Community Climate Resilience Building: A Case Study of Tidal Flooding in Kerala, India

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ABSTRACT

Sea level rise due to climate change threatens coastal communities, causing coastal flooding and other extreme weather events. This study explores a community-based approach integrated with scientific data collection methods to develop bottom-up strategies for building climate resilience, focusing on tidal flooding in the lowland coastal plains of Ernakulam district, Kerala. Community engagement was facilitated through a multilayered approach by collaborating with grassroots organizations and different tiers of government. Through low-cost, decentralized data collection methods, affected regions and deviations from expected tidal impact patterns were identified. Open-ended interviews revealed traditional adaptive strategies practiced by the community that are effective in guiding scientific planning and development to build local, context-aware resilience in coastal regions. The results of this study demonstrate that continuous community engagement, participatory methodologies and reciprocal learning are critical in developing sustainable solutions to tidal flooding and in empowering communities to advocate for their own solutions.

Keywords

Tidal flood, community resilience, coastal flooding, climate change, impact-based.

INTRODUCTION

Recent decades have seen an unprecedented rate of disruption of the planet's natural climate balance due to human activities. Climate change refers to alterations in climate that are directly or indirectly linked to human activities, which modify the composition of the global atmosphere and exceed natural climate variability observed over similar time frames (United Nations Framework Convention on Climate Change, 1992). This has led to a steady rise in global temperatures, a phenomenon known as global warming. Most of the extra heat trapped by the atmosphere (90%) has been absorbed by the ocean (Schuckmann et al., 2020) which warms up the ocean and contributes to sea-level rise through thermal expansion (WCRP Global Sea Level Budget Group, 2018), and melting ice (Stocker et al., 2013). The rate of sea level rise has more than doubled between 2006-2015, from 1.4 mm per year between 1901-1990 to 3.6 mm per year, according to the Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report.

Rising sea levels are increasingly threatening coastal areas (Lindsey, 2022), causing distress to millions of people living along the coast. Approximately 40% of the world's population lives within 100 kilometers of the coast (United Nations Department of Economic and Social Affairs, 2008). This includes over 3 billion people, many of whom reside in densely populated coastal cities. Additionally, about 10% of the global population (around 748 million people) live within 5 kilometers of the shoreline (Kulp & Strauss, 2019). Additionally, compared to states away from the coast, states near the coast have more elderly people who may be vulnerable in an emergency

(National Oceanic and Atmospheric Administration, 2013).

Climate change is a serious threat to India's coastal regions, affecting millions of people who depend on the natural resources of those ecosystems. The country's peninsular shape and surrounding water bodies, including the Bay of Bengal to the east, the Indian Ocean to the south, and the Arabian Sea to the west, cover approximately 7500 km of coastline. About 250 million people live within 50 km of the Indian coastline (Roy et al., 2023). It is highly vulnerable to floods and cyclones due to several factors such as low-lying terrain, dense population, and environmental degradation. India is particularly sensitive to sea level rise, as the Indian Ocean is rapidly warming (Das & Swain, 2024). Rising sea levels pose a serious threat to coastal communities, putting people living in vulnerable areas such as fishing communities and marginalized groups at risk of losing their homes and livelihoods. This situation may pose additional social, economic, and humanitarian challenges.

Kerala, a densely populated Indian state with a 590 km coastline, is at risk of being affected by sea level rise. When sea level rises above a certain threshold it enters land through river mouths and spreads according to the elevation and morphology of the coastal landscape. This phenomenon called "tidal flooding" inundates low-lying areas in a region (Sreeja et al., 2022). Such flooding is common in coastal areas and usually occurs in Kerala from October to December around new moon and full moon days. It is often nicknamed "nuisance flooding" (Li et al., 2021), which belies the long-term impact it has on coastal communities.

Community resilience here refers to a community's ability to withstand and adapt to the impacts of climate change. To enhance this resilience, it is essential to identify and strengthen communities while implementing locally relevant and tailored actions that improve their capacity for climate change adaptation and outcomes (Edwards & Wiseman, 2011). Community resilience is defined as a community's response to and recovery from disasters and emergencies (Koliou et al., 2020). Coastal communities have been practicing different indigenous methods to build resilience against tidal flooding such as mangrove plantations, traditional bund systems, and adaptive rice cultivation practices.

Flood hazard, vulnerability, and risk maps are crucial for planning and intervention in flood-prone areas. The scientific approach to tidal flood assessment involves the use of a combination of hydrological, statistical, and machine-learning models to monitor, analyze, and visualize tidal data from various sources. Identification of tidal flood risk areas is possible using geoprocessing techniques, digital elevation models (DEMs), and tidal level data (Araújo et al., 2021). Satellite data, remote sensing, and Geographical Information System (GIS) help to identify tidal flood inundation areas and analyze the relationship between flood points and various biophysical factors (Sulistiyono et al., 2024). The information that science can provide about the real world is incomplete (Wynne, 1992). Real-world applications can rarely be implemented without the integration of community insight.

Rahman et al. (2023) & Roy (2018) underscore the critical importance of adopting a community-based approach while explaining the climate vulnerabilities of Indigenous communities. This methodology is essential for developing bottom-up strategies that directly involve and empower affected communities in addressing climate-related challenges. Embracing a community-based approach acknowledges the unique insights, traditional knowledge, and perspectives of indigenous peoples and serves as a source of optimism in disaster research. By fostering collaboration and engagement at the community level, this approach enhances the effectiveness of mitigation and adaptation strategies and promotes resilience and sustainability (Gaillard, 2012). The community-based approach offers a promising avenue for creating meaningful and context-specific solutions that consider the needs and experiences of Indigenous communities in the face of climate vulnerabilities. It creates avenues for inventive solutions by developing responses to climate risks that are location-specific, community-engaged, resource-efficient, cost-effective, and sustainable (Datta & Kairy, 2024).

