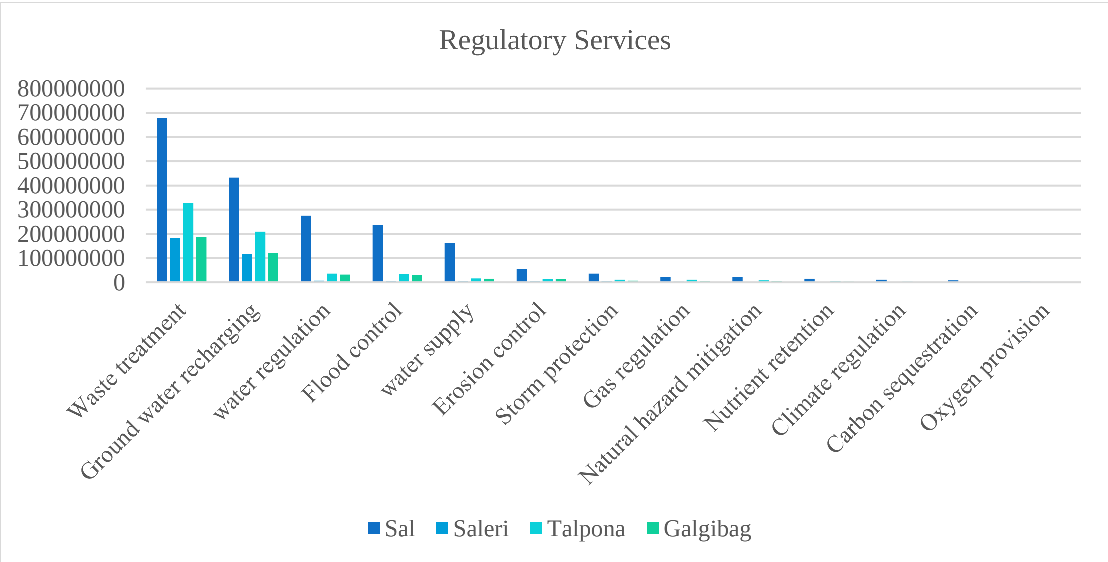


Figure 18: Value of Regulatory Service in four CCZ

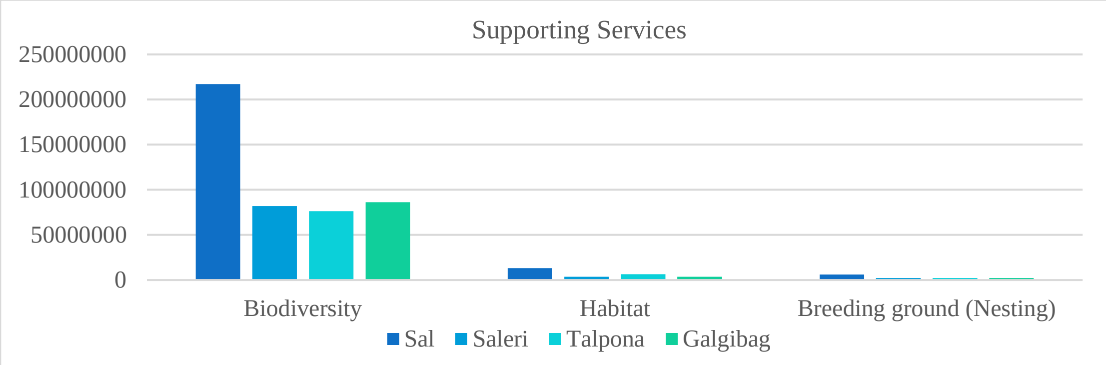


Figure 19: Value of Supporting Service in four CCZ

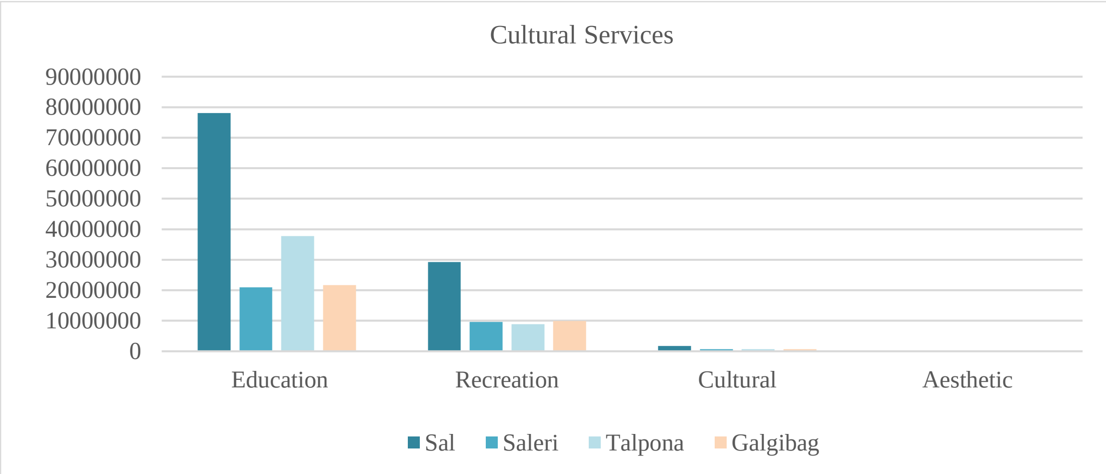


Figure 20: Value of Cultural Service in four CCZ

The table displays the first two highest value Ecosystem Services selected for Each CCZ. It is observed that out of the three provisional services in each CCZ, fisheries and agriculture made the highest contribution, making it a significant parameter to consider. In terms of regulatory services, Waste treatment and groundwater recharge had the highest contributions in Sal and Talpona CCZ, whereas flood control was highest in Saleri and Galgibag. Therefore, these parameters are considered for regulatory services in the respective CCZ. Among the three parameters, biodiversity and habitat contributes the most to supporting services, while in cultural services, education and recreation have the highest contribution.

