GIS-Based Flood Resilient Shelter Design: Innovations and Implications for Urban Flood Management in Ernakulam District, Kerala

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Abstract: Background: ***Kerala has experienced flooding several times, with major disasters in 2018 and 2019. In cities across the country, including Kochi, Thiruvananthapuram, and Kottayam, rapid urbanization, the encroachment of water bodies, and a lack of effective drainage infrastructure have exacerbated flood vulnerabilities. Significant climate change impacts require innovative flood-resilient shelter strategies built on GIS-based spatial analysis and vernacular architecture methodologies.***
Aim: This study aimed to propose and design a flood relief shelter in flood-prone areas in Kerala.
Objective: (O1) To understand cities in Kerala using GIS Mapping. (O2) To analyze 15 literature reviews related to flood-prone areas in Kerala. (O3) To visualize Kerala's spatial data and Urban Design Development, we propose a flood relief shelter design.
Methodology: To identify flood-prone areas via GIS-based spatial data analysis, assess extant research studies on flood resilience, and determine potential GIS-driven flood shelter locations based on urban vulnerability mapping. This study incorporated a vernacular flood-adaptive architecture in shelter design. Using ArcGIS Pro and 2011 census data, this study mapped flood vulnerability zones, assessed encroachment patterns, loss of green cover, and disaster resilience policies, and proposed site selection criteria for flood shelters.
Research Questions: This study seeks to answer the following key questions: What are the primary causes of flooding in Kerala? Which vernacular architectural solutions exist for flood resilience? How can GIS mapping optimize the selection of flood shelter sites?
Methods and results: Creating Aluva, Kochi, and Kothamangalam flood inundation GIS Mapping using ArcGIS Pro, visualize maps showing the sustainable indicators: Environmental impact and changes (encroachment of water bodies, loss of green cover and policies for conservation) and Natural calamities and resilience (Flood frequencies, economic loss and recovery, and community resilience and government interventions) and propose a flood relief shelter for flood-prone areas.
Conclusion/Limitations: Literature reviews revealed gaps in current flood mitigation policies, emphasizing the need for resilient, amphibious, and elevated housing models. These findings highlight that GIS-based flood mapping can optimize flood shelter site selection by identifying high-risk urban zones. Kerala can enhance its flood resilience strategies by integrating vernacular architectural principles into its amphibious and elevated shelter designs. This study provides a foundation for future GIS-driven flood mitigation planning with potential applications in other high-risk Indian cities.

Keywords: Climate-adaptive architecture, disaster risk reduction (DRR), flood-resilient shelter design, geospatial flood risk mapping, urban flood mitigation, vernacular flood-resistant architecture.

Introduction

Kerala's topography, which is characterized by high rainfall, numerous rivers, and coastal proximity, makes it highly susceptible to monsoon-induced flooding. The 2018 and 2019 Kerala floods affected 5.4 million people, resulting in over 500 deaths and damage amounting to ₹40,000 crore[11]. Cities such as Kochi, Thiruvananthapuram, and Kottayam are particularly vulnerable to rapid urbanization, unplanned construction, and inadequate drainage systems[9]. Previous research has emphasized the role of GIS mapping in flood management, but there has been limited focus on utilizing GIS for flood-relief shelter planning[10]. This study addresses this gap by proposing GIS-based site selection for flood shelters while incorporating vernacular flood-resilient architectural strategies.

Aim

This study aims to analyze GIS-based flood risk data and propose resilient flood-relief shelters in Kerala's flood-prone cities.

Objectives

The objectives of this research are to assess flood-prone zones in Kerala through GIS analysis, review flood resilience literature to identify existing gaps, visualize spatial data on urban encroachments, green cover loss, and disaster mitigation efforts, and propose a site selection strategy for flood relief shelters based on GIS findings. Additionally, this study integrates vernacular architectural principles into flood-resistant shelter designs.

Research Questions

This study seeks to answer the following key questions:

What are the primary causes of flooding in Kerala?

Which vernacular architectural solutions exist for flood resilience?

How can GIS mapping optimize the selection of flood shelter sites?

What are the primary causes of flooding in Kerala?

The flooding issue in Kerala is driven by a combination of natural factors and human activities, making it a recurring challenge for the state. Geographically, Kerala is wedged between the Western Ghats and the Arabian Sea, making it highly susceptible to intense monsoon rain [4]. Every year, the southwest monsoon brings heavy downpours, sometimes reaching extreme levels in a single day, as seen during devastating floods in recent years [11]. The steep slopes of the Western Ghats force rainwater to rush down rapidly, triggering flash floods in high-altitude regions, while low-lying coastal areas, particularly places like Kuttanad, suffer from prolonged waterlogging due to poor drainage systems [9].

However, human interference has significantly worsened the situation. Rapid urban expansion, especially in cities such as Kochi and Thiruvananthapuram, has led to the large-scale destruction of wetlands, which act as natural buffers against flooding [1][2]. The loss of these wetlands severely disrupts natural drainage, increasing the chance of water accumulation. Additionally, deforestation, rampant quarrying, and widespread land-use changes have further weakened the capacity of the land to absorb rainwater, causing excessive surface runoff and soil erosion [8]. The impact of poorly managed dams cannot be overlooked. Kerala has several large reservoirs that play a crucial role in water regulation, but the uncoordinated release of dam water during peak monsoon seasons has worsened flooding in many areas [10].

Another major contributor to Kerala's worsening flood scenario is climate change. Over the years, the state has witnessed an increase in unpredictable extreme weather patterns [13]. Rainfall is no longer evenly distributed across the monsoon season but instead occurs in short bursts of high intensity, leading to sudden flooding [14]. This unpredictability and increased urbanization and environmental degradation have made floods more frequent and severe. Addressing this challenge requires a well-thought-out strategy that integrates scientific research, sustainable urban planning, and improved land and water management practices [3].

Which vernacular architectural solutions exist for flood resilience?

Kerala's traditional architecture has long been adapted to withstand heavy monsoon rain and frequent flooding. Unlike modern concrete structures, which often overlook drainage concerns, vernacular homes incorporate natural flood-resilient features that harmonize with the environment. One of the most effective strategies is the use of raised plinths and stilts, especially in flood-prone areas, such as Kuttanad, where homes are elevated to allow water to flow beneath them and prevent structural damage [15]. Another key feature is the steeply sloped and overhanging roofs seen in Nalukettu-style houses, which effectively channel rainwater away and reduce moisture build-up [14]. Nadumuttam, or the central courtyard, plays an essential role in flood resilience by facilitating rainwater percolation into the ground and reducing surface runoff [15]. Locally sourced materials such as laterite stone, timber, and lime plaster further enhance durability, as they are naturally water-resistant and better suited for Kerala's humid climate than modern cement-based alternatives [14]. Additionally, older settlements are often built on elevated land, strategically avoiding flood-prone zones, a principle largely overlooked in modern urbanization, leading to increased waterlogging [1].

Today, architects and urban planners are reintroducing traditional techniques into contemporary housing. The concept of amphibious housing, inspired by Kerala's stilted dwellings, is gaining attention because it allows structures to rise and fall with fluctuating water levels [10]. By blending heritage wisdom with modern engineering, Kerala developed sustainable flood-resistant housing solutions that are both practical and environmentally adaptable [15].

How can GIS mapping optimize the selection of flood shelter sites?

GIS-based flood mapping has revolutionized disaster preparedness in Kerala by enabling authorities to identify safe and accessible locations for emergency shelters with greater accuracy. Unlike traditional methods that rely on past flood records and local knowledge, GIS provides a scientific, data-driven approach for flood shelter site selection [6]. The first step in this process is flood hazard mapping, which analyzes historical flood data, elevation models, and hydrological patterns to classify regions based on flood risk [3]. This ensures that shelters are placed in low-risk areas, thereby minimizing potential damage during extreme weather events.

Additionally, proximity analysis was used to evaluate whether the proposed shelter sites were close to essential infrastructure, such as hospitals, roads, and relief centers, ensuring quick access during emergencies [7]. To further refine the site selection, GIS employs multi-criteria decision analysis (MCDA), which evaluates multiple risk factors, including flood depth, population density, and road connectivity, allowing authorities to rank shelter locations based on safety and accessibility [3].

The integration of real-time flood monitoring with GIS has been a major advancement in recent years. The Kerala State Disaster Management Authority (KSDMA) has started using IoT-based water level sensors and satellite imagery to track flood progress in real-time [11]. This allows authorities to dynamically adjust evacuation plans and direct affected populations to safer locations as flood conditions evolve.

GIS is no longer just a static planning tool; it is now actively shaping emergency response strategies in Kerala. By continuously updating flood risk models and shelter placement plans, the state is improving its ability to protect lives and minimize disaster impacts in a more systematic and efficient manner [18].

Inferences from Literature Studies

The table below provides a detailed review of the literature on urbanization, land-use change, and wetland conservation in Kerala, India. It assesses a range of studies by summarizing their objectives, methods, results, limitations, gaps, and key takeaways. These studies were based on a variety of research methods, including remote sensing, GIS studies, case studies, and literature reviews. Some of the more notable findings include urban flooding caused by wetland reclamation, biodiversity decline, and the impact of structural flood mitigation measures in vulnerable areas. Many limitations result from reliance on secondary data, narrow focus on a single region, and a lack of policy efforts. The gaps themselves suggest that localized empirical work, proactive policy measures, and modern technology being added to traditional conservation efforts is urgently required. This review highlights the need for stricter land use planning and urbanization associated with sustainable development to preserve wetlands.