There is a noticeable gap in research regarding the effective involvement of communities in building climate resilience. Many studies tend to take either scientific or sociological approaches separately without considering the benefits of combining both perspectives. This narrowed focus overlooks the tacit knowledge and practical solutions that local communities have accumulated over time. Furthermore, there is a lack of structured approach for engaging communities in the development and implementation of nature-based and science-based solutions. This gap in understanding hinders initiatives that could leverage valuable local knowledge, ultimately compromising the effectiveness of such interventions designed to reduce the effects of tidal flooding. The primary objective of this study is to incorporate community knowledge into scientific research and promote community engagement in combating tidal flooding.

Study Area

The study is conducted in the lowland coastal plains of Ernakulam district, located on the western side of Kerala (Figure 1). This region extends from latitude 9.7737°N to 10.2080°N and from longitude 76.1628°E to 76.3900°E, covering an area of 470 sq.km. It encompasses 25 local self-governments (LSGs), comprising 20% of the district

area and 43% of the population (Census, 2011). The coastal belt stretches from Chellanam to Vypin, a distance of 48 km, with most of the region lying less than 7 m above mean sea level (MSL). Coastal alluvial soils and laterites are prevalent, particularly along the areas adjacent to the coast, which are characterized by multiple backwater channels. These are collectively referred to as the Cochin backwaters and constitute part of the Vembanad-Kole wetlands, a designated Ramsar site. Furthermore, the average annual rainfall in this region is recorded at 3359.2 mm (Shyam, 2013). The low-lying terrain and the creeks in the region cause the inflow of tidal waters, affecting livelihoods, agriculture, roads, and buildings.

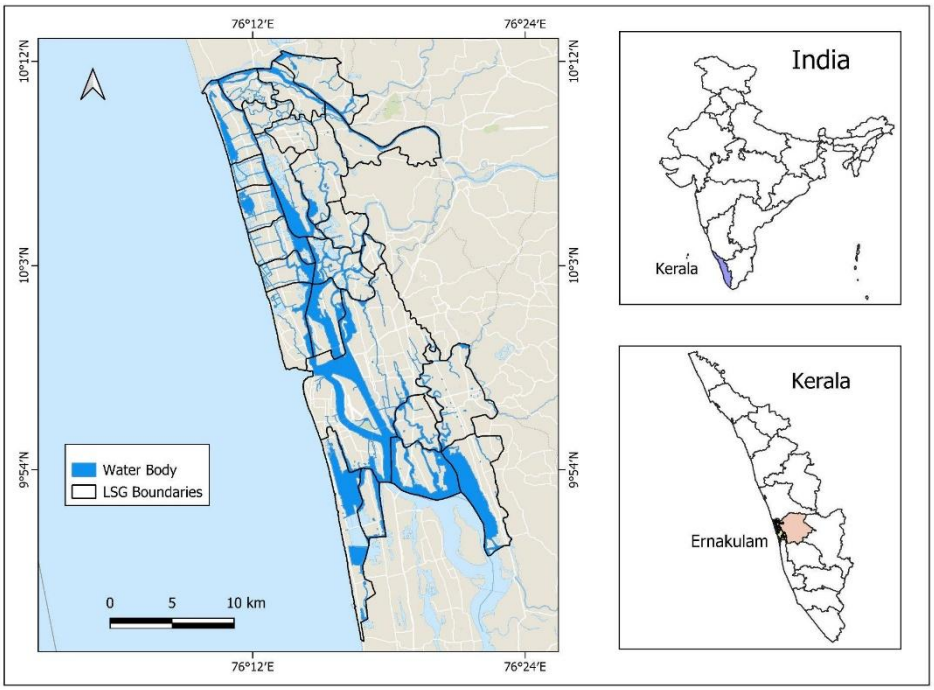

Figure 1. Study Area of Coastal Lowland Areas of Ernakulam District, Kerala

METHODS AND METHODOLOGY

Developing bottom-up strategies for community engagement is a complex and iterative process. Climate-vulnerable communities are often tethered to their specific geographical spaces that shape their socio-economic context and tend to be skeptical of external researchers. Meaningful participation can only be ensured through long-term engagement and culturally adaptive strategies through building trust with the communities. Establishing an initial connection between the community and the research effort is then a vital first step in the trust-building process. Percolation into the local community was implemented in this study through a trial and error mode that employed a combination of participatory methodologies and stakeholder engagement strategies. These methodologies included liaising with government authorities, collaborating with grassroots organizations, identifying key community actors, engaging student bodies, and adopting creative participatory approaches. Each of these strategies is explained below, followed by the various tools and methods used in these community interventions (Figure 2).

