Creating Resilient Infrastructure to Respond to Emerging Climatic Calamities: Scope of Amphibious Architecture for the Below Sea Level Settings in Kuttanads, India

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Abstract

The coastal regions of India have been the hub of various human activities, resulting in the major cities developed along the sea-coast. Kerala is the Southernmost state in India that was worst hit by disastrous floods in both 2018 and 2019. According to a forecast by the Indian Ministry of Earth Sciences, the calamity may be repeated every year in the future, too, due to the changes in the weather patterns. Hence, there is a need for urgent mitigation in terms of flood and resilient infrastructure. This is a flood for which no law has been provided, since it is unprecedented. In this context, this paper discusses the feasibility of amphibious structures-those that rise and fall with the water level-as a flood-resilient solution for Kerala.

The research adopted a mixed-method approach to examine the impact of repeated floods in Kuttanad, Kerala. It employs case studies, in-depth, qualitative interviews, a quantitative survey and a literature survey. The literature survey produces data related to amphibious architecture as a sustainable solution for flood-prone areas. In-depth qualitative interviews were carried out with the residents who can articulate their adaptation strategies, infrastructure and amphibious architecture. A quantitative survey was carried out to assess the impact of flood and response strategies targeting the government officials. The case study examines the first-ever floating house of India at Changanassery and generate insights from an interview with the architect delving deep into amphibious design. It also examines a number of case studies from different parts of the world, drawing inferences related to safeguarding flood-prone communities and especially Kuttanad in Kerala.

Finally, the paper produces design guidelines, to respond to the floods by considering ways in which amphibious architecture responds effectively to flooding, enhancing its resilience.

Keywords: Floating Cities, Rising Sea Levels, Floods, Amphibious Architecture, Adaptive Architecture

Introduction

India is a peninsular country surrounded by the Arabian Sea, the Bay of Bengal, and the Indian Ocean, making flooding a grave concern. Floods represent one of the most common natural catastrophes of the country; every year, it causes great losses to property and human lives. As shown in the Figure 01, and according to GSI, about 12.5% of the total area of India is prone to floods. The major river systems, such as the Ganga, Brahmaputra, Godavari, and other rivers, including their tributaries, have posed a perennial threat in these regions, especially during the monsoon rains which heighten the flood conditions, particularly in the South and the East. Indeed, newer approaches towards management of floods with the recurrence of floods and the rise in the sea levels due to climatic changes assume significance, especially in the coastal and riverine areas. It is no longer sufficient to merely construct embankments, coastal barriers, and other heavy engineering solutions. With the rise in the global sea levels associated with climate change, there is a rising need for innovative and adaptive architectural designs that keep communities out of the reach of these swelling dangers. In this context, amphibious architecture emerges as one promising solution.

Fig. 01: Indian Climatic Disaster Risk Map
Source: https://en.m.wikipedia.org/wiki/File:India_climatic_disaster_risk_map_en.svg

Amphibious architecture is what works both out of water and during a flood: the structures adapt to the fluctuating water levels without structural damage. Thus, so-called buoyant foundations are provided with an anchoring system through the use of vertical guideposts, uprising and going down with water, which prevents these buildings from floating away or sustaining structural damage. Once the floodwaters recede, the building would return to its former position. Thus, the ability of structures to sit atop floodwaters and function cohesively makes this concept a workable solution for flood mitigation in at-risk communities.

In fact, the following rationale considers the increasing need to build such resilience in the light of the widespread impacts of climate change globally within communities susceptible to flooding on all coasts: Human endeavors, particularly those involving greenhouse gas emissions, have warmed the planet; to this, glacier melting, ice sheet discharges, and ocean expansion contribute significantly.

Indeed, according to the Intergovernmental Panel on Climate change, there has been an increase of 1.5 degrees Fahrenheit in temperature over the past hundred years; this has numerous serious implications for the coasts worldwide. Unsurprisingly, climate-driven changes pose a heightened threat for the Indian coastal cities, which hold large sections of its population. Research on the sea-level rise and greenhouse gas emission shows frightening trends, where a huge part of the Indian coastline may suffer extreme flooding within this century.

Therefore, as shown in the Fig 1, states like Kerela may fall into cyclone prone areas with the extension of this flooding cycle in places like Kuttanad due to climate change. For instance, the building infrastructure must be resilient enough to respond to such dynamics. In this context, amphibious architecture remains one feasible sustainable solution to mitigate flood risks in areas below the mean sea level. This research examines the potentials of using amphibious architecture to deal with this emerging situation.