Sno	Title of the paper	Journal Name and Publisher	Month and Year of Publication	Objectives of the Study / Research	Methodology adopted in the Study / Research	Results of the Study / Research	Limitations of the Study / Research	Gaps Identified in the Study / Research	Remarks
1	Wetland Conservation and Sustainable Development in Kerala, India	Chitra Karunakaran Prasanna, P. A. Vikas	Jan-21	To explore the significance of wetlands in Kerala and their contribution to sustainable development.	Comprehensive review of existing literature and data on Kerala's wetlands, focusing on their ecological importance, challenges, and conservation policies.	Highlights threats to Kerala's wetlands, including pollution, encroachment, and reclamation; emphasizes the need for integrated ecosystem approaches.	Relies primarily on secondary data sources, which may not capture the most current on-ground realities.	Calls for more localized studies assessing specific wetlands and research on socio-economic impacts of wetland degradation on local communities.	Underscores the importance of wetlands in achieving sustainable development and calls for better conservation policies and enforcement mechanisms.
2	Reclamation of Wetlands and its Impacts on Urban Development - A Case Study in Kerala	Dr. S. G. Sonar, Susan Deepthi P.	Feb-18	To assess the effects of wetland reclamation on urban development in Kerala.	Case study analysis involving field surveys and interviews with local stakeholders.	Found that wetland reclamation has led to increased urban flooding and loss of biodiversity.	Limited to a specific region, which may not be representative of all areas in Kerala.	Suggests the need for broader studies encompassing multiple regions to understand the statewide impact.	Recommends implementing stricter regulations to prevent further wetland reclamation.
3	Land Cover Change Analysis with Special Reference to Forests and The Resilience of the Built Environment to Flooding: The Case of Alappuzha District in the South Indian State of Kerala Using Remote Sensing and GIS	Afeef Abdurahman Choorapulakkal,Muhammed Gbolahan Madandola, Amina Al-Kandari, Raffaello Furlan	Jun-24	Examine the impact of frequent flooding on built environments in Alappuzha District. Identify key structural vulnerabilities and propose adaptive design solutions.	Mixed-methods approach using satellite imagery, field surveys, and stakeholder interviews. Analysis of past flood events and their impact on buildings.	Highlighted major structural vulnerabilities, such as poor drainage systems and weak foundations. Found that traditional stilt houses showed better resilience compared to modern concrete structures.	Limited generalizability to other regions with different hydrological conditions. Does not account for policy and governance issues affecting flood resilience.	Need for policy-driven interventions to enforce resilient building codes. Lack of comprehensive evaluation of indigenous flood adaptation strategies.	The study provides insights into regional flood impacts but calls for policy and regulatory measures. Future research should integrate climate change projections into flood resilience planning.
4	The relevance of wetland conservation in Kerala	Sheeba Abraham	Mar-15	To emphasize the importance of wetland conservation in Kerala's ecological and socio-economic context.	Review of existing literature and case studies related to Kerala's wetlands.	Identified key wetlands facing degradation; discussed the benefits of conservation efforts on local communities.	Lacks primary data collection; relies on secondary sources.	Calls for empirical studies to assess the effectiveness of conservation initiatives.	Advocates for integrating traditional knowledge with modern conservation practices.
5	Land use/land cover changes in Ashtamudi wetland region of Kerala - A study using remote sensing and GIS	R. Sajeev, V. Subramanian	May-03	To analyze the land use and land cover changes in the Ashtamudi wetland region over a period.	Utilized remote sensing and GIS techniques to assess temporal changes.	Detected significant reduction in wetland areas due to urbanization and industrial activities.	Dependent on the accuracy of satellite imagery and classification methods.	Calls for integration of socio-economic data to understand driving forces behind land use changes.	Emphasizes the urgency for sustainable land use planning to protect remaining wetlands.
6	The application of remote sensing and geographic information system techniques for the analysis of land use and land cover changes in Wayanad district of Kerala	Bijosh M G	Sep-24	To apply remote sensing and GIS techniques to analyze land use and land cover changes in Wayanad district.	Analysis of satellite images over different time periods using GIS tools.	Identified substantial deforestation and conversion of wetlands into agricultural land.	Limited by the resolution of available satellite data.	Recommends higher resolution data for more detailed analysis.	Highlights the need for conservation strategies to mitigate environmental degradation.
7	Applications of Remote Sensing and GIS in Geospatial Terrain Evaluation of Thrissur Forest Division, Kerala, India	ISAR Publications	Apr-16	To evaluate the terrain of Thrissur Forest Division using remote sensing and GIS applications.	Employed digital elevation models and spatial analysis techniques.	Mapped areas susceptible to erosion and landslides.	Does not account for real-time environmental changes.	Suggests incorporation of real-time monitoring systems.	Provides valuable data for forest management and conservation planning.
8	Evaluating the Relation Between Land Use Changes and the 2018 Floods in Kerala, India	Lina Hao, Cees van Westen, A. Rajaneesh, K.S. Sajinkumar, Tapas Ranjan Martha, Pankaj Jaiswal	May-22	To assess the relationship between land use changes and the 2018 Kerala landslides, focusing on whether changes from 2010 to 2018 influenced the disaster.	Kerala has 4,728 landslide sites, with 2,223 in Idukki. Land use data (2000–2018) from national sources and satellite images ensured accuracy through standardized classification.	Findings show 58% of landslides occurred in vegetated areas, with 50% affecting buildings and roads, mainly from forest plantations. About 25% occurred in built-up areas. However, 90% in Kerala and 83% in Idukki had no major land use changes.	The study excluded key factors like rainfall, soil conditions, and human interventions beyond land use. Standardized land classification may have caused minor errors.	The research lacked an analysis of how rainfall, soil stability, deforestation, and urban expansion contributed to landslides, limiting its scope in understanding all contributing factors.	Findings indicate land use changes were not the primary cause of the 2018 disaster, emphasizing the need for future research on multiple environmental factors.
9	Land use/land cover changes (1988–2017) in Central Kerala and the effect of urban built-up on Kerala floods 2018	Merin Skariah, Chethamangalath Damodaran Suriyakala	May-22	To investigate the impact of land use changes on the 2018 Kerala floods.	Comparative analysis of land use data from 1988 to 2017 with flood-affected areas.	Established a correlation between increased urban built-up areas and flood severity.	Focuses on a specific timeframe, potentially overlooking longer-term trends.	Calls for studies covering extended periods to capture long-term impacts.	Advocates for sustainable urban planning to reduce flood risks.

Table 1 Review of Literature Studies

Sno	Title of the paper	Journal Name and Publisher	Month and Year of Publication	Objectives of the Study / Research	Methodology adopted in the Study / Research	Results of the Study / Research	Limitations of the Study / Research	Gaps Identified in the Study / Research	Remarks
10	Design of A Sustainable Flood Resistant Structure for Rebuilding Resilient Kerala Post Floods	Sahana Hashim, M Sirajuddin	Jan-21	To design sustainable flood-resistant structures for post-flood reconstruction in Kerala.	Architectural design and simulation of flood-resistant building models.	Proposed designs that can withstand future flood events.	Limited to structural design without considering socio-economic factors.	Recommends integrating community needs and economic considerations into design.	Contributes to building resilience against future natural disasters.
11	Satellite-based assessment of the August 2018 flood in parts of Kerala, India	Geomatics, Natural Hazards and Risk (Published by Taylor & Francis)	Jan-19	To assess the extent and impact of the August 2018 Kerala floods using satellite imagery	Remote sensing techniques and GIS-based satellite imagery analysis	Identified the flood-affected regions, evaluated the spatial extent of flooding, and provided insights into the severity of the disaster	The study relied on satellite data, which may have limitations in capturing local-scale variations	Need for integration with ground-based hydrological data for better accuracy; Lack of socio-economic impact assessment	Useful for policymakers in disaster management and mitigation planning
12	The Resilience of the Built Environment to Flooding: The Case of Alappuzha District in the South Indian State of Kerala	Afeef Abdurahman Choorapulakkal, Muhammed Gbolahan Madandola, Amina Al-Kandari, Raffaello Furlan,Goze Bayram and Hassan Abdelgadir Ahmed Mohamed	Jun-24	To examine flood resilience in Alappuzha's built environment, focusing on vulnerability, building practices, and suitable approaches.	Conducted a qualitative literature search on Scopus and Google Scholar, analyzing data related to flood vulnerability and resilience in the region.	Provided a comprehensive understanding of contemporary trends in flood resilience, construction practices, and the built environment in Alappuzha.	Provided a comprehensive understanding of contemporary trends in flood resilience, construction practices, and the built environment in Alappuzha.	The study identifies key gaps in urban resilience research, emphasizing the need for advanced statistical methods to analyze resilience predictors, integrated urban-coastal research, and greater political-economic recognition to prevent social injustice and environmental degradation. Addressing these gaps will enhance resilience strategies, particularly in disaster-prone regions like Kerala.	Highlights the need for effective solutions to enhance flood resilience in Alappuzha's built environment.
13	Urban Resilience: A Critical Study on Kerala Flood-2018	Sameer Ali Ar and Abraham George	Jun-21	To evaluate the factors contributing to Kerala's rapid recovery post the 2018 floods and to develop a flexible and effective urban resilience planning approach.	The study involves a critical analysis of Kerala's response to the 2018 floods, comparing it with similar-scale disasters in India and globally. It examines urban planning techniques, infrastructural capabilities, and community responses.	The research highlights Kerala's strong resilience, emphasizing the importance of adaptive planning, design, and infrastructure to not only restore but improve conditions post-disaster.	The study's resilience model is limited in its broader application as it relies on qualitative analysis of a single disaster without comprehensive data or long-term impact evaluation. Additionally, while it emphasizes government efforts in flood recovery, it does not deeply assess policy shortcomings or governance challenges, restricting its relevance to urban flood management.	The study identifies a need for urban planning approaches tailored to unique city landscapes, rather than generic models, to enhance resilience effectively.	The paper underscores the significance of exceeding pre-disaster conditions through innovative planning and infrastructural improvements to better withstand future disasters.
14	Planning and Design of a Flood Resilient Building Based on Impact Study	Radha Unnikrishnan M, Ancy Jaison, Anukrishna P C	Nov-22	Develop a framework for designing flood-resilient buildings using impact study insights. Assess the effectiveness of flood mitigation strategies in different urban and rural settings.	Field surveys and case study analysis. GIS-based flood risk mapping and simulation. Structural modeling to test flood resistance.	Proposed a design framework integrating flood-resistant materials, elevated structures, and drainage enhancements. Found that integrating GIS-based planning with structural design improves resilience.	Study is limited to specific climatic and geographical conditions; broader validation needed. Lack of real-time testing under extreme flood conditions.	Need for interdisciplinary studies incorporating socio-economic factors in flood-resilient design. Limited analysis of long-term maintenance and cost-effectiveness.	Emphasizes integrating flood risk assessment tools with architectural planning. Future research should focus on adaptive strategies for different urban typologies.
15	Integration of Flood-Resilient Amphibious Building Technology with the Sustainable Vernacular Architecture of Kerala -A Case of Thevarpathiyil Ancestral Home	Nanma Gireesh	Jan-21	Analyze the vernacular architectural features of the 109-year-old Thevarpathiyil ancestral home in Kerala. Explore integration of traditional design elements with modern flood-resilient amphibious building technologies.	Case study approach focusing on Thevarpathiyil ancestral home. Detailed architectural analysis of vernacular flood-resilient features. Comparative assessment of traditional features with contemporary amphibious technologies.	Identified key vernacular design elements such as elevated plinths and strategic material use for flood resilience. Demonstrated potential for integrating traditional practices with modern amphibious technologies for sustainable flood resistance.	Limited to a single case study; broader application needs further validation. Lacks quantitative assessment of structural performance under varying flood conditions.	Need for more experimental studies validating the feasibility of hybrid vernacular-amphibious architecture. Lack of detailed cost-benefit analysis for implementation at scale.	The study emphasizes the importance of blending traditional and modern techniques for flood resilience in Kerala. Future studies should explore practical implementation across multiple case studies.