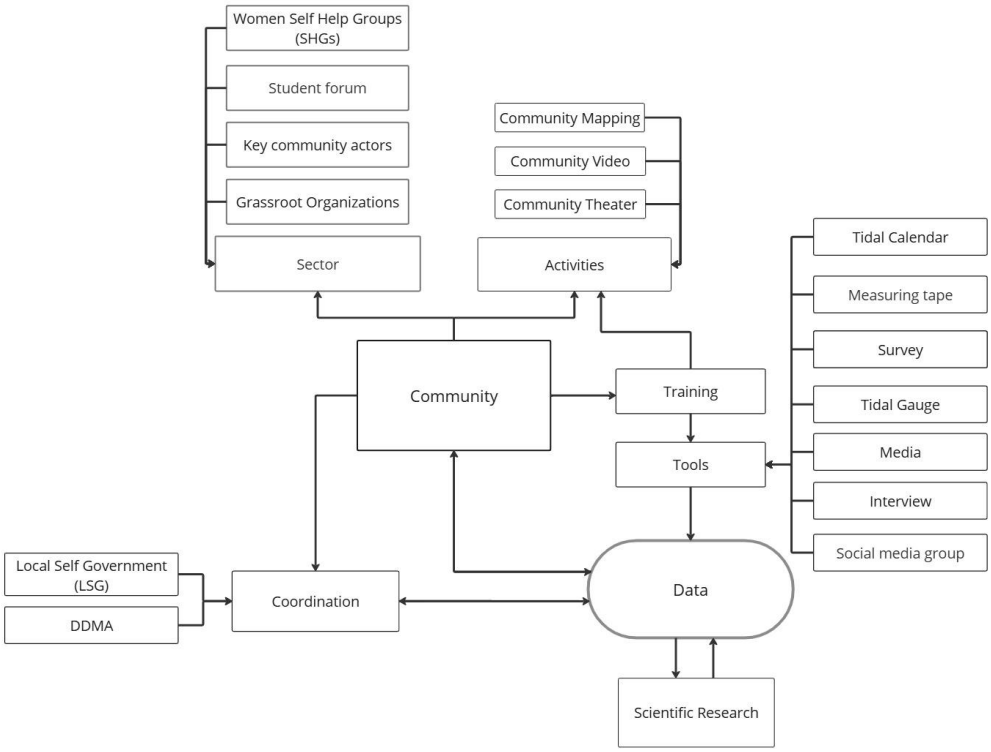

Figure 2. Research Design Flow Chart

COMMUNITY INTERVENTION METHODOLOGY

Liaising with Government Authorities

Government bodies play a crucial role by providing agile access to communities, direction in policy, and resources for adaptation initiatives. Local governance has two parallel systems of working - one arm is the bureaucratic district administration headed by the district collector under the state's revenue department, and the other is the 3-tiered elected LSGs. Our engagement was multi-tiered in approach, targeting all levels of the administrative system. Initially, we collaborated with the lowest level of LSGs that enabled deep interaction with the community. This helped us to contextualize the problem to implement localized climate adaptation strategies and set up community engagement programs. We held multiple meetings with LSG body presidents and elected members spanning 15 coastal LSGs in the Ernakulam district, to seek support in organizing campaigns that discuss the severity and extent of the tidal flooding issue (Figure 3). The District Disaster Management Authorities (DDMAs) along with the District Planning Committee, were closely involved in initial discussions on disaster preparedness, risk reduction measures, and mitigation efforts. This ensured that our research aligned with existing governance frameworks and had institutional backing to engage at the policy level.

Figure 3. Meeting with the District Planning Committee to Discuss the Tidal Flood Project and Seek Collaboration with Local Self-Governments at Ernakulam District Panchayat

Local organization support

Securing a place of trust among community members entails gaining the support of local organizations active in public engagement. Following the initial meetings and discussions with the LSGs, volunteer training sessions for women self-help groups (SHGs) such as green waste management volunteers and community health groups from coastal LSGs were held with the support of the DDMA (Figure 4). The SHG collaboration was particularly insightful in understanding the disproportionate impacts of climate change on women, which then enabled us to target resilience-building strategies through a gendered lens. Through gender counter-mapping sessions, they were trained to become community researchers. Women were gathered through this initiative to document the local impacts of climate change and advance it into community-level mitigation planning. Ties were established with local people's movement groups dedicated to conserving and managing natural resources in the region. Participatory frameworks and campaigns were co-developed with these grassroots organizations in coastal Ernakulam to strengthen community connect.

Figure 4. Volunteer Training Sessions for Women Self-help Groups held at Ezhikkara, Ernakulam

Community Key Actors

Co-creation was fostered through identifying and consulting key community actors who hold wide influence or deep tacit knowledge that catalyze expansion into larger social networks. The team consulted with local fishermen to co-design community mapping tools to validate predicted tidal flood patterns against on-ground observations. Qualitative interviews with farmers in the community provided insight into currently practiced resilience measures, documenting traditional adaptive strategies against tidal flooding (Figure 5).

Figure 5. Qualitative Interview with a Local Farmer to Document Traditional Climate Adaptive Strategies at Ezhikkara

Student Groups

Students were engaged through various training programs conducted across schools and colleges in the wider Ernakulam region. Through training student forums and science clubs, around 100+ young individuals developed the capacity to serve as on-ground volunteers in distributing tidal flood mapping tools across 13 LSGs while furthering their own understanding of the local impacts of climate change. Figure 6 illustrates the distribution of the tidal calendars to households affected by tidal flooding, accompanied by detailed instructions by trained student volunteers. Engaging students as on-ground volunteers provided a cost-effective and efficient means of expanding outreach, enabling rapid dissemination and retrieval of tidal flood mapping tools across a broader network.

Figure 6. Trained Student Volunteers Distributing Tidal Flood Mapping Tools Among Impacted Households Along Coastal Ernakulam, Kerala

METHODS/TOOLS

Data Collection Methods

• Grassroots Organization Field Survey – Based on ad-hoc reports about flooding in coastal regions, an initial field study was conducted in collaboration with grassroots organizations. This helped us identify the issue of tidal flooding prevalent in the region. Local community members utilized household items such as tailor tapes and rulers to measure tidal levels in select locations, providing quantitative data on tidal impacts.