Selected Ecosystem Services for Each CCZ

Sal	**Saleri**	**Talpona**	**Galgibag**
Provisional services			
Fisheries	Fisheries	Fisheries	Fisheries
Agriculture	Agriculture	Agriculture	Agriculture
Regulatory Services			
Waste treatment	Waste treatment	Waste treatment	Waste treatment
Ground water recharging	Ground water recharging	Ground water recharging	Ground water recharging
Supporting Services			
Biodiversity	Biodiversity	Biodiversity	Biodiversity
Habitat	Habitat	Habitat	Habitat
Cultural Services			

Education	Education	Education	Education
Recreation	Recreation	Recreation	Recreation

9.2. Discussion on Livelihood Dependency Analysis

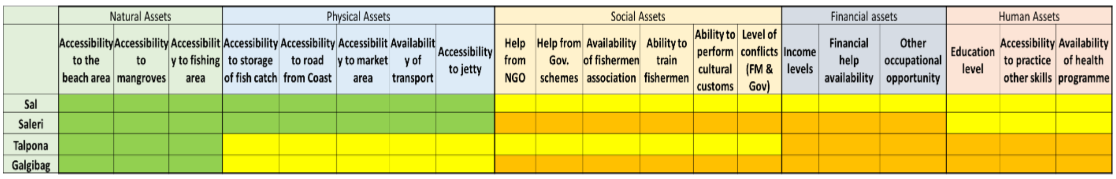
In Sal, the population dependent on fisheries is increasing, while tourism dependency is on the decline. This suggests a shift towards traditional livelihoods in this region, with the community possibly finding more reliable income from fisheries rather than tourism. Saleri presents with the population showing a increase in dependency on both fisheries and tourism, particularly in 2011, although the rate of increase in tourism dependency has slowed by 2021. Talpona has witnessed a rapid rise in dependency on both fisheries and tourism from 2001 to 2011, continuing through to 2021. This trend suggests a robust integration of both sectors into the local economy, with the community increasingly reliant on both for their livelihoods. In Galgibag, although the population shows less overall dependency on both fisheries and tourism compared to the other CCZs, there is a gradual increase in both areas from 2011 to 2021. This indicates a growing but cautious adoption of these economic activities in the region.

The fisheries livelihood performance shows that Sal has a strong asset base across almost all categories, particularly in Physical and Social Assets, which are crucial for sustaining fisheries activities. Talpona and Saleri have moderate to strong scores across the categories, with Saleri showing a slight edge in Social Assets. Galgibag again shows a lower overall performance, particularly in Financial Assets, suggesting challenges in accessing financial resources and support for fisheries.

For tourism, Sal has relatively lower scores overall, indicating fewer resources and support for tourism activities compared to the other regions. Saleri and Talpona display relatively balanced scores across all asset categories, indicating a well-rounded support system for tourism activities. Galgibag shows strong performance in Natural Assets but lower scores in other categories, suggesting that while the natural environment is favorable, other supports like social and financial infrastructure are weaker.

9.2.1. Selection of the assets for the proposals on livelihood dependency

Each indicator is assessed based on whether it is performing Good, medium, or bad. The indicators that performed bad were listed separately. Based on these indicators, it was determined which assets would require proposals in the concerned CCZ. For example, in terms of fisheries, the Saleri CCZ is performing well in natural and physical assets, but badly in social and financial assets. Therefore, this CCZ will need proposals related to the social and financial assets. In terms of tourism, Galgibag is performing poorly in physical, social, financial, and human assets. Consequently, this CCZ will need proposals related to these assets.



Assets performance for fisheries

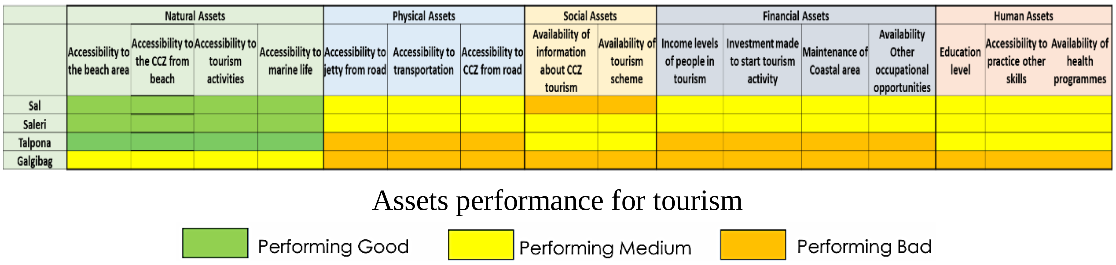


Figure 21: Assessing performance of each indicator in the assets

Table 5: Selecting the assets for proposals relating to livelihood dependency

	Sal	Saleri	Talpona	Galgibag
Fisheries				
Livelihood dependency on fisheries	Gradual increase in dependency	Decrease in dependency	Drastic increase in dependency	Slow increase in dependency
Livelihood performance	Livelihood performance is well	Proposal in social asset required Proposal in Financial asset required	Proposal in Financial asset required Proposal in Human asset required	Proposal in social asset required Proposal in Financial asset required Proposal in Human asset required
Tourism				
	Sal	**Saleri**	**Talpona**	**Galgibag**
Livelihood dependency on fisheries	Decrease in dependency	Gradual increase in dependency	Drastic increase in dependency	Slow increase in dependency
Livelihood performance	Proposal in social asset required	Livelihood performance is well	Proposal in Financial asset required	Proposal in social asset required Proposal in Financial asset required Proposal in Human asset required

10. CONCLUSION AND WAY FORWARD

10.1 Conclusion

The analysis of ecosystem services and livelihood dependency across the four CCZs—Sal, Saleri, Talpona, and Galgibag—reveals an interplay between ecological value and the economic activities of estuarine ecosystems.