Table 2 Review of Literature Studies

SNo	Title of the Paper	Climate-adaptive architecture	Disaster risk reduction (DRR)	Flood-resilient shelter design	Geospatial flood risk mapping	Urban flood mitigation	Vernacular flood-resistant architecture
1	Wetland Conservation and Sustainable Development in Kerala, India		✓				
2	Reclamation of Wetlands and its Impacts on Urban Development - A Case Study in Kerala					✓	
3	Land Cover Change Analysis with Special Reference to Forests and The Resilience of the Built Environment to Flooding: The Case of Alappuzha District in the South Indian State of Kerala Using Remote Sensing and GIS	✓	✓		✓	✓	✓
4	The relevance of wetland conservation in Kerala		✓				
5	Land use/land cover changes in Ashtamudi wetland region of Kerala - A study using remote sensing and GIS				✓		
6	The application of remote sensing and geographic information system techniques for the analysis of land use and land cover changes in Wayanad district of Kerala				✓		
7	Applications of Remote Sensing and GIS in Geospatial Terrain Evaluation of Thrissur Forest Division, Kerala, India				✓		
8	Evaluating the Relation Between Land Use Changes and the 2018 Floods in Kerala, India		✓				
9	Land use/land cover changes (1988–2017) in Central Kerala and the effect of urban built-up on Kerala floods 2018				✓		
10	Design of A Sustainable Flood Resistant Structure for Rebuilding Resilient Kerala Post Floods			✓			✓
11	Spatiotemporal Analysis of Flooding in Kerala Over the Last 5 Years Using GIS (2018-2022) | AGSRT				✓		
12	The Resilience of the Built Environment to Flooding: The Case of Alappuzha District in the South Indian State of Kerala		✓				
13	Urban Resilience: A Critical Study on Kerala Flood-2018	✓	✓			✓	
14	Planning and Design of a Flood Resilient Building Based on Impact Study		✓	✓	✓	✓	✓
15	Integration of Flood-Resilient Amphibious Building Technology with the Sustainable Vernacular Architecture of Kerala -A Case of Thevarpathiyil Ancestral Home		✓	✓			✓

Table 3 Table of Taxonomy (about given keywords)

Methodology

The study gathered GIS mapping data to analyze flood vulnerability and shelter site selection in Ernakulam district, incorporating Census 2011 data, flood frequency records, and water body encroachment information [6]. Additionally, disaster resilience indicators such as government policies and community preparedness levels were examined to assess Kerala's capacity to mitigate flood risks [13]. A thorough literature review was conducted, analyzing 15 research papers, along with data from Kerala's official GIS platform for Ernakulam District [3]. This helped identify the best practices for flood shelter design, amphibious housing, and traditional vernacular resilience techniques [15].

For data processing and visualization, ArcGIS Pro was used to map flood-prone areas by overlaying hydrological data, tracking green cover loss, and assessing land use encroachments [7]. The GIS-based analysis helped to define scientific site selection criteria for flood shelters, ensuring that shelter locations were not only safe but also accessible [10]. The literature findings were systematically categorized by comparing the global flood-resilient shelter models with Kerala's traditional flood-resistant construction techniques. This comparative approach provides a deeper understanding of how modern innovations and old architectural practices can be integrated to improve disaster resilience [14].

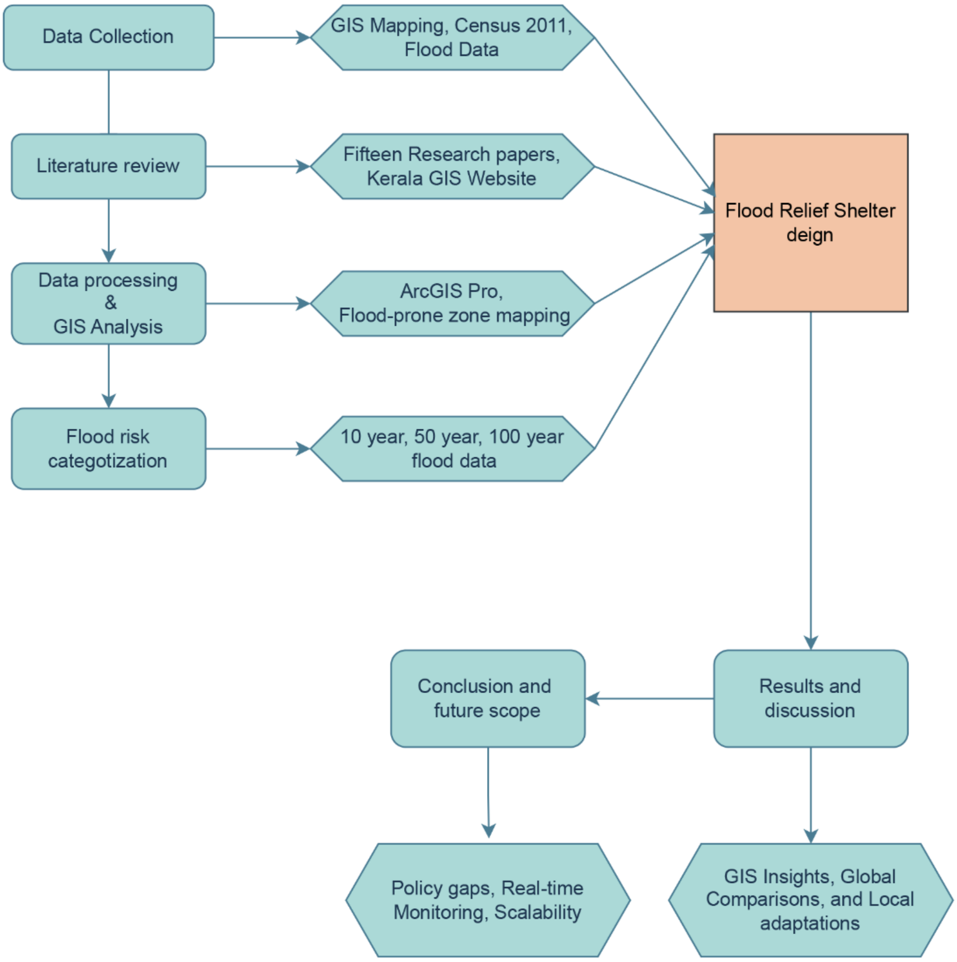

Figure 1 Methodology Chart

Flood Risk considerations for Shelter design

To assess flood risk for relief shelter placement, this study considers return periods of 10-year, 50-year, and 100-year floods, balancing frequent flood events that require immediate shelter deployment with severe floods that demand long-term resilience strategies [9]. A 10-year flood represents frequent urban flooding, necessitating readily deployable temporary shelters in vulnerable areas [11]. The 50-year flood accounts for moderate flood scenarios, where elevated and amphibious shelters are essential for mitigating displacement [15].