• Small-Scale Community Monitoring –We installed 18 manual tidal gauges across the study area. This initiative marks the first community tidal-level monitoring network in the country, addressing the sparse distribution of state-owned tidal stations and enhancing local monitoring capabilities. Additionally, we collaborated with a sensor technology company to set up an automated tidal weather station, to provide tidal level data at 15-minute intervals.

• Structured Survey by Student Community – Structured surveys were implemented with students trained in quantitative and qualitative research methods. The training emphasized data collection and the importance of gathering lived experiences and stories to enrich the data by respectfully approaching the community.

• Open-Ended Interviews – Qualitative interviews were conducted to gain a deeper understanding of tidal flooding and local coping mechanisms. These interviews explored various practices, such as integrated farming of saline-resistant rice crop variety and prawn called *Pokkali*, mangrove planting, and traditional bund construction, allowing for rich qualitative insights into community resilience strategies.

• Tidal Calendar – We designed a low-tech, inexpensive, and accessible tool in the form of a calendar to document the extent, duration, and timing of tidal floods (Figure 7). The calendar was co-created with the input of community members such as fishermen, farmers, and other key community actors. The calendar was deployed to 10,000 households across 13 LSGs by our volunteers. The respondent households were geotagged, and participant data were documented. This tool facilitated systematic hyper-local data collection and helped in tracking tidal patterns over time.

Figure 7. Tidal Calendar

Community Activities

We enlisted subject experts to provide training sessions, providing agency to community members for building resilience by learning new skills. These activities represent various methods through which stakeholder participation was facilitated.

• Community mapping - Multiple training sessions and right-based campaigns were conducted with community members to equip them to record and map administrative boundaries, geographical features, and important landmarks. The community members mapped points of interest within the study area, such as major waterways, potential shelters, and high-risk areas in their respective LSGs. The mapping also took into account the regional context, with participants marking critical landmarks and buildings for ease of navigation during an extreme event. The mapping was then used to prepare a tidal flood mitigation plan. This exercise helped enhance the community researcher's geospatial analysis skills.

• Community videos - Trained residents volunteered to document their lived experience and region-specific tidal flooding impact through video production techniques. The videos were captured on the volunteers' own devices and compiled into a short documentary as a method of outreach.

• Community theater - Community members from impacted regions collaborated under the tutelage of a drama professor to create a theatrical play that narrated their adverse realities in living with tidal flooding. The play was used as an alternative storytelling tool as part of the awareness campaign, which also unlocked a medium of creativity for the community members.

Media and Public Outreach

Various news channels covered the project and magazine articles were published by the team. Advocacy efforts were sustained over the span of 3 years, including the rights-based awareness campaign and general information workshops, which ensured consistent public engagement. A high-impact short documentary was also produced with like-minded creative professionals, portraying the stories of climate champions and their struggles against tidal flooding.

Data Analysis

A variety of analytical tools were employed for data visualization and analysis. For geospatial analysis, GIS software was utilized for mapping and analyzing spatial data to visualize tidal flood patterns and to identify inundated regions. Google Earth Pro was used to visualize satellite imagery and to visually assess major geographical features of the affected regions, while Google Earth Engine facilitated the analysis of large meteorological datasets, including satellite imagery and Digital Elevation Models (DEMs). We compared several DEMs to identify the most suitable for the study area, including ALOS Palsar DEM, FABDEM, SRTM, and Coastal DEM. The DEM-based analysis helped identify catchment areas, map channels, and pinpoint low-lying areas vulnerable to tidal flooding. Statistical analysis and data visualization were conducted using Python and R, leveraging open-source libraries such as Pandas and Matplotlib to bring together meteorological, infrastructural, and social data. Together, these tools provided a robust framework for analyzing tidal flood impacts and identifying critical patterns and trends in the study area.

Virtual Community Space

A WhatsApp group was created for community members to report concerns and issues related to tidal flooding within an LSG. This virtual community space comprised LSG residents, local governance leaders, and scientific researchers, creating a collaborative platform for engagement. The group served as a forum for consultations and discussions, enabling participants to exchange information, share suggestions, and provide updates on tidal events, impacts, and the research progress.

RESULTS AND DISCUSSIONS

This study emphasizes the importance of the involvement of the community and their knowledge in resilience building against tidal flooding. The qualitative interviews revealed three main resilience methods practiced by the community: *Pokkali* farming, mangrove cultivation, and traditional bund construction. These measures, which are based on traditional knowledge, allow for strengthening community resilience. *Pokkali* cultivation, an ancient integrated farming system strategically uses saline water intrusion to grow a climate-adaptive rice crop and prawn in rotation (Radhika, 2019) (Figure 8). Also, planting mangroves along the coast has been useful in buffering against storm surges, coastal erosion, and tidal flooding - a natural defense system based on local ecological knowledge (Wesenbeeck et al., 2016). Lastly, the age-old techniques of bund construction to control tidal flooding (Feates, 2008) and prevent soil erosion illustrate traditional engineering principles passed down over generations, constituting a sustainable intervention for managing water in hazard-prone areas. This practice involves using dredged mud from the backwaters to build raised platforms around houses and the construction of bunds (Figure 9). By increasing the height of their homes and surrounding areas, community members aim to protect themselves and their belongings from the impacts of tidal flooding. Thus, the necessity for envisaging effective climate change adaptation strategies in such community-led case studies puts greater emphasis on local knowledge and traditional practices.