The aim of this research is to investigate amphibious architecture as a sustainably adaptable resilient solution to recurrent floods in below sea-level settings in order to improve the quality of life of the inhabitants in Kuttanad, Kerala. Its objectives are as follows

1. To assess the effects of repeated flooding within Kuttanad, Kerala, and assess infrastructure resilience.
2. To investigate the viability of amphibious architecture as a flood-resistive design in flood-prone regions.
3. To discuss with architects about the potential case studies, including India's first floating house in Changanassery, to gain insights
4. To develop design guidelines for amphibious structures suited to unique environmental challenges in Kuttanad.
5. To ascertain the potential contribution of amphibious architecture toward enhanced living conditions and the safety of communities within flood-prone areas.
6. To recommend Amphibious architecture incorporation into the development plan as sustainable resilient infrastructure in Kerala.

Theoretical Framework

This research is grounded in the concepts of resilient infrastructure, climatic calamities, and amphibious buildings, which together frame the architectural response to flooding in Kuttanads, India.

Resilient infrastructure refers to systems designed to anticipate, absorb, and recover from climate-related disturbances. The UNDRR (2017) defines it as an infrastructure that adapts to changing conditions and recovers rapidly from disruptions. In architectural terms, Ahern (2011) expands this to include flexibility, multifunctionality, and the capacity to transform after disturbances, making built environments adaptive rather than merely robust.

Climatic calamities are extreme weather events intensified by climate change, including floods, cyclones, and rising sea levels. The IPCC (2022) highlights that low-lying regions like Kuttanads are increasingly vulnerable. Olshansky et al. (2012) stress the need for anticipatory design strategies, arguing that resilient architecture must move from reactive to proactive approaches. Sibley and Jackson (2012) suggest that vernacular wisdom, when reinterpreted through modern resilience thinking, offers valuable adaptive potential.

Amphibious buildings are structures that rest on land during the dry seasons and float during the floods, using buoyant foundations. English (2009) describes them as a hybrid solution that allows vertical mobility without relocation. They integrate flexible utilities and passive flood response systems, offering a sustainable, place-retentive adaptation for flood-prone communities (English, 2016). Nguyen et al. (2011) further affirm that amphibious housing provides a viable alternative to permanent elevation or relocation in deltaic regions.

In summary, the convergence of resilient infrastructure, climatic risk, and amphibious strategies informs a new vernacular architecture—one that embraces water as a dynamic context rather than an adversary.

Review of Literature

The rising frequency and intensity of floods, particularly in lowlands like Kuttanad, Kerala, demand innovative and sustainable architectural designs. Several researchers and practitioners have tested the viability of amphibious architecture as a solution for resilience in flood-prone areas. This section critically examines leading literature towards the purpose of the present study to include amphibious design within the traditional building culture of Kerala.

Elizabeth English (2009) is a leading commentator in amphibious design. Her work with the Buoyant Foundation Project in post-Katrina Louisiana demonstrates the way houses could be retrofitted with buoyant foundations that allow them to float with floodwater without structurally un-anchoring. English (2016) emphasizes that amphibious retrofits offer a cost-effective and culturally suitable alternative to permanent elevation or relocation, particularly beneficial in rural communities in Kuttanad.

Nguyen, Shaw, and Takeuchi (2011) examine community-based adaptations in the Mekong Delta region in Vietnam, focusing on conventional floating and amphibious housing. They illustrate how vernacular building systems that utilize local materials and skills can be modified to withstand seasonal flooding. This supports the idea that indigenous knowledge in Kuttanad can be integrated with modern amphibious technologies for more context-sensitive designs.

Patel, Kumar, and Tripathi (2020) examine floating and amphibious houses in Bihar and Assam in India, regions that face similar flood issues as Kerala. They point out that centralised flood control mechanisms are often inadequate and argue for decentralized, adaptive housing strategies, suggesting that amphibious structures could offer a scalable and sustainable alternative. Similarly, Sarda (2017) examines the resilience of the coastal cities of India, concluding that existing urban planning approaches are insufficient to tackle long-term climate challenges. In fact, she calls for integrating Nature-based and adaptive infrastructure solutions indirectly supporting the introduction of amphibious architecture into mainstream development.

In contrast, Jain and Jaiswal (2018) analyze flood management failures in Indian states and recommended design interventions that are proactive rather than reactive. Their critique of rigid infrastructure systems makes a case for flexible, amphibious housing solutions in flood-prone rural contexts like Kuttanad. Adding to this, Sibley and Jackson (2012) argue that vernacular architecture, when merged with modern technologies, can result in hybrid forms of resilient design. This reinforces the core goal of this study: to devlop traditional houses of Kerala into a flood-resilient vernacular through amphibious adaptation.

Finally, there is also a real-world implementation of a case in India. Its first amphibious house in Changanassery provides local validation of the feasibility of such technologies. Designed by Gopala Krishnan Acharya, the structure floats during the floods and returns to its original position once waters recede. The architect’s insights provide practical guidance on material selection, foundation systems, and community acceptance—factors critical to the scalability of amphibious housing in Kerala.