Category	Details Covered
High-Risk Flood Zones	Kochi (MG Road, Marine Drive, Kadavanthra), Aluva (Periyar Riverbanks), Perumbavoor, Vyttila (Traffic Hub, Waterlogging), North Paravur (Backwater Flooding)
Major Water Bodies	Periyar River (Main flooding source), Edappally Canal, Thevara-Perandoor Canal, Muvattupuzha River, Vembanad Lake (Backwater influence)
Urbanization Impact	Wetland encroachment (Maradu, Vyttila), drainage obstruction due to construction (Kakkanad, Thrikkakara), rapid land-use change (IT hubs & metro expansion)
Flood Return Periods	10-year (frequent, short-term waterlogging), 50-year (moderate inundation, urban drainage failure), 100-year (severe flooding, major displacement)
Shelter Suitability	High-ground locations (Kakkanad, Thrippunithura), elevated shelters in flood zones (Aluva, North Paravur), amphibious designs for backwater regions
Infrastructure Gaps	Poorly placed emergency shelters (far from flood-prone areas), inadequate drainage maintenance, encroached canal networks, lack of flood evacuation corridors
Policy Recommendations	Enforcing flood-resilient zoning laws, integrating shelters with existing infrastructure (schools, metro stations), community flood mapping initiatives, restoring riverbanks and natural drainage channels

The 100-year flood represents an extreme event, emphasizing the need for permanent, high-ground shelters integrated with urban planning [10]. Floods beyond the 100-year return period, such as 200-year or 500-year floods, are rare and require large-scale infrastructural interventions rather than stand-alone shelter solutions [3]. Therefore, this study prioritizes shelter adaptability for practical and recurring flood scenarios, ensuring feasible and scalable designs that enhance the urban flood resilience of Ernakulam [6].

Table 4 History of Flood risk assessment of various parts of Kerala

Flood vulnerability in Ernakulam: A Multi-Context Analysis

Ernakulam's flood vulnerability is a complex challenge owing to its diverse geography and rapid urbanization. The district faces three primary types of flooding: riverine floods from the Periyar River, flash floods in hilly terrains such as Kothamangalam, and coastal inundation in low-lying urban areas of Kochi due to sea-level rise and inefficient drainage [3]. These variations make flood response and shelter planning particularly challenging because a one-size-fits-all solution is ineffective [8].

Aluva, positioned along the Periyar floodplains, frequently witnesses high water levels during monsoons and dam releases, turning streets into waterways [11]. Kothamangalam, nestled in the foothills of the Western Ghats, experiences rapid runoff, leading to flash floods that cut off villages from essential services [9]. Meanwhile, Kochi's urban sprawl and encroachment of backwaters worsened tidal flooding, leaving homes and businesses waterlogged [7]. With thousands of people displaced annually, the need for localized, adaptive shelter solutions is evident.

Elevated and amphibious housing in Aluva, terrain-sensitive evacuation routes in Kothamangalam, and an integrated drainage infrastructure in Kochi could significantly improve resilience [15]. Community-driven solutions, such as multiuse shelters in schools and temples, can provide immediate refuge while leveraging local knowledge and resources [14]. By blending traditional wisdom with modern GIS-driven planning, a sustainable flood relief strategy can emerge that respects Kerala's landscape while ensuring that its people remain safe and prepared [10].

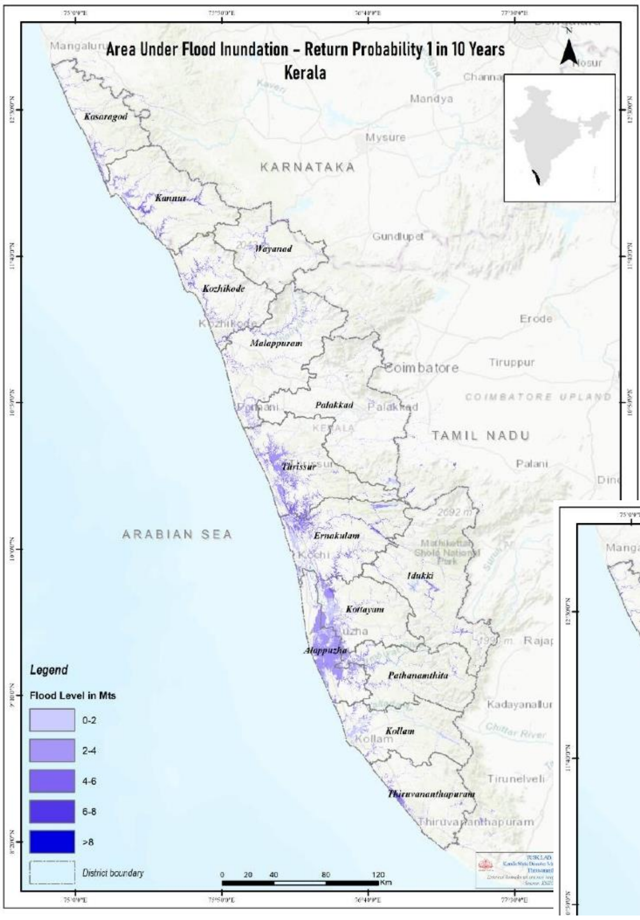

Figure 2 Area under flood inundation- Return probability: 1 in 10 years

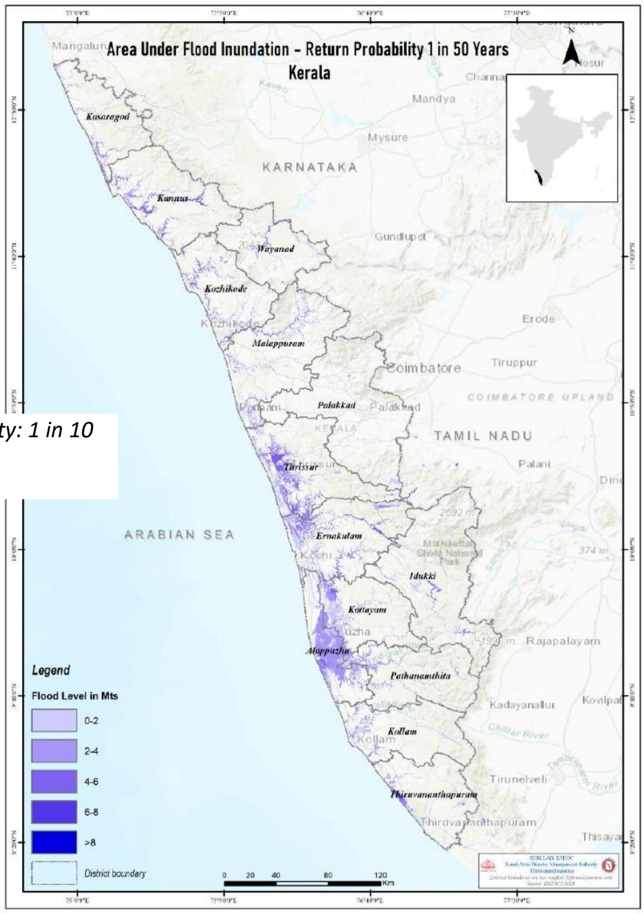

Figure 3 Area under flood inundation- Return probability: 1 in 50 years

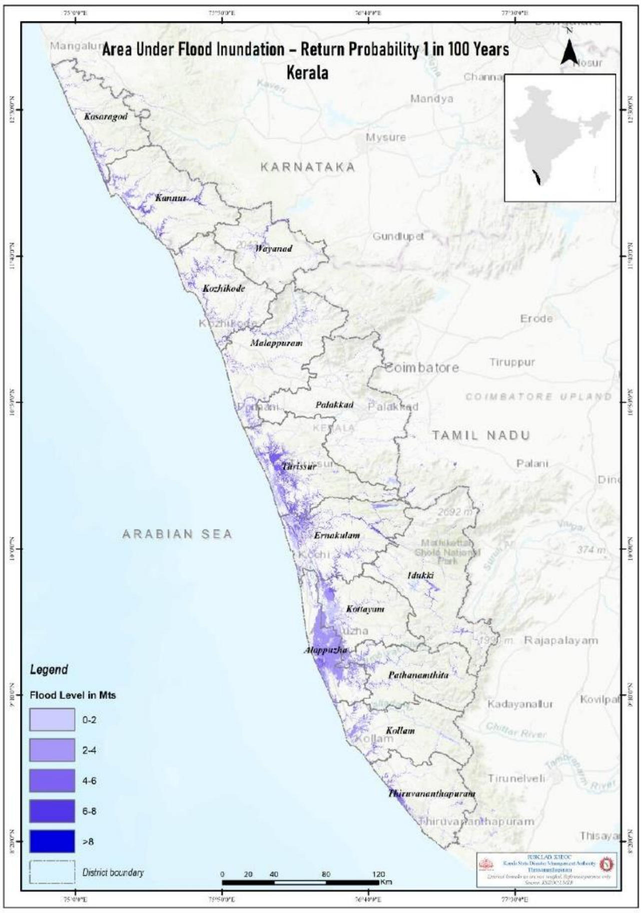

Figure 4 Area under flood inundation- Return probability: 1 in 100 years

Aluva: Battling Riverine Flooding in a Densely Urbanized Hub

Aluva, a highly urbanized area along the Periyar River, is one of Kerala's most flood-prone regions [3]. The Periyar, which is vital for water supply, agriculture, and the economy, also poses a major flood risk [11]. Heavy monsoon rains and dam releases from the Idukki and Idamalayar reservoirs cause river overflows, submerging streets, homes, and businesses [7]. Flood levels have reached 10.83 meters, severely disrupting transportation, health care, and education [9].

The 2018 Kerala floods left Aluva underwater for several days, highlighting the need for resilient infrastructure and evacuation centers [6]. As a key transportation hub with railway stations, highways, and commercial areas, Aluva requires adaptable relief shelters [14]. The challenge is to identify flood-free zones within a dense urban fabric. Integrating shelters into schools, government buildings, and community halls allows them to be repurposed during floods, ensuring efficient evacuation and minimal post-flood disruptions [15].