Figure 8. Farmers Engaged in *Pokkali* Harvesting at Ezhikkara, Ernakulam

Figure 9. Dredging Mud from the Backwaters, to Elevate Field Bunds at Ezhikkara, Ernakulam

Conversations with coastal communities in the study area indicate that they have been tracking tidal patterns according to lunar phases. However, rapidly changing climate and associated sea level rise accelerate tidal flooding impact beyond mitigation by indigenous methods alone. Our research explores a complementary scientific approach to enhance existing community resilience for better adaptive strategies. We adopted a trial-and-error approach, intentionally allowing room for ambiguity and adaptation given the novelty of such a community-driven model for which a predefined strategy would be infeasible. All implemented methodologies were designed to be low-tech and relational for the ease of use by community members. The results from the project's study are outlined below.

Establishing a strong connection and working with the support of the LSGs proved effective in building trust with a broader section of the community and created avenues to conduct extensive research. Our continued collaboration with LSGs led to the convening of two notable events. One, a meeting of elected representatives titled Conference of Panchayats (COP), which provided a platform for LSG leaders to voice concerns and co-create mitigation strategies (Figure 10). The other, a special *Gramasabha*, which is a general body assembly of all residents within the LSG was held to address tidal flooding. It marked the first community gathering focused

on climate change-induced tidal flooding following an extreme weather event, where residents articulated their needs and challenges. The insights from this gathering were documented and led to a resolution submitted to district and state authorities, amplifying community voices at the administrative level. A correspondence from the LSG, supported by our research findings, was sent to the state government and received a positive response, inviting participation in the broader climate resilience movement. Liaising with the DDMA prompted tidal flooding to be officially recognized as a disaster, which proved vital for resource mobilization. The active engagement of grassroots organizations and women's self-help groups has been crucial in contextualizing the research, contrasting existing mitigation strategies with local socio-cultural dynamics, ultimately empowering communities to advocate for their needs and enhancing resilience against climate change. As community awareness grows, they are able to increasingly advocate for solutions, prompting governmental agencies to take timely action.

Figure 10. Conference of Panchayats held at District Collectorate, Ernakulam

The data collection process facilitated the collection of insights and data that support scientific planning and development of tidal flood mitigation projects. The structured surveys improved area coverage and highlighted the limitations of inadequate calendar data. Open-ended interviews offered qualitative depth for evaluating community resilience strategies, such as *Pokkali* cultivation and mangrove restoration. The training in quantitative and qualitative methods ensured consistency and rigor in data collection, establishing a robust foundation for analyzing the findings and supporting community resilience strategies against tidal flooding. Observations revealed critical insights, including the identification of affected regions and deviations from expected impact patterns, highlighting a disjunction between conventional scientific knowledge and on-ground realities. The tidal calendar ensured continuous data validation and bridged community inputs with scientific monitoring. Additionally, the information collected enabled a detailed analysis of time series data. The ground data collected also significantly advanced awareness among local populations regarding the frequency, severity, and local impacts of tidal flooding. Figure 11 displays the surveyed tidal flood-affected households within an LSG.

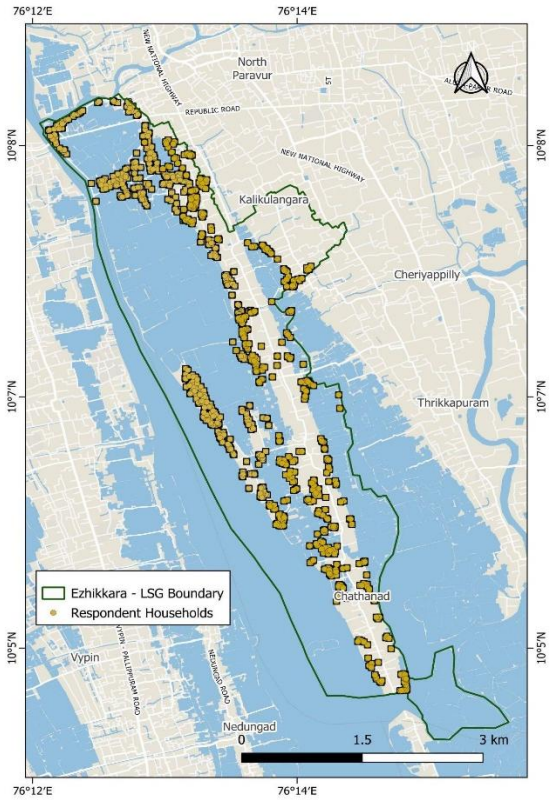

Figure 11. Geotagged Survey Respondent Households in Ezhikkara, Ernakulam

The data analysis component included geospatial analysis and statistical analysis of community data. Satellite elevation data from DEMs showed notable deviations from observed elevation data for our target study area, leading us to compare various DEM datasets. The availability of ground-based community-sourced data opened up the opportunity to perform effective ground truthing, which can significantly improve the accuracy of the DEMs. The integration of hyper-local data validated the elevation models and highlighted discrepancies in global datasets. This approach demonstrates that incorporating localized, high-fidelity data can fundamentally enhance the quality and reliability of global elevation datasets. Consequently, such improvements can be expected to yield more accurate and actionable results in subsequent impact analyses, including flood risk assessment and land-use planning.

A subset of the tidal calendars distributed was collected from a single LSG. In total, we received 367 calendars, out of which 165 had entries for observed tidal flood levels, and associated duration and timing. This information can assist us in understanding the extent and severity of tidal flooding in the region. As part of a preliminary analysis, we looked at the relationship between the frequency of tidal flooding and the number of impacted houses, which is depicted in Figure 12.