Together, these works form a strong foundation for rethinking architecture in flood-prone zones and support the integration of amphibious design into the development strategy of Kerala.

Research Methodology

This study employs mixed research methods to explore the effects of recurring floods in Kuttanad, Kerala, on people's lives, in order to create ways of producing amphibious architecture. It examines the adaptation of the residents to these circumstances, infrastructure adjustment, and how amphibious architecture could provide sustainable solutions. It also examines how technological advancements in architecture could potentially affect their resilience from the prevalent flooding that occurs two to three times a year.

Primary data collection was carried out by the author through qualitative interviews with people in flood-prone areas, living in architecturally advanced houses. This revealed the experiences of the residents, the damage to the houses and the infrastructure, and the mitigation measures implemented during the floods. Details of data collection carried out is as follows.

Data Collection Methods

1. Direct Observation: This consisted of on-site monitoring and observation of new government construction projects. An observation guide, structured with both open-ended and specific questions, was used in gathering responses from the informants as data sources relevant to the research. All the interviews and onsite observations have been carried out during May, 2022 for 10 days.
2. Literature Survey and Record Analysis: This is also known as a literature study, in which relevant data is gathered based on scientific resources-both published and unpublished. Data gathering sources included books on both physical and digital platforms, as well as journal articles.
3. Interviews: Personal interviews with informants were undertaken, including residents of Kuttanad and areas around the region, government officials who had experience in the response against flood situations, architects, and construction workers involved in designing new structures. Respondents were chosen by convenient sampling. It gave an opportunity for the researcher to interact directly with the respondents face to face, and extract information through direct and indirect questions.
4. A quantitative survey was carried out by the author with the officials in the government in order to gather data on flood impact and response strategies.
5. Case studies across the world have been studied which resemble similar conditions of Kuttanad.

The author interacted with the government officials during the interviews. Questions were asked from the government officials to obtain precise data regarding the local losses during the floods. The research also includes a living case study of the first floating house in India, which is located in Changanassery, Kerala. Its architect was interviewed in the process, with the view of gaining insight into critical design considerations for the amphibious houses. The resultant reviews have been used to inform the case studies and provide the grounding for a questionnaire on specific research questions and analysis. The mixed-method approach therefore offers comprehensive insights into the scope and potential of amphibious architecture in flood-prone settings.

Findings from Literature

Types of Water based Buildings: Terp Dwelling

A terp is a man-made mound of earth constructed to afford an elevated and safe ground during the floods. First terps were built about 500 B.C. in the Netherlands, where tidal disruptions in the nearby rivers affected everyday life. These mounds, which were often rising to 15 meters, were built to keep the residents dry and allow space for animals and food storage. Around 1000 A.D., the villagers have begun connecting these mounds with one another to form a dike system that would protect their fields from flooding. Terp houses still appear well above the ground to stay dry until the water is at its high point. Figure 2 shows an example of a terp dwelling from the Netherlands.

Fig. 02: Bridge House in Achterhoek, Netherlands
Source: Bridge House (online)

Fig. 03: Sandy Orchid Lodge Texas
Source:Sandy Orchid Lodge (online)

Static Dwelling:

One of the more general approaches to retrofitting against flooding is to elevate the house to the minimum BFE. If correctly elevated, only the largest floods would inundate the living space of the house. There are two major techniques for elevating one's house:

1. Elevating by constructing a new or extended foundation under it.
2. Leaving the structure of the house intact and creating within it an elevated floor or building a new second storey.

The Figure 3 shows an example of a static dwelling from Texas.

Pile Dwellings:

Pile dwellings are a structure standing on columns or piles of concrete, steel, or wood above the ground, usually seen at shallow waters and places that are easily affected by changing water levels. These are raised 8-15 feet off the ground. It protects the structure against flooding. In Indonesia and Singapore, "kelongs" are good examples for fishing. Figure 4 shows an example of a static dwelling around the Alps.

Fig. 04: Prehistoric Pile Dwelling around the Alps
Source: The prehistoric pile dwellings around the Alps (online)

Fig. 05: House Boats of Kerela
(Source:vAuthor)

Timber piles, having served for over 6,000 years, offer lightweight, renewable, and highly treatable and drive-able material. If underwater, they can last indefinitely; those above the waterline may last over a hundred years with proper maintenance. Concrete piles may be either precast or cast-in-place and offer durability without the prospect of rust or decay at a lower cost than steel. Steel piles take up numerous forms of cross-section and are much strong and adaptable. When submerged in water, they easily corrode and therefore are not as durable compared to concrete. Due to their