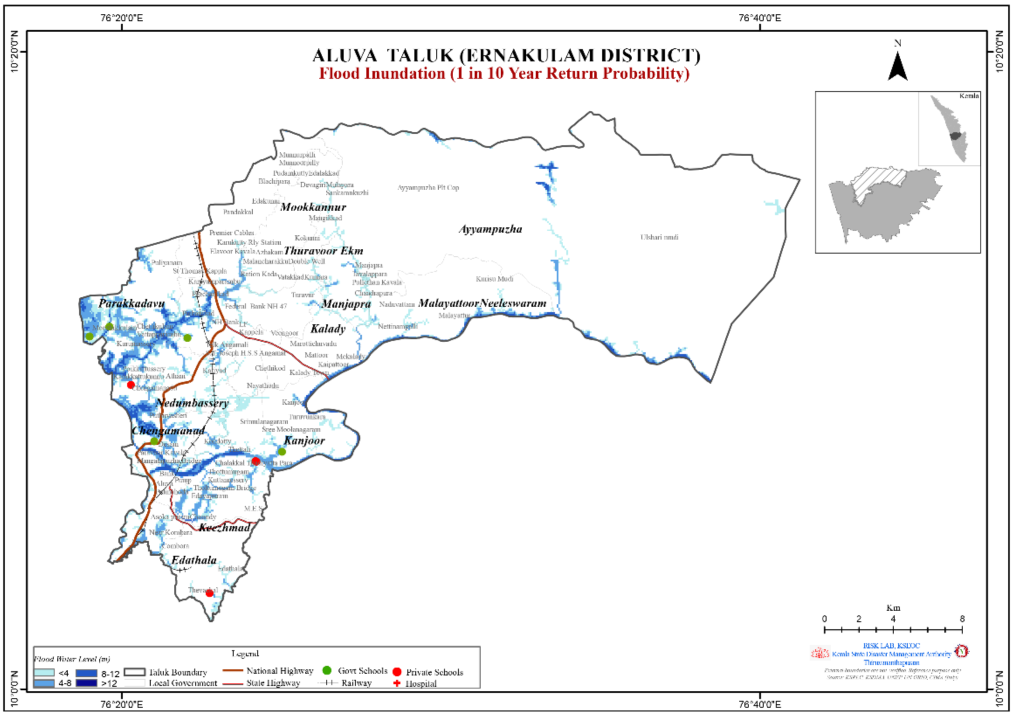

Figure 6 Aluva Taluk (1 in 10 years)

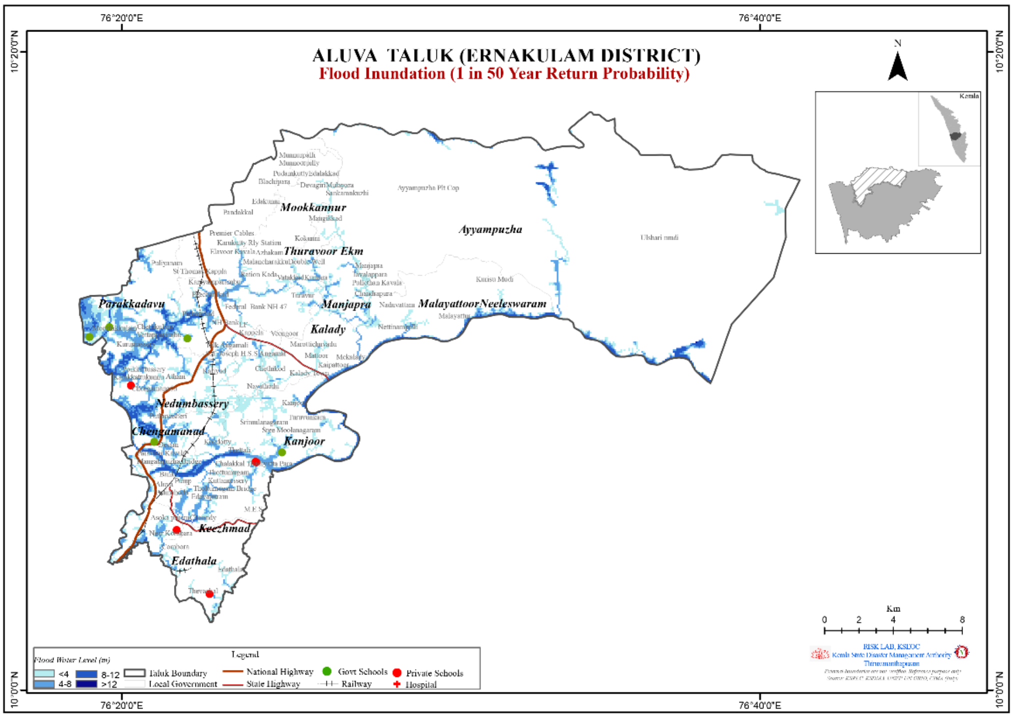

Figure 5 Aluva Taluk (1 in 50 years)

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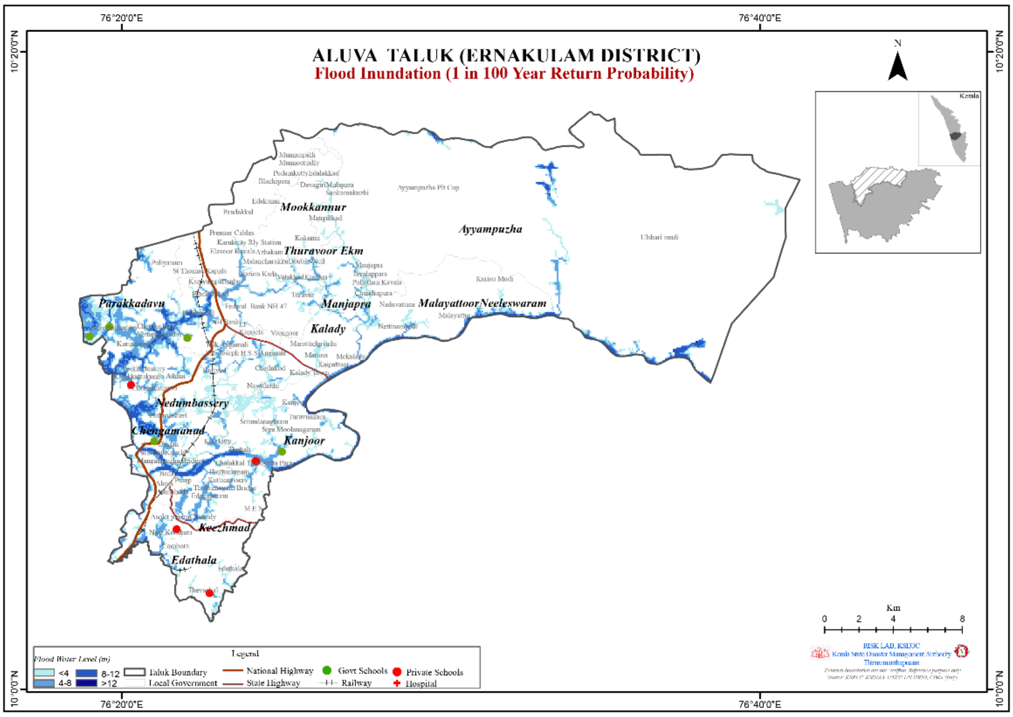

Figure 7 Aluva Taluk (1 in 100 years)

ERNAKULAM DISTRICT — ALUVA TALUK

1 in 10 YEAR (Historic)

Sl No	LSG	Flood Inundation Area (Km2)	Max. Flood Level (m)
1	Aluva Municipality	2.15	8.14
2	Angamaly Municipality	7.27	7.69
3	Ayyampuzha	16.46	41.07
4	Chengamanad	8.68	8.49
5	Choornikkara	3.83	8.2
6	Edathala	1.50	7.68
7	Kalady	5.23	10.38
8	Kanjoor	5.65	12.02
9	Karukutty	0.85	6.75
10	Keezhmad	5.65	11.92
11	MalayattoorNeeleswaram	9.93	21.98
12	Manjapra	3.32	7.49
13	Mookkannur	0.86	5.76
14	Nedumbassery	9.26	7.69
15	Parakkadavu	8.99	7.82
16	Sreemoolanagaram	4.22	11.92
17	Thuravoor Ekm	2.59	5.98
18	Tripunithura Municipality	3.39	5.05

1 in 50 YEAR (Historic)

Sl No	LSG	Flood Inundation Area (Km2)	Max. Flood Level (m)
1	Aluva Municipality	2.60	9.6
2	Angamaly Municipality	8.15	7.69
3	Ayyampuzha	21.91	49.87
4	Chengamanad	10.51	10.2
5	Choornikkara	4.60	9.98
6	Edathala	1.96	9.57
7	Kalady	7.62	12.77
8	Kanjoor	7.76	14.57
9	Karukutty	0.96	6.75
10	Keezhmad	7.09	12.37
11	MalayattoorNeeleswaram	13.34	24.79
12	Manjapra	4.96	9.95
13	Mookkannur	1.61	6.17
14	Nedumbassery	11.47	7.94
15	Parakkadavu	9.12	7.82
16	Sreemoolanagaram	5.69	12.86
17	Thuravoor Ekm	4.93	7.61
18	Tripunithura Municipality	3.53	5.87

1 in 100 YEAR (Historic)

Sl No	LSG	Flood Inundation Area (Km2)	Max. Flood Level (m)
1	Aluva Municipality	2.70	10.17
2	Angamaly Municipality	8.66	7.85
3	Ayyampuzha	24.22	52.21
4	Chengamanad	11.19	10.69
5	Choornikkara	4.76	10.42
6	Edathala	2.22	10.29
7	Kalady	9.05	13.5
8	Kanjoor	8.75	15.42
9	Karukutty	0.99	7.19
10	Keezhmad	7.63	12.67
11	MalayattoorNeeleswaram	14.48	25.69
12	Manjapra	5.37	10.83
13	Mookkannur	1.68	6.47
14	Nedumbassery	12.20	8.08
15	Parakkadavu	9.41	8
16	Sreemoolanagaram	6.18	13.2
17	Thuravoor Ekm	5.44	8.33
18	Tripunithura Municipality	3.59	6.02

Table 5 Aluva Taluk: Historical Flood Data

Kochi: Coastal Flooding and Drainage Failures in a Megacity

Kochi, Kerala’s commercial capital, faces severe coastal flooding owing to its low elevation, tidal surges, rapid urbanization, and poor drainage infrastructure [9]. Unlike Aluva’s seasonal riverine floods or Kothamangalam’s extreme weather risks, Kochi’s flooding is unpredictable, triggered by high tides, cyclones, and unchecked construction that obstructs natural water flow [7]. Areas such as Fort Kochi, Mattancherry, and Vypin frequently experience prolonged waterlogging, leading to health hazards, infrastructure damage, and disruptions in daily life [3].