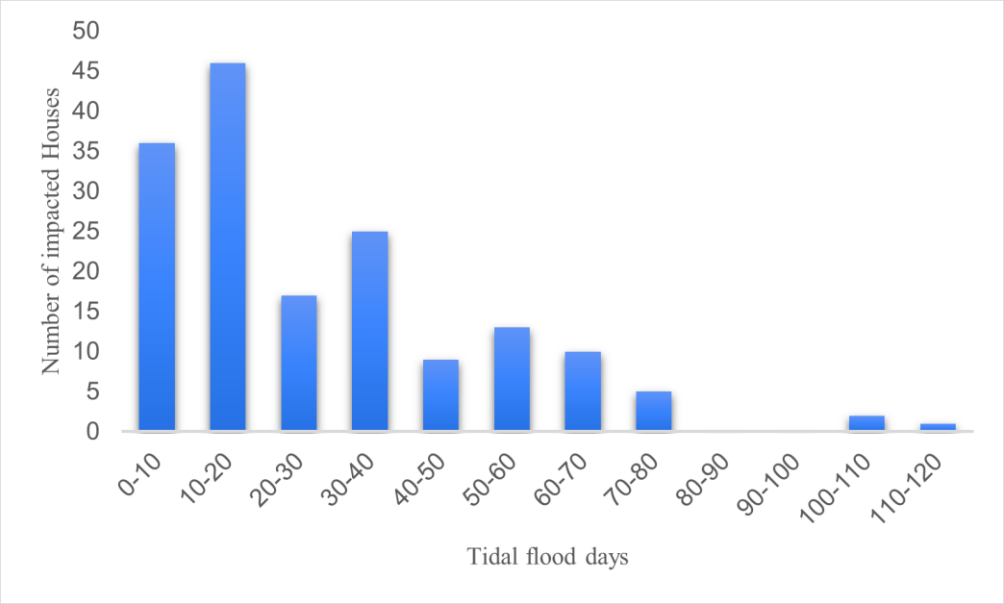

Figure 12. Impacted Houses vs. Tidal Flooded Days

The social media group, which was intended to be a virtual community space for raising concerns, unexpectedly yielded robust findings and consistent real-time data, including photographic and video documentation over four consecutive high tides. The community's voluntary participation in data sharing was a testament to their sense of ownership. By leveraging social media as a tool for communication and information dissemination, the initiative aimed to foster a more informed and responsive community capable of addressing the challenges posed by tidal flooding.

Community mapping, which was facilitated by women from SHGs, played a critical role in capacity building, empowering participants to become community researchers and initiators of their solutions. The formation of community researchers also led to the identification of outdated administrative maps during subsequent studies; equipped with their training, they provided feedback that corrected jurisdictional boundaries, facilitating more efficient data collection and addressing a significant on-field challenge (Figure 13). Community members produced videos documenting the impacts of tidal flooding following training, utilizing storytelling as a means of outreach and gaining recognition beyond their local context. Additionally, the community theater project resulted in a powerful theatrical performance that was screened across multiple locations in the country (Figure 14). The performance and the short film gained public acclaim, bringing widespread attention to the issue of tidal flooding and sparking critical conversations on the impact on communities. Media coverage concerning tidal issues elevated the topic of tidal flooding into mainstream discussions and the broader public sphere due to consistent campaigning over three years.

Figure 13. Community Mapping - Boundary Map Created by Trained Women Self-help Groups

Figure 14. Screening of Community Theatre at Thrissur

The results underscore the advantages of incorporating community insights in the examination of tidal flooding that has long faced biases in research methods, particularly in top-down scientific methodologies where researchers tend to work independently from the communities they aim to assist. To tackle this problem effectively, a system of feedback that taps into community knowledge can serve as an asset in pinpointing deficiencies and ensuring that scientific research remains pertinent and impactful. Building relationships within the community is also important; regularly engaging with stakeholders, student forums and SHGs allows researchers to truly understand the local environment better and establish long-term collaborations. By enabling communities to take charge of their progress and devise lasting solutions for sustainability, this method fosters a collaborative approach to research that seeks to bridge the gap between researchers and the communities they support in a meaningful way.

Limitations

The study encountered obstacles when attempting to establish relations with the community. Establishing connections among groups took considerable time, and ensuring compensation for activities like retrieving tidal calendars presented challenges across multiple domains. Communities tend to be non-homogeneous in nature due to factors like politics, religion, and economics. This led to disparities in influence, with some individuals having a stronger voice than others.

While data continued to be actively recorded over a three-month period, participant retention decreased. Efforts to deploy data collection tools across multiple coastal panchayats expanded the reach to a larger community; however, insufficient community interaction resulted in poorer data quality and quantity during the retrieval phases. Lack of adequate incentivization degraded data quality, prompting research into fair compensation methods to enhance community engagement and feedback.

Additionally, biases in responses from community representatives led to the exclusion of certain highly impacted communities, further skewing recorded tidal data. The physical data collection devices proved susceptible to damage, necessitating supplementary surveys to support retrieval efforts. However, challenges in maintaining active community engagement were noted, potentially attributed to a lack of motivation or a perception that reporting information would not lead to effective solutions. This highlights the decline in data reporting after three months, underscoring the complexities of sustaining community involvement in such initiatives.