In Sal, there is a clear shift towards fisheries as the primary livelihood, with a decline in tourism dependency. This is supported by the strong asset base in Physical and Social Assets, crucial

for sustaining fisheries. The dominance of Provisional Services, contributing nearly 79.44% of the total economic value, further underscores the region's reliance on traditional livelihoods.
Saleri and Talpona show a balanced dependency on both fisheries and tourism, with the populations increasingly relying on these sectors. Both regions have a moderate to strong asset base, with Saleri slightly outperforming in social assets. The significant role of Regulating Services, where they contribute around 32.30% at Saleri and 46.15% at Talpona of the total economic value, highlights the importance of maintaining ecological functions.
Galgibag shows a gradual increase in both fisheries and tourism despite having a lower overall dependency on these sectors as compared to other CCZs. While the region has strong natural assets for tourism, it performs weaker in financial assets for fisheries. Regulating services make a significant contribution to the economic value, accounting for about 43.06%, highlighting the importance of ecological stability. However,
The CCZs demonstrate a strong dependency on Provisional and Regulating Services, which are key to the Total Economic Value of the CCZs. Fisheries are increasingly becoming the primary livelihood, especially in Sal, supported by a robust asset base. In other CCZs fisheries and tourism both are seen in increasing trend. Although cultural services often receive significant attention and are perceived as highly valuable, they contribute the least to Total Economic Value (TEV). In contrast, provisioning services and regulating services provide the highest contribution. The lower contribution of supporting and cultural services at all the CCZs suggests potential areas for development to enhance the region's overall resilience.
For livelihood performance in fisheries, all CCZs are excelling in natural assets, followed by physical assets. However, social and financial assets require improvement and recommendations. In tourism, all CCZs are performing well in natural assets, followed by human assets. Conversely, physical, financial, and social assets are underperforming and need recommendations for improvement. Proposals and recommendations should be shaped based on the performance of these assets and the population's dependency on tourism and fisheries.
The proposals might address different aspects but they should be connected to each of the parameters of the analysis. It is in general considered that the proposal given for ecosystem service valuation will also cater to the benefits of other analysis. The proposals given for livelihood dependency should have a relation with ecosystem services and vice versa

10.2.Proposal and Recommendation

10.2.1. Management of Ecosystem Services

In the areas, where ecosystem services such as Regulating and Supporting Services are crucial, the proposal emphasizes strict protection. These areas include ecologically sensitive zones like CRZ 1A and 1B, and regions within a 100-meter buffer from tidal waterbodies. Development activities would be heavily restricted, focusing instead on enhancing ecological functions through afforestation, community-led conservation efforts, and controlled eco-tourism. These actions would aim to preserve the natural assets that are vital for sustaining the ecological balance and supporting fisheries, a key livelihood in these regions.
The CCZs both tourism and fisheries are significant and would see regulated development under this proposal. The focus would be on promoting activities that support both Regulating and Provisional Services, such as sustainable tourism initiatives and infrastructure improvements while ecological preservation, ensuring that the development supports the livelihoods dependent on these services while adhering to environmental regulations.

In the Talpona Coastal Conservation Zone (CCZ), there are plans to develop key infrastructure including a fishing jetty to meet the growing demand for fisheries in the region. Furthermore, proposals for recreational spaces and nature trails aim to boost tourism, benefiting both the local economy and cultural preservation efforts. This approach prioritizes sustainable development that caters to the ecological and economic requirements of the region.