Effective shelter planning must be integrated with urban infrastructure, utilizing elevated, multipurpose designs that serve as both temporary refuges and community spaces [15]. Given the city’s limited land availability, shelters should be designed to maximize vertical space while incorporating built-in water management features, such as rainwater harvesting, permeable ground surfaces, and elevated platforms, to reduce stagnation and enhance long-term flood resilience [10].

Figure 9 Kochi Taluk (1 in 10 years)

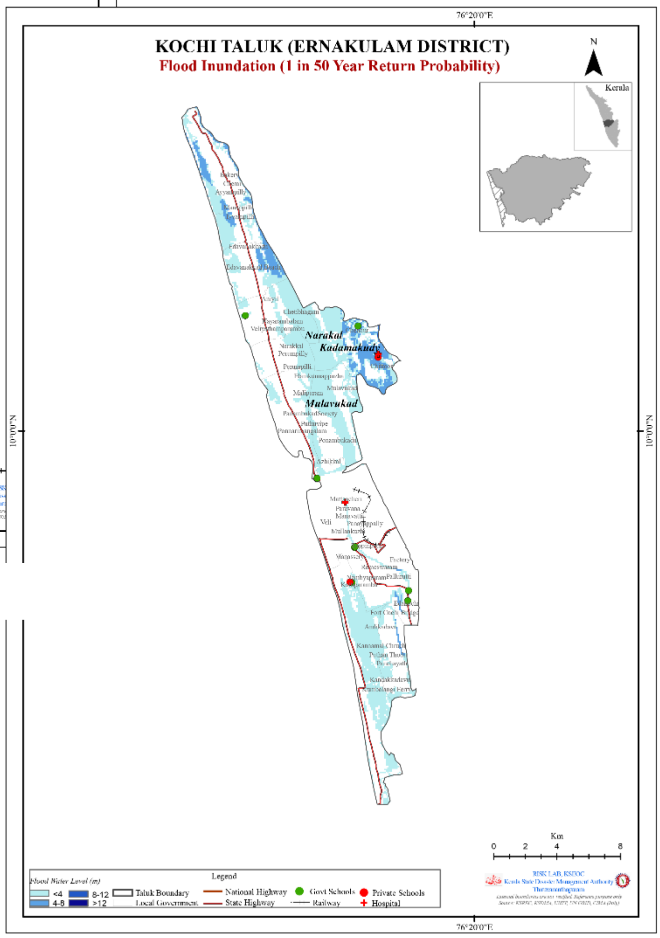

Figure 8 Kochi Taluk (1 in 50 years)

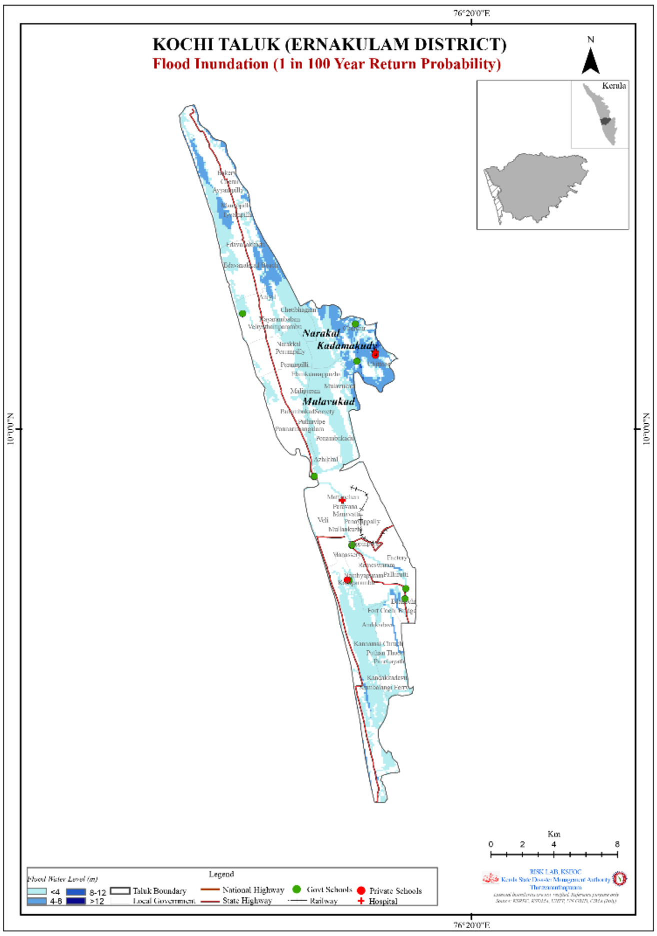

Figure 10 Kochi Taluk (1 in 50 years)

ERNAKULAM DISTRICT											
KOCHI TALUK											
1 in 10 YEAR (Historic)				1 in 50 YEAR (Historic)				1 in 100 YEAR (Historic)			
Sl No	LSG	Flood Inundation Area (Km2)	Max. Flood Level (m)	Sl No	LSG	Flood Inundation Area (Km2)	Max. Flood Level (m)	Sl No	LSG	Flood Inundation Area (Km2)	Max. Flood Level (m)
1	Chellanam	14.62	3.12	1	Chellanam	15.59	3.59	1	Chellanam	19.35	5.15
2	Cochin Corporation	3.88	3.09	2	Cochin Corporation	4.17	3.6	2	Cochin Corporation	4.24	3.7
3	Edavanakkad	3.34	2.39	3	Edavanakkad	5.34	3.93	3	Edavanakkad	6.22	5.17
4	Elankunnapuzha	3.08	2.24	4	Elankunnapuzha	3.62	2.75	4	Elankunnapuzha	3.76	2.86
5	Kadamakudy	11.10	4.33	5	Kadamakudy	13.94	8.2	5	Kadamakudy	14.69	8.31
6	Kumbalanghi	3.44	3.12	6	Kumbalanghi	3.71	3.6	6	Kumbalanghi	3.90	3.87
7	Kuzhuppilly	2.94	4.93	7	Kuzhuppilly	3.51	6.17	7	Kuzhuppilly	3.78	6.55
8	Mulavukad	9.61	2.51	8	Mulavukad	10.01	3.86	8	Mulavukad	10.23	5.23
9	Narakal	2.75	1.18	9	Narakal	2.85	1.37	9	Narakal	2.87	1.47
10	Nayarambalam	5.51	1.16	10	Nayarambalam	6.01	2.87	10	Nayarambalam	7.25	3.44
11	Pallippuram	5.37	6.73	11	Pallippuram	5.99	7.31	11	Pallippuram	6.77	7.57

Table 6 Kochi Taluk: Historic Flood Data

Kothamangalam: Inland Flooding and Terrain-Based Challenges

Kothamangalam, particularly the Malayattoor-Neeleswaram region, faces unique flood challenges due to its hilly terrain, experiencing inland flooding, flash floods, and landslides [8]. With flood levels reaching up to 27.29 meters, the region is highly vulnerable to sudden disasters, exacerbated by rapid water runoff and heavy upstream rainfall in the Periyar River basin [3]. Unlike Aluva, which has strong transportation networks, Kothamangalam suffers from limited road connectivity and rugged terrain, making evacuations difficult [9]. Relief shelters must be self-sufficient, elevated, and strategically located in naturally higher areas in order to withstand prolonged exposure to extreme weather [7]. Given the region's rural nature, shelters should function as long-term community hubs equipped with food storage, medical aid, and alternative energy sources [14]. Additionally, their design must ensure accessibility, sustainability, and resilience, allowing them to support stranded residents when external assistance is delayed [15]

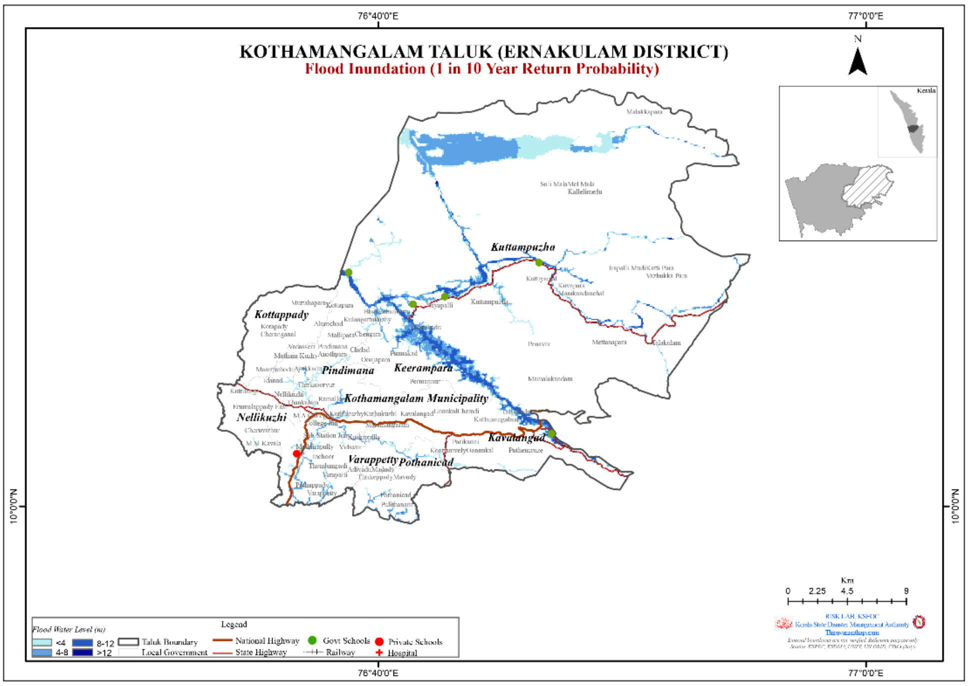

Figure 12 Kothamangalam Taluk (1 in 10 years)