Future Action Plan

The ongoing research aims to further elucidate and deduce the socio-environmental impacts of tidal flooding and enhance community resilience against it. Building on our comprehensive ground data collection, we plan to refine our methodology through expert consultations, engaging a diverse panel of local specialists, including LSG leaders, environmentalists, policymakers, farmers, and scientific researchers. This collaboration will validate our findings and identify methodological gaps, ensuring that our approach is inclusive and reflective of varied community perspectives. Our ongoing data analysis will focus on quantifying and visualizing the future impacts of tidal flooding, facilitating the development of predictive models and interactive dashboards. A methodology that incorporates multiple stakeholders and measures the impact of possible solutions will prove critical for climate adaptation policies (Figure 15).

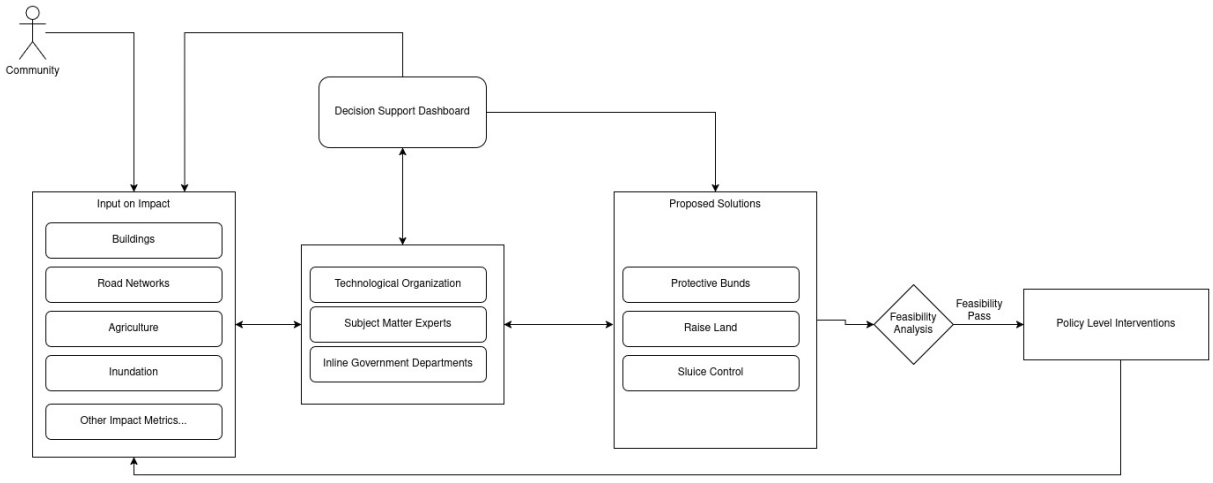

Figure 15. Steps to Operationalize Climate Adaptation Policies

Another pressing demand is the mitigation of the long-term damage to buildings and infrastructure due to saline water intrusion. An organization under the Council of Scientific and Industrial Research, India, has developed a saline-resistant form of concrete that can be fabricated locally. Even after having undergone extensive laboratory testing in a reputed research lab, its real-world application is very sparse. In partnership with the patent holder, we are exploring ways to empower the community by providing access to this new technology. Our approach includes training community members in its fabrication and deployment, fostering both livelihood opportunities and self-reliance.

Additionally, we have plans to advocate at the district and state levels for policy recognition of tidal flooding as a natural disaster, which is essential for securing state support and funding for affected communities. Through the mobilization of local stakeholders and active contributions from LSGs, we aim to foster a participatory framework

that acknowledges diverse motivations and agendas, ultimately strengthening community resilience in the face of climate change.

CONCLUSION

Tidal flooding, a climate-aggravated natural disaster, necessitates sustainable solutions through a complementary approach of scientific interventions with Indigenous climate-adaptive strategies in building coastal community resilience. This study examines the integration of local knowledge with quantitative data collection methods to strengthen community resilience. Engagement with governmental agencies, grassroots organizations, and key stakeholders proved essential in trust-building with the community to create channels for participatory methodologies in scientific research. Through low-cost, accessible tools such as tidal calendars, tailor tapes, and community mapping, local insights were incorporated into structured adaptation strategies. The research fostered reciprocal learning, advancing scientific analysis while equipping communities with the knowledge and agency to advocate for their own solutions.

Despite challenges in data consistency, continuous community engagement, and administrative barriers, the research demonstrated the potential of decentralized, low-tech approaches to building resilience in coastal regions. Future efforts will focus on refining predictive modeling, advocacy for formal disaster recognition at the policy level, and deploying saline-resistant infrastructure material. By prioritizing an impact-based and community-driven approach, this research empowers communities to lead their resilience-building efforts and challenges conventional top-down methodologies, for a more inclusive and responsive climate adaptation paradigm.

ACKNOWLEDGMENTS

We thank the ISCRAM community for this opportunity. We are deeply grateful to C. Jayaraman, K.G. Sreeja, and C.G. Madhusoodhanan for their guidance and dedicated efforts in implementing this project. We also extend our thanks to the LSG officials for their cooperation and valuable insights. We are grateful to Saumya John for her invaluable assistance in reviewing and proofreading the paper. Most importantly, this research wouldn't have been possible without the contributions of the coastal community.

CONFLICT OF INTEREST

The research was funded by the Alumni Engagement Innovation Fund of the U.S. Department of State. All corresponding authors are employees of EQUINOCT Community Sourced Modelling Solutions, a climate tech company that implemented the project. The authors declare no competing interests.

REFERENCES

Araújo, P. V. N., Amaro, V. E., Aguiar, L. S., Lima, C. C., & Lopes, A. B. (2021). Tidal flood area mapping in the face of climate change scenarios: case study in a tropical estuary in the Brazilian semi-arid region. *Natural Hazards and Earth System Sciences*, *21*(11), 3353-3366.