10.2.2. Framework for Analysing Ecosystem Services and Livelihood Dependency

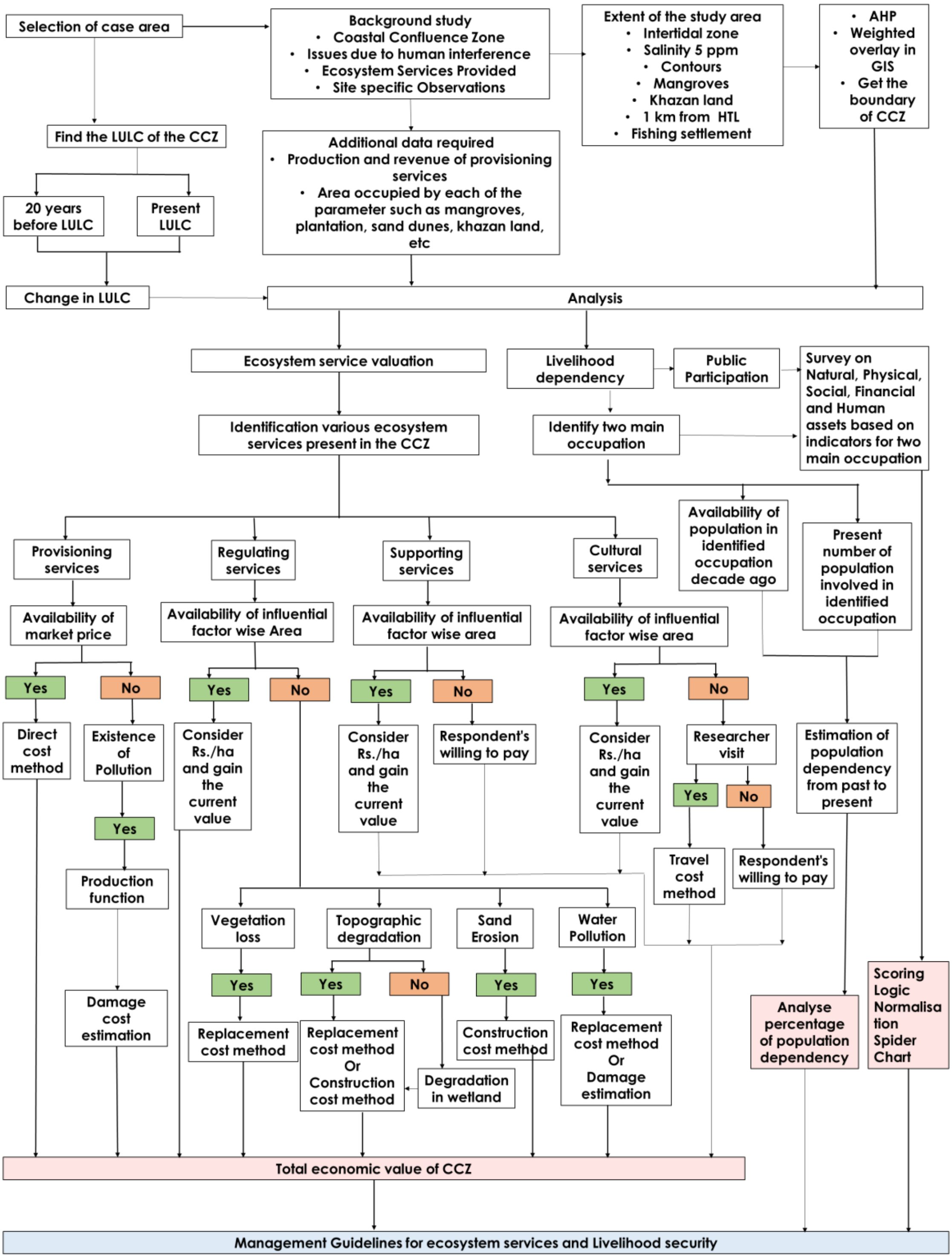


Figure 22: Proposed Framework for analysing ecosystem services and livelihood dependency at Coastal Confluence Zone

10.2.3. Protection of Turtle Nesting Areas

Talpona and Galgibag CCZs, along with Agonda Beach in the Saleri CCZ, are key turtle nesting sites. These areas should be designated with clear beach boards during the breeding season. Visitors must be kept 50 meters away from nesting sites, with special permissions needed for educational access. Vehicles are to be prohibited, and beach shack operators must follow strict guidelines on litter, lighting, music, and water sports after sunset.

10.2.4. Climate Smart Plantation and Groundwater Recharging for Enhanced Ecosystem Services

The proposals for climate-smart plantation and building agriculture-responsible communities are critical components of the biodiversity parameter. These initiatives extend beyond biodiversity, significantly benefiting regulating, supporting, and provisioning services. By implementing these strategies, we can enhance water regulation, groundwater recharge, flood control, and nutrient cycling, all of which are essential for maintaining ecological balance and supporting local economies.

The Climate Smart Plantation initiative aims to improve soil health, promote biodiversity, and restore habitats by reintroducing native plant species. It is an approach to planting and managing vegetation that involves using climate-adapted, native species and sustainable practices like agroforestry and reforestation to mitigate climate impacts. Coconut plantations are particularly significant given the economic benefits they provide for nearby communities. The cultivation of khazan land-specific paddy is well-suited to the local conditions and holds significant cultural and economic value. These plantation areas can also serve recreational and educational purposes.

Building Agriculture Responsible Communities will promote sustainable agricultural practices while supporting economic growth. Training programs can be offered to locals, equipping them with the skills needed to manage native species, grazing, and crop cultivation in the CCZ area. By integrating agriculture with eco-tourism, these communities can generate income while preserving the environment.

Furthermore, Groundwater Recharging is crucial for sustaining these agricultural practices. Implementing rainwater harvesting, utilizing parks for water collection, and restoring water bodies, such as lakes and tanks, will contribute to groundwater recharge and water regulation. Restrictions on groundwater withdrawal within 200 meters of the High Tide Line (HTL) as per CRZ rules will ensure that local communities can sustainably use this resource without compromising the environment.

By focusing on sustainable agriculture and groundwater management, the initiatives will benefit regulating services, such as water regulation and flood control, supporting services like nutrient cycling and habitat restoration, and provisioning services, including food production and economic growth.

10.2.5. Recommendations for Fisheries Based on Asset Indicators Requiring Attention

A. Assistance from Non-Governmental Organizations (NGOs)

- The goal is to improve the lives of fishermen through comprehensive development in the areas of health, education, water and sanitation, and economic development.
- Multiple NGO groups can be invited to monitor and support fishing communities.
- Identified issues should be reported to the concerned government department and followed up until a solution is implemented.

B. Government Schemes and Financial Support

- The National Scheme of Welfare of Fishermen offers financial aid for the construction of houses, community halls, and the installation of tube wells. Government officials to work on ground level to monitor appropriate implantation.
- The government aims to develop model fishermen villages by providing basic amenities.
- Other initiatives like Pradhan Mantri Matsya Sampada Yojana (PMMSY) should be communicated to fishing communities through social gatherings, social media, or outreach campaigns.

C. Availability of Fishermen's Associations

- Active fishermen's association meetings should be held to raise and address community issues with local governing bodies and the Department of Fisheries.
- Regular health check-ups and medical assistance should be provided to fishermen communities.

D. Training for Fishermen

- The responsibility lies with the fishermen's association of each village to train and equip new fishermen, ensuring their competence when working on trawlers.

E. Cultural and Religious Practices

- Fishermen should be permitted to engage in cultural and religious activities with proper safety measures and waste management practices, especially when venturing into the sea.

F. Resolution of Conflicts

- Any conflicts between the government and fishing communities should be promptly addressed to avoid negative impacts on the economy. The Department of Fisheries should appoint dedicated personnel to bridge the gap and find solutions.

G. Diversification of Occupational Opportunities and Skills

- Fishermen communities should be supported in exploring other occupational opportunities, such as the tourism sector.
- Community centers and workshops should be established for skill development and career guidance seminars could be organized in fishermen's village schools.

Recommendations for Tourism Based on Asset Indicators Requiring Attention

A. Availability of information about CCZ tourism

- Strategic tourism planning and implementation of Tourism Circuit Plans.
- Creating awareness and providing information about CCZ tourism through hoardings, boards at the site, and nearby villages for both locals and tourists.
- Social media advertisements and promotions targeting locals, domestic, and foreign travelers.

B. Economic Development through Tourism

- Generating jobs directly through hotels, restaurants, taxis, souvenir sales, the production of local food, and handicrafts and indirectly through the supply of goods and services needed by tourism-related businesses

- Ensuring timely visits of the Tourism department officers to check the functioning of the tourism activities.