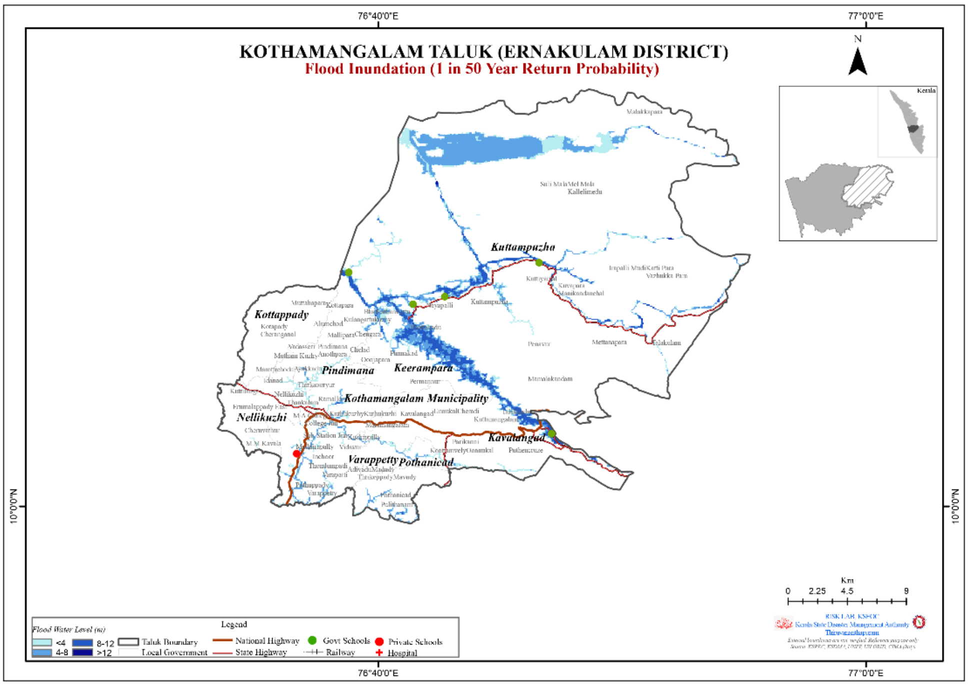

Figure 11 Kothamangalam Taluk (1 in 50 years)

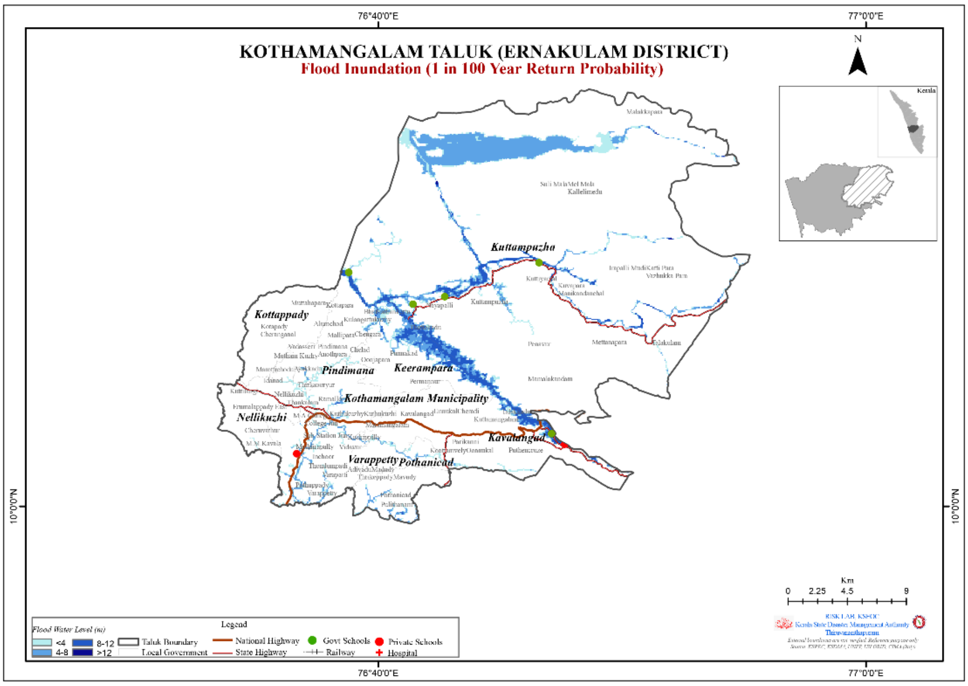

Figure 13 Kothamangalam Taluk (1 in 100 years)

ERNAKULAM DISTRICT											
KOTHAMANGALAM TALUK											
1 in 10 YEAR (Historic)				1 in 50 YEAR (Historic)				1 in 100 YEAR (Historic)			
Sl No	LSG	Flood Inundation Area (Km2)	Max. Flood Level (m)	Sl No	LSG	Flood Inundation Area (Km2)	Max. Flood Level (m)	Sl No	LSG	Flood Inundation Area (Km2)	Max. Flood Level (m)
1	Kavalangad	7.36	33.11	1	Kavalangad	9.77	41.57	1	Kavalangad	10.29	45.34
2	Keerampara	22.24	23.62	2	Keerampara	24.28	29.02	2	Keerampara	24.74	30.82
3	Kothamangalam Municipality	15.55	20.56	3	Kothamangalam Municipality	25.34	22.75	3	Kothamangalam Municipality	27.73	23.34
4	Kottappady	0.63	8.43	4	Kottappady	5.53	15.62	4	Kottappady	6.17	16.94
5	Kuttampuzha	67.34	57.2	5	Kuttampuzha	73.54	57.21	5	Kuttampuzha	75.67	57.21
6	Nellikuzhi	5.87	21.58	6	Nellikuzhi	8.60	24.91	6	Nellikuzhi	9.06	26.07
7	Pallarimangalam	0.78	3.8	7	Pallarimangalam	1.31	16.25	7	Pallarimangalam	1.41	16.25
8	Pindimana	12.56	32.9	8	Pindimana	14.40	38.35	8	Pindimana	14.93	40.23
9	Pothanicad	2.08	9.22	9	Pothanicad	2.43	10.66	9	Pothanicad	2.59	11.16
10	Varappetty	3.51	12.66	10	Varappetty	8.73	20.29	10	Varappetty	11.97	21.83

Table 7 Kothamangalam Taluk: Historic Flood Data

Proposal-Project GRUHAM: Emergency flood relief shelters

Innovative Shelter for Kerala's Flood-Prone Regions

In the heart of Kerala's flood-prone belt, Kochi, Aluva, and Kothamangalam, an innovative shelter concept, redefined resilience and adaptability. Designed to provide both safety and functionality, this temporary refuge seamlessly integrates sustainability, modern engineering, and Kerala's vernacular charms.

Sustainability and Climate Adaptation

Kerala's tropical monsoon climate is characterized by intense rainfall, high humidity, and fluctuating temperatures. These conditions make flood-resistant construction imperative, particularly in vulnerable regions, such as Kochi, Aluva, and Kothamangalam. Shelters embrace sustainability by using locally available materials, passive cooling techniques, and adaptable structural elements. Incorporating rammed earth, bamboo, and fiber cement concrete (FCC) panels enhances thermal insulation and ensures comfort under humid conditions while maintaining structural stability.

A Dynamic and Expandable Design

At its core, the shelter was a 6m x 2m compact unit, offering an enclosed space of 14 square meters. When unlocked, it transformed dramatically, expanding outward into a 6m x 9m footprint, creating a total area of 54 square meters. This innovative mechanism allows corridors to unfold on all four sides, maximizing space efficiency, while maintaining a minimal footprint when closed. Internally, the layout was designed for functionality and occupant comfort.

- Front Section: A kitchenette provides the basic cooking facilities.
- Rear Section: A restroom ensures that essential sanitation needs are met.
- Sleeping Arrangements: The shelter accommodates five beds, two positioned near the sliding UPVC door, and three in the 3m extension created by the fold-down wall, ensuring optimal space utilization.

To shelter the extended floor space, a wax-coated canvas, supported by 50mm x 50mm Square Hollow Sections (SHS), acts as a retractable covering mechanism. This flexible structure operates similarly to a Japanese hand fan or harmonium, allowing for adaptable use based on weather conditions.