Census of India. (2011). *Provisional population totals paper 1 of 2011: Kerala*. https://kerala.gov.in/census2011

Das, A., & Swain, P. K. (2024). Navigating the sea level rise: Exploring the interplay of climate change, sea level rise, and coastal communities in India. *Environmental Monitoring and Assessment,* 196(11), 1010.

Datta, R., & Kairy, B. (2024). Decolonizing Climate Change Adaptations from Indigenous Perspectives: Learning Reflections from Munda Indigenous Communities, Coastal Areas in Bangladesh. *Sustainability*, *16*(2), 769. https://doi.org/10.3390/su16020769.

Edwards, T., & Wiseman, J. (2011). Climate change, resilience and transformation: challenges and opportunities for local communities. *Climate Change and Human Well-Being: Global Challenges and Opportunities*, 185-200.

Feates, N. (2008). *Large scale use of muddy dredged materials for sustainable flood defences and habitat management*. Technical Report. HR Wallingford.

Gaillard, J. C. (2012). The climate gap. *Climate and Development*, *4*(4), 261–264. https://doi.org/10.1080/17565529.2012.742846.

Intergovernmental Panel on Climate Change. (2023). *Climate change 2023: Synthesis report*. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar6/syr/.

Koliou, M., van de Lindt, J. W., McAllister, T. P., Ellingwood, B. R., Dillard, M., & Cutler, H. (2020). State of

the research in community resilience: Progress and challenges. *Sustainable and Resilient Infrastructure*, *5*(3), 131-151.

Kulp, S. A., & Strauss, B. H. (2019). New elevation data triple estimates of global vulnerability to sea-level rise and coastal flooding. *Nature Communications*, 10(1), 1-12.

Li, S., Wahl, T., Talke, S. A., Jay, D. A., Orton, P. M., Liang, X., & Liu, L. (2021). Evolving tides aggravate nuisance flooding along the US coastline. *Science Advances*, 7(10), eabe2412.

Lindsey, R. (2022). *Climate change: Global sea level.* Climate.gov. https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level

National Oceanic and Atmospheric Administration. (2013). *National coastal population report: Population trends from 1970 to 2010.* NOAA State of the Coast Report. https://cdn.oceanservice.noaa.gov/oceanserviceprod/facts/coastal-population-report.pdf

Radhika, A. (2019). *Implications of geographical indications for rice in Kerala* (Doctoral dissertation, College of Horticulture,).

Rahman, M. M., Tasnim, F., Uddin, A., Chayan, M. S. I., Arif, M. S. I., & Hossain, M. T. (2023). Assessing vulnerability in ethnic Munda community: A study on a cyclone-prone area of Bangladesh. *International Journal of Disaster Risk Reduction*, *95*, 103884.

Roy, P., Pal, S. C., Chakrabortty, R., Chowdhuri, I., Saha, A., & Shit, M. (2023). Effects of climate change and sea-level rise on coastal habitat: Vulnerability assessment, adaptation strategies and policy recommendations. *Journal of Environmental Management*, *330*, 117187. https://doi.org/10.1016/J.JENVMAN.2022.117187

Roy, S. (2018). Livelihood resilience of the indigenous Munda community in the Bangladesh Sundarbans forest. *Handbook of Climate Change Resilience*, 1-22.

Shyam, T. S. A. (2013). *Ground water information booklet of Ernakulam district*. Kerala State, Thiruvananthapuram.

Sreeja, K. G., Madhusoodhanan, C. G., & Chillayil, J. (2022). Between the devil and the deep sea: Tidal flooding in the estuarine villages of Kerala. *Enabling Environment, June-July Special Edition 2022*, IIA Cochin Centre.

Stocker, T. F., Qin, D., Plattner, G. K., Alexander, L. V., Allen, S. K., Bindoff, N. L., ... & Xie, S. P. (2013). Technical summary. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 33-115). Cambridge University Press.

Sulistiyono, N., Hasibuan, S. G., Daulay, A. F., Setiawan, Y., Arifanti, V. B., Suyadi, S., ... & Rijal, S. S. (2024). Spatial Distribution of Tidal Floods Using Geographic Information System (GIS) in Medan Belawan District. In *E3S Web of Conferences* (Vol. 519, p. 03017). EDP Sciences.

United Nations Framework Convention on Climate Change. (1992). *United Nations Framework Convention on Climate Change*. https://unfccc.int/resource/docs/convkp/conveng.pdf.

United Nations Department of Economic and Social Affairs. (2008). *World urbanization prospects: The 2007 revision*. https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/unpd_egm_200801_presentation_heilig.pdf

Van Wesenbeeck, B. K., van der Meulen, M. D., Pesch, C., de Vriend, H., & de Vries, M. B. (2016). Nature-based approaches in coastal flood risk management: Physical restrictions and engineering challenges. *Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice*, 181-198.

Schuckmann Von, K., Cheng, L., Palmer, M. D., Tassone, C., Aich, V., Adusumilli, S.,... & Wijffels, S. E. (2020). Heat stored in the earth system: Where does the energy go? The GCOS earth heat inventory team. *Earth System Science Data Discussions*, *2020*, 1-45.

Wynne, B. (1992). Uncertainty and environmental learning: reconceiving science and policy in the preventive paradigm. *Global Environmental Change*, 2(2), 111-127.

WCRP Global Sea Level Budget Group. (2018). Global sea-level budget 1993-present. *Earth System Science Data*, *10*(3), 1551–1590, https://doi.org/10.5194/essd-10-1551-2018.