C. Maintenance of Coastal area:

- Key management policies dealt with by the CZMP
- Maintaining coastal landforms, physical coastal processes, and conserving nature
- Encouraging knowledge sharing and community engagement

D. Tourism Schemes:

- Ensuring effectivness of Goa Tourism Policy 2020, The Goa Tourist Places (Protection and Maintenance) Act, 2001, Swadesh Darshan Scheme, CBSP Scheme

E. Other occupational opportunities and accessibility to practicing other skills

- Ensuring education for the local people involved in tourism.
- Introducing more tourism-related professions and schemes to maintain the active participation of locals
- Ensuring timely interaction of the tourism department authorities with the locals to know the issues and provide financial assistance

F. Availability of health programs

- Ensuring better health services for the locals involved in tourism activities
- Arranging for doctors to visit the nearest community centers for monthly check-ups of workers involved in water and air sports activities
- Monitoring water sport and air sport activities for safety by authorities

11. REFERENCE

1. Master of Environment Planning and Management. (2022). *Regional Environmental and Development Plan of South Goa District 2041*. School of Planning and Architecture, Vijayawada, Government of India.
2. Admin. (2023, March 6). It’s raining Olive Ridley eggs in Canacona; in a record, Agonda is visited by 42 mother turtles to lay eggs. Goemkarponn. Available at: https://goemkarponn.com/its-raining-olive-ridley-eggs-in-canacona-in-a-record-agonda-is-visited-by-42-mother-turtles-to-lay-eggs/
3. Admin. (2023, March 6). It’s raining Olive Ridley eggs in Canacona; in a record, Agonda is visited by 42 mother turtles to lay eggs. Goemkarponn. Available at: https://goemkarponn.com/its-raining-olive-ridley-eggs-in-canacona-in-a-record-agonda-is-visited-by-42-mother-turtles-to-lay-eggs/
4. Anon. (2018, June 26). Now, take a walk through the mangroves at Patto. The Goan Every day. Available at: https://www.thegoan.net//now-take-a-walk-through-the-mangroves-at-patto/43674.html
5. Deejay Farm. (2018, March). Coconut cultivation and its importance. Available at: https://deejayfarm.com/blog/coconut-cultivation-and-its-importance/
6. Anon. (2018, May 11). Mud houses are the new fad in the capital. Times of India. Available at: https://timesofindia.indiatimes.com/city/thiruvananthapuram/mud-houses-are-the-new-fad-in-the-capital/articleshow/64116032.cms?from=mdr

7. Anon. (n.d.). Galgibaga beach - the turtle nesting beach. Palolem Beach Goa. Available at: https://m.facebook.com/PalolemBeachGoa/photos/galgibaga-beach-the-turtle-nesting-beach-one-of-the-cleaneset-beach-with-its-smo/272601682783847/
8. Anon. (n.d.). Major Estuarine Systems of India and their Fisheries. Available at: https://basu.org.in/wpcontent/uploads/2020/11/Major-Esturine-Systems-of-India-and-their-Fisheries.pdf
9. Auropremi, P. G. (2019, April). Planning and Management of Coastal Ecosystem Services of Puducherry Coastal Region. School of Planning and Architecture, Vijayawada.
10. Baitalik, A. (2015, April). Estuarine landforms of Puri coast in Orissa, India. International Journal of Science and Research (IJSR), 4(4).
11. Gubalani, R. (2020, July 16). Livelihood assessment: A participatory tool for natural resource dependent communities. Philippine News Agency. Available at: https://www.pna.gov.ph/articles/1109158
12. Huang, T., Chen, S.-g., & Zhang, H.-z. (2013, November). The urban ecological sensitivity analysis of Enshi city based on GIS and analytic hierarchy process model. Advanced Materials Research, 671-674.
13. Singh, I. J., Singh, S. K., Singh, A. R., & Singh, S. (2004). Assessment and monitoring of estuarine mangrove forests of Goa using satellite remote sensing. Photonirvachak - Journal of the Indian Society of Remote Sensing, 32.
14. Lax, J., & Krug, J. (2013). Livelihood assessment: A participatory tool for natural resource dependent communities. Thünen Working Paper 7, Johann Heinrich von Thünen Institut, Braunschweig.
15. Mirsky, S. (2019, June 12). A biodegradable label doesn’t make it so. Scientific American. Available at: https://www.scientificamerican.com/podcast/episode/a-biodegradable-label-doesnt-make-it-so/
16. Nayak, G. (2021, December). Changing tropical estuarine sedimentary environments with time and metals contamination, west coast of India. Journal Indian Association of Sedimentologists, 38(2).
17. Pradhan, A. (2016). State of India's rivers for India Rivers Week. Available at: https://indiariversblog.files.wordpress.com/2017/05/goa-report.pdf
18. Nepal, S., Flügel, W.-A., & Shrestha, A. B. (2014, September). Upstream-downstream linkages of hydrological processes in the Himalayan region. Ecological Processes.
19. Thrush, S. F., Townsend, M., Hewitt, J. E., Kraan, C., Lohrer, A. M., Lundquist, C. J., & Carter, K. (2014, January). The many uses and values of estuarine ecosystems. In: Ecosystem Services in New Zealand – Condition and Trends. Manaaki Whenua Press, 226-237.
20. Ramachandra, T. V., Rajinikanth, R., & Bharath, H. A. (2019, November). Valuation of Aghanashini estuarine ecosystem goods and services. Journal of Biodiversity, 45-58.
21. Biggs, R. B., & Cronin, L. E. (1981). Special characteristics of estuaries. In: Neilson, B. J., & Cronin, L. E. (Eds.), Estuaries and Nutrients. Contemporary Issues in Science and Society. Humana Press. https://doi.org/10.1007/978-1-4612-5826-1_1
22. Scanes, P., Ferguson, A., & Potts, J. (2017). Estuary form and function: Implications for palaeoecological studies. In K. Weckström, K. Saunders, P. Gell, & C. Skilbeck (Eds.), Applications of paleoenvironmental techniques in estuarine studies (pp. 9-44). Springer. https://doi.org/10.1007/978-94-024-0990-1_2

Online Sources:

1. Major Estuarine Systems of India and their Fisheries. Available at: https://basu.org.in/wpcontent/uploads/2020/11/Major-Esturine-Systems-of-India-and-their-Fisheries.pdf
2. Pradhan, A. (2016). State of India's rivers for India Rivers Week. Available at: https://indiariversblog.files.wordpress.com/2017/05/goa-report.pdf
3. U.S. Geological Survey. (n.d.). Find a feature: Confluence. Available at: https://www.usgs.gov/educational-resources/find-feature-confluence
4. Town & Country Planning Department, Goa. Available at: https://tcp.goa.gov.in/
5. Goa Coastal Zone Management Authority. Available at: https://czma.goa.gov.in/
6. Collectorate South Goa - Government of Goa. Available at: https://southgoa.nic.in/
7. Directorate of Fisheries, Goa. Available at: https://fisheries.goa.gov.in/contact-us-2/
8. Government of Goa. (2020). Goa Tourism Policy 2020. Available at: https://www.nsws.gov.in/s3fs/2021-08/Goa%20Tourism%20Policy%202020.pdf

ABSTRACTS

Lessons from coastal communities addressing environmental & economic needs: an example of Eluru, A.P.

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According to the Intergovernmental Panel on Climate Change (IPCC), global mean sea levels are expected to rise by 0.6 to 1.1 meters by the year 2100 under high-emission scenarios (IPCC, 2021). Detailed assessment of sea level rise along India’s coasts, have noted the increasing vulnerability of densely populated regions such as the Sundarbans, Gujarat, and Andhra Pradesh. Their study suggests that sea levels along the Indian coastlines are rising at a rate of approximately 1.7 mm per year, aligning with global trends. The definition of coastal areas as per the Millennium Assessment reports of the United Nation Development Program on ecosystems and ecosystems services within reporting categories, sets the Boundary Limits for Mapping of coastal areas as extending landward to a distance 100 km from shore.

On the basis of this, Eluru, Andhra Pradesh (AP), with geographical coordinates of 16°42′42″N and 1°06′11″E, located on the eastern coastal plains, approximately midway between the Krishna and Godavari rivers and about 50 kilometres inland from the Bay of Bengal, is part of the large coastal areas that lie in Andhra Pradesh. As such, with a length of 975 km AP has the third longest coastline in India after Gujarat and Tamil Nadu. Multiple studies by organizations like IPCC and the United Nations Development Programme (UNDP) have recognized the vulnerability of coastal regions. Eluru is also, quite rich in inland water systems, with it being located near Kolleru Lake which is around 15km from the municipal area. The river Tammileru, streams and canals also pass through Eluru. Thus, areas like Eluru are an example of a wetland ecosystem in a coastal region which as per the Millennium Assessment Reports of UNDP needs to be assessed from twin points of view of coastal systems as well as of inland water systems. The Kolleru lake, which is actually connected to the Bay of Bengal, which is 50 kilometres away, as well, has an international importance because it is one out of the total 26 sites in India that RAMSAR convention had identified, the Kolleru lake (identified as a RAMSAR site in 1990), on account of its unique qualities such its large area, biological richness, ecological diversity and the unique role it plays in preventing floods between two deltaic regions of Godavari and Krishna rivers. It has luxuriant diversity of flora and fauna, with a total of 60 species of fauna, primarily the migratory birds including Pink Flamingos. Nearly 5, 00,000 to 10, 00,000 migratory birds annually visit the weed infested areas, fish ponds, and agricultural fields of the lake during different seasons. According to secondary sources, there has been decline in birds count since 2013 due to the current use of land for human habitations, road and bridge construction activities and sewage dumping, which are environmentally degrading the lake badly. Issues faced by the lake for a long time included bunding to create fish tanks for fish farming which is destroying the lake, land grabbing, pollution of lake and ground water by chemicals and sewage dumping.

Based on work carried out by SPA Vijayawada Team for Preparation of GIS based Master Plan for Eluru PACKAGE- VIII under AMRUT Funded Scheme, project reports for same been submitted to the Client, Directorate of Town & Country Planning, AP, the project team of SPA, Vijayawada studied these above issues alongside other issues, in the endeavour to a frame a Sustainable Master Planning approach. Efforts were made to address this environmentally sensitive context, wherein due consideration to the environmental issues in planning and decision-making process were stressed upon, alongside forecasting the disaster vulnerability for the project-area in view of the parts of the project-area lying in flood- prone areas.

It was assessed that Eluru, in its broader coastal area-wetland context lying in between two major rivers, has got abundant water bodies, like streams, canals, ponds as well. These if managed and handled properly would prove to be a strength in the vision towards future sustainable planning approach. Proper conservation of the water bodies can go a long way towards enabling sustainable spatial development in the future. It was surmised that given Eluru's unique context, a vigilant eye on the environmental issues is needed to ensure sustainable development process of Eluru. Alongside that, there is need for exploring the potential for integrating traditional Indian architectural techniques with modern sustainable design principles to create more resilient buildings in general in coastal areas. Dwellings should be structures that can withstand flooding, salinity, and extreme weather conditions using affordable, locally sourced materials, alongside effective waste management systems. Improper waste management in coastal areas leads to environmental degradation, exacerbating the effects of flooding and sea level rise. The same was happening in Kolleru Lake as briefly mentioned here, wherein improper sewage disposal into the Ramsar Convention listed Wetland was degrading it environmentally. Further, in coastal Andhra Pradesh, waste management challenges are compounded by frequent floods and cyclones. The need for decentralized, community-driven waste management solutions, that are both affordable and adaptable to local conditions is pressing. These include recycling, composting, and the use of natural filtration systems to handle waste during and after extreme weather events.

We have to use our indigenous time-tested planning and architectural techniques but adapt them as per prevailing global norms, as we move towards safeguarding the environment of our coastal areas in times of rising sea levels and increased vulnerability to people living in coastal areas of AP and India.