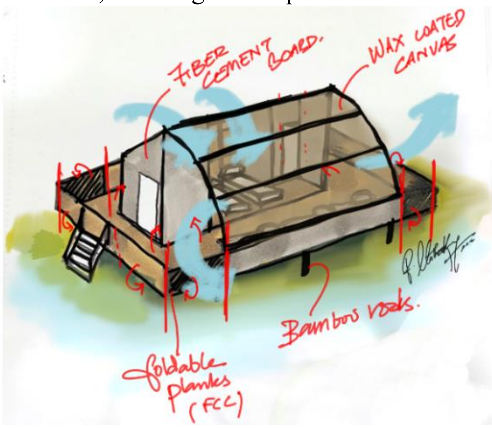

Figure 14 Conceptual Sketch of the Shelter

Structural Integrity and Material Innovation

The shelter was constructed using a combination of fiber cement concrete (FCC) boards on both the inner and outer faces, supported by a light-gauge steel frame (SHS). The walls, floors, and parapet maintain a robust 110 mm thickness, consisting of FCC boards enclosing a rammed earth infill. This combination ensures high durability, moisture resistance, and thermal efficiency, making it ideal for the climate of Kerala. Aesthetic integration with Kerala's architectural heritage is achieved through clay tile shingles, which emulate traditional roofing while being lightweight and cost effective.

Foundation and Flood Resilience

Recognizing the ever-present risk of flooding, shelters are elevated 1.5 meters above ground level. This elevation was supported by a grid of nine bamboo columns (100 mm diameter) interconnected by 100 mm SHS beams. Bamboo ensures flexibility and structural integrity, allowing the shelter to withstand environmental stresses while remaining lightweight and adaptable.

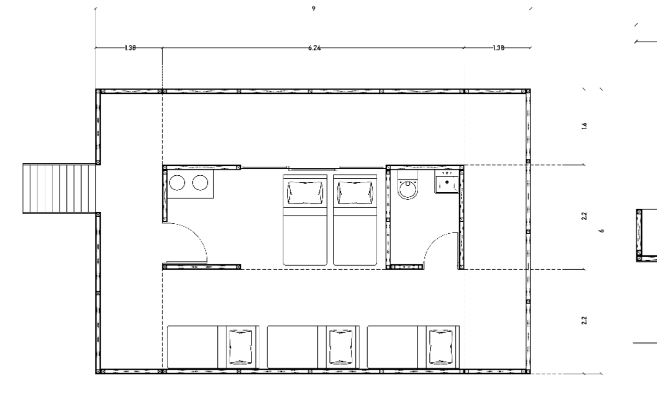

Figure 16 Floorplan of the Shelter

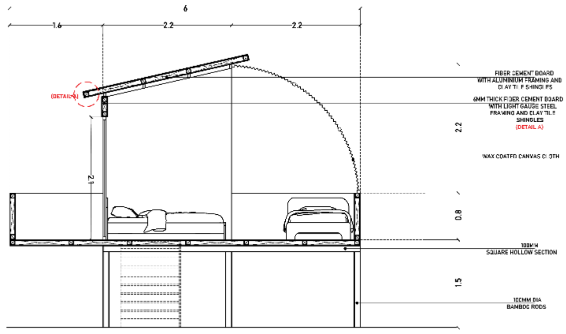

Figure 15 Sectional elevation of the Shelter

Enhanced Mobility and Accessibility

Mobility and accessibility are the key considerations in shelter design. The integrated ladder staircase provides convenient access to the elevated structure, thereby ensuring safety during flood conditions. Corridor extensions not only expand the usable space but also create an open-plan environment that enhances ventilation and daylight penetration. By incorporating sliding UPVC doors and flexible shading elements, the shelter maintains a seamless connection between indoor and outdoor spaces while ensuring adaptability to changing weather conditions.

Modular Construction and Scalability

The modular nature of this shelter allows for quick assembly and disassembly, making it ideal for disaster-relief scenarios. Prefabricated Light Gauge Steel Frame (SHS) components facilitate rapid deployment and significantly reduce construction time. The design is scalable, allowing multiple units to be interconnected and forming larger community housing setups. This adaptability makes shelters suitable for temporary relief housing and semi-permanent settlement solutions in flood-prone areas.

Disaster-Resilient Construction and Safety Features

With flood preparedness as a key focus, shelters incorporate elevated construction to minimize water damage. The 1.5m elevation above ground level ensures that essential living spaces remain dry, even during severe flooding. The grid of nine bamboo columns (100 mm diameter), reinforced with 100 mm SHS beams, offers a structurally sound foundation capable of withstanding lateral forces from rising water levels. These safety features make the shelter a viable emergency response solution in flood-prone regions

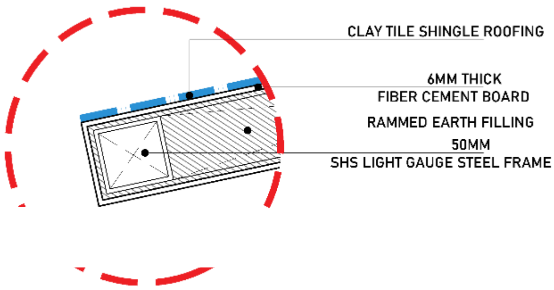

Figure 17 Roof Detail

A Vision for Adaptive and Sustainable Shelter Design

This design seamlessly fuses practical engineering with vernacular architecture, resulting in a resilient, cost-effective, and culturally attuned shelter for Kerala's flood-prone communities. By prioritizing sustainability, flexibility, and local materials, it serves as a forward-thinking solution for disaster relief and temporary housing, setting a precedent for future climate-resilient infrastructure.

Figure 18 Exterior elevation 1

Figure 19 Exterior elevation 2

Figure 21 Interior elevation 1

Figure 22 Interior elevation 2

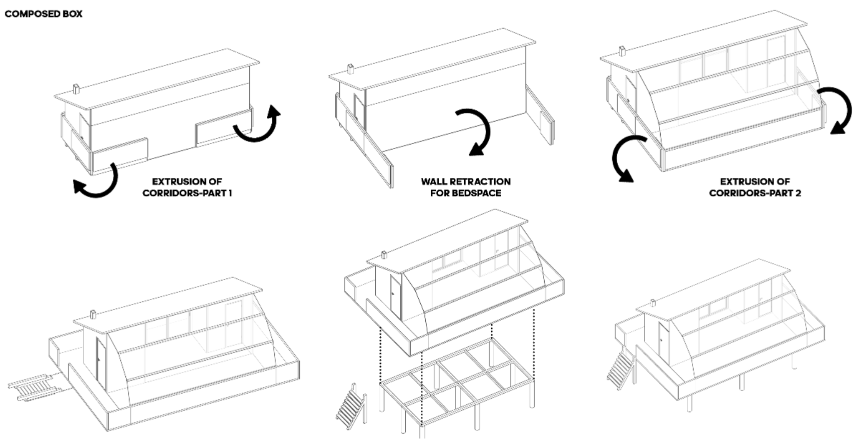

Figure 20 Process of unwrapping the module

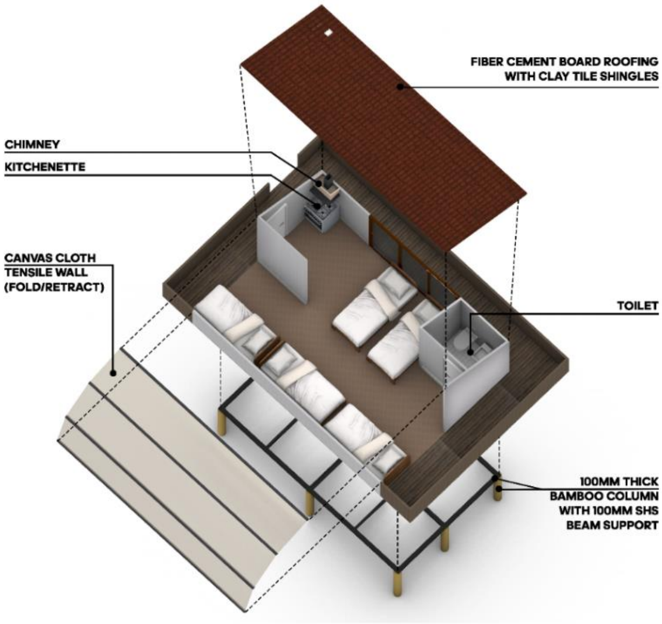

Figure 23 Axonometric exploded view of the Shelter

Results and Discussion

GIS mapping insights revealed that urban encroachment into floodplains significantly exacerbates the impact of flooding [9]. A strong correlation existed between the reduction in green cover and increased flood vulnerability [6]. Furthermore, there was a noticeable lack of planned flood shelters in high-risk zones [3]. The literature review indicates that flood-resistant shelter solutions include elevated stilt housing, amphibious homes, and floating shelters [15].

Kerala's vernacular architecture, characterized by raised plinths, sloped roofs, and lightweight timber construction, provides natural flood resilience [14]. Additionally, global flood mitigation strategies such as Thailand's amphibious homes and the Netherlands' floating houses offer applicable models for Kerala [10]. Based on GIS-based site selection, the proposed flood shelter designs prioritize elevated low-density zones near community hubs [7]. The shelter design incorporates amphibious and elevated structures capable of withstanding rising water levels; sustainable materials such as bamboo, timber, and lightweight concrete; and flexible modular designs for rapid deployment [15].

Limitations and Future Scope

This study faced limitations, including time constraints that restricted the integration of real-time GIS data. Additionally, the research focused solely on the over-prone areas of Ernakulam district, Kerala. Future research should expand to other high-risk Indian cities such as Thiruvananthapuram, Chennai, Mumbai, and Kolkata for comparative GIS analysis. Furthermore, integrating real-time flood monitoring systems for predictive modeling can enhance the effectiveness of flood mitigation strategies.

Conclusion

This study demonstrates that GIS-based flood mapping can optimize flood shelter site selection by identifying high-risk urban zones. By integrating vernacular architectural principles into amphibious and elevated shelter designs, Kerala can enhance its flood-resilience strategies. The findings provide a foundation for future GIS-driven flood mitigation planning, with scalability to other Indian cities.

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