Resilience to Extreme Heat through Temperature Trends Analysis in Low-income Housing Settlements - Vijayawada

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Abstract

Assessing heat-related health risks is a critical component in advancing the sustainable development of urban areas, particularly in the context of increasingly extreme climate conditions. Heat health risk assessments serve as integral elements within risk governance frameworks, aimed at minimizing heat-induced morbidity and mortality. Early warning systems (EWS) are pivotal in this framework, providing timely and actionable data that supports the prevention and management of heat-related illnesses, thereby mitigating the adverse impacts of extreme heat on vulnerable populations. A key focus within this governance model is the revitalization of low-income housing settlements, which are disproportionately affected by heat stress due to substandard housing conditions and limited access to adaptive technologies. This study centers on Vijayawada, a city significantly affected by high ambient temperatures and characterized by a substantial number of low-income housing settlements. The research analyzed maximum temperature thresholds and thermal performance across 12 representative low-income housing settlements in Vijayawada. The results indicated that indoor temperatures peaked at 45.9°C, with an average indoor temperature of 34.64°C recorded during the summer months (March–July). For the remainder of the year, indoor temperatures consistently exceeded 30°C, resulting in prolonged exposure to extreme heat for the inhabitants. These elevated indoor temperature conditions, sustained over more than half the year, exacerbate heat-related health risks, particularly for those in socioeconomically disadvantaged areas. The findings underscore the necessity for urban planners and policymakers to prioritize the implementation of comprehensive thermal adaptation strategies in high-risk, low-income neighborhoods. These strategies should focus on improving the indoor thermal environment to mitigate heat stress. Additionally, the study highlights the critical role of early warning systems and decision-support tools in informing targeted interventions to enhance indoor thermal conditions. By integrating infrastructure upgrades with proactive early warning mechanisms, cities can significantly enhance resilience and better safeguard vulnerable populations against the detrimental effects of extreme heat.

Keywords: Extreme Heat; Low-income housing; Early Warning; Heatwaves; Coping Strategies

References

Berger, T., & Chundeli, F.A., (2023). Tolerance to Heat as a Coping Strategy of Low-Income Households in India and Austria. In: Binti Singh, Tania Berger, Manoj Parmar. (eds) Negotiating Resilience with Hard and Soft City. 1st Edition, pp. 111-124. Routledge India. ISBN 9781032440378

Berger, T., Chundeli, F.A., Pandey, R., Jain, M., Tarafdar, A. and Ramamurthy, A., 2022. Low-income residents' strategies to cope with urban heat. Land Use Policy, 119, p.106192. https://doi.org/10.1016/j.landusepol.2022.106192**.**

Chundeli, F.A., & Berger, T., (2023). Thermal Performance Evaluation of Low-Income

Housing Units Using Numerical Simulation. Human Centric CAADRIA 2023, CEPT University. The 28th International Conference of the Association for Computer-Aided Architectural Design Research in Asia. March 21-23.

Golechha, M., Shah, P., & Mavalankar, D. (2021). Threshold determination and temperature trends analysis of Indian cities for effective implementation of an early warning system. Urban Climate, 39, 100934. https://doi.org/https://doi.org/10.1016/j.uclim.2021.100934

Pothamsetty, A., & Chundeli, F.A. (2024). Optimizing Urban Morphology to Mitigate Urban Heat Islands: A Case of Hyderabad. In Proceedings of Energise 2023- Lifestyle, Energy Efficiency, and Climate Action, pp 198- 206, Alliance for an Energy-Efficient Economy.

Xie, Y., Xu, F., Ye, Q., Zhai, Z., Yang, H., Feng, X., Shi, J., & Hu, W. (2024). Spatial distribution of old neighborhoods based on heat-related health risks assessment: A case study of Changsha City, China. Sustainable Cities and Society, 114, 105740. https://doi.org/https://doi.org/10.1016/j.scs.2024.105740

Tackling financial uncertainties during disasters through Indigenous Cooperative Models

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Abstract

Coastal cities have been increasingly experiencing more and more disasters and extreme climate events. Much research is being done on making these cities resilient and adaptive. However, this research will focus on building financial resilience during such disasters. Taking urban floods in Chennai as a case study, this study aims to optimise financial management to enhance community resilience. Inefficient financial planning can hinder effective response and recovery. Recurrent floods call for comprehensive solutions, considering both physical infrastructure and financial aspects. Disaster Risk Financing (2015) by OECD stresses the importance of assessing the financial impacts of disasters on the economy and the risk-bearing capacities of affected populations and sectors. A holistic approach should combine physical infrastructure improvements with risk financing mechanisms, insurance frameworks, and other financial strategies. Risk transfer methods, like insurance, relieve governments of relief financial pressures and expedite the recovery process. The research assesses the financial damages caused by urban floods, considering both tangible and intangible losses. Tangible losses are calculated by estimating per capita damages using a household survey and developing depth-damage curve equations for each zone. Intangible losses are quantified by establishing a relationship between social indicators and total damages. The study also examines the financial capacity of the city government to fund recovery efforts. Results show significant variability in financial allocation, with existing budgets falling short of proposed limits. To bridge the funding gap, the study proposes a community risk financing mechanism through disaster risk insurance. This research contributes to the limited knowledge on the financial resilience of Indian local governments during disasters and provides a budget allocation framework for planned response, recovery, and reconstruction. This study also discusses potential methods to mobilise funds, based on Indigenous Cooperative Models. Taking inspiration from the Grameen Bank model proposed by Nobel laureate Muhammad Yunus, a spatial vulnerability-informed insurance framework is proposed for Indian coastal cities.

A Positive Perspective of Impact of Cyclones on Human Settlements, Bay of Bengal, Andhra Pradesh, India

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Abstract

Coastal human settlements, situated at the meeting point of land and sea, encounter distinct difficulties as a result of increasing sea levels, coastal erosion, severe weather, and growing urbanization. The impact of cyclones based on the geographical situation of the location will be varying a lot. The sustenance of the settlement depends on the sustainable technics being adopted over a period of time based on the experiences and getting adopting to the available knowledge and developments.

The potential benefits from the tropical cyclones will enhance the water availability to the plant material which enhances, majorly the productivity of agriculture sector. The drizzling nature of precipitation will have effective reduction of the heat wave impact on urban areas. This leads to climate change in the region, the results will expand with various options for surrounding eco system.

Since the effects of cyclones are unpredictable, understanding their advantages and the valuation techniques that go along with them is crucial to mitigating their destruction.

Due in part to its funnel-like form and geography, which features shallow water for a considerable distance away from the shore, the Bay of Bengal is vulnerable to significant storm surges. The Bay of Bengal's greater surface area facilitates quicker heating, which raises evaporation. An area of high pressure is created by faster evaporation, which leads to instability in the region.

Insights from the 2004 Tsunami and Future Prospects in Remote Sensing and Early Warnings

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Abstract

The 2004 Indian Ocean tsunami was among the most lethal natural catastrophes, resulting in extensive devastation and significant fatalities across many nations. The experience highlighted the critical need for improved disaster planning and response strategies, particularly the formation of sophisticated early warning systems. Remote sensing technologies were crucial in catastrophe detection and post-tsunami damage evaluation, enabling researchers to investigate tsunami physics and get essential characteristics. Aerial imagery was crucial in comprehending the tsunami's inland penetration, providing insights into inundation zones and associated concerns. The amalgamation of optical imagery, Synthetic Aperture Radar (SAR) data, and Light Detection and Ranging (LiDAR) facilitated the extraction of comprehensive information on the tsunami's effects. SAR data, specifically, demonstrated efficacy in identifying changes in surface attributes, while LiDAR offered accurate assessments of structural damage and topography. Remote sensing facilitated the analysis of tsunami-related damage and delineated inundation zones, crucial for future urban planning and mitigation strategies.

Moreover, machine learning and deep learning algorithms have been used to automate tsunami damage assessment, enhancing the efficiency and precision of disaster response. AI-driven algorithms have improved the interpretation of remote sensing data by detecting trends in tsunami characteristics and destruction. Notwithstanding these achievements, several difficulties persist. The aforementioned technologies encounter constraints like data precision, temporal lags, and the need for enhanced integration. Advancements in remote sensing and artificial intelligence will be essential for creating more effective early warning systems and improving disaster response, hence providing enhanced protection for at-risk coastal areas. This Paper discusses the need of ongoing study and technological progress in tsunami detection and damage mitigation to improve global resilience to future catastrophes.

Strengthening Climate Resilience: Enhancing Capacity Building with Traditional Knowledge Systems in Coastal Zones

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Abstract

Climate change and its extremes have severe impact on the coastal regions. Tsunami, Coastal flooding, storm surge and coastal erosion are fallouts of such extremes. These events pose risk of loss of life and in adds on to the existing stress on the health and economic activities of the coastal population. Since the local communities are accustomed to changing circumstantial information, they also have traditional knowledge systems to deal with ecological problems in coast. Strategies based on evidence that support resource control, forecasting climate through the use of environmental facts and constructing structures that will withstand climate change are some of the efforts that aim at tackling disasters. In some coastal fishing communities, factors such as winds and animal behaviour as well as tides are taken as directions to extreme weather conditions preparedness. These practices prove to be an innate line of defence against natural disasters and in effective ways at the community level.

Integration of modern knowledge and innovation with the traditional practices provides better front for progressing towards resilience. The introduction of modern instruments such as Real time Data Surveillance systems, Geographical Information System, and 3D weather imaging into indigenous meteorology is likely to improve the forecasting of their traditional systems. Various research suggests that Participatory methods which explores the integration of indigenous knowledge into development assistance yield better result. For instance, participation of target populations within the planning and decisions, as well as the actions articulated towards the reduction of disaster risk, ensures more cultural appropriateness and local relevance of the undertaking.

The combination of the resource management technique with climate-adaptive infrastructure such as raised housing and flood-resistant structures has significantly improved the resilience capacity against disaster threats. In conclusion, the strengthening of climate resilience in coastal zones comes down to the merging of such old erudite knowledge systems into contemporary capacity development frameworks. Exploiting their strengths will be the means to form a broad framework toward disaster preparedness and climate adaptation for coastal communities. Through education, incremental integration of technology, citizen science and participatory governance, impacts of such climate-related disasters can be mitigated, and sustainable development can be ensured through structured capacity building in vulnerable coastal regions for progressing towards climate resilience.

Keywords: Traditional Knowledge System, Resilience, Capacity Building, Coastal Zones

Planning framework for climate and disaster resilient transport infrastructure

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Abstract

Coastal cities face increased exposure to climate hazards due to growing populations and economic activities particularly in low-lying coastal areas. Coastal transport infrastructure, including seaports, roads, and rail lines, is also at significant risk of flooding, which has detrimental effects on trade and local economies. This is especially critical in a country like India, where about 95% of trade by volume occurs through ports. This emphasizes the need for a robust planning framework for Climate Resilient Coastal Transport Infrastructure to address the pressing challenges posed by sea-level rise, storm surges, and extreme weather events that threaten transport hubs and networks.

It is also forecasted that intense rainfall, similar to the Mumbai floods in 2005 and Gujarat floods in 2006, could occur in other areas along the west coast if effective measures are not implemented. The rise in sea level may place some of India's largest cities at risk of flooding, impacting a total of 36 million people in the country by 2050, emphasizing the urgency of integrating climate adaptation into planning. Many coastal settlements, particularly slums, are located in flood-prone and geologically unstable areas, making vulnerable communities even more susceptible to climate-induced disasters.

The proposed framework highlights the importance of integrating climate change considerations into all phases of transport planning to mitigate infrastructure disruptions caused by flooding and extreme weather. The framework includes comprehensive risk assessments to identify vulnerable infrastructure and the application of adaptive design principles. It also emphasizes policy integration to align climate adaptation strategies with broader urban development goals, aiming to create a resilient coastal transport network that supports sustainable development and protects coastal transport systems from the growing threats of climate hazards. By incorporating these proactive strategies, transport systems can significantly improve their resilience and ensure that they remain functional and accessible amidst a changing climate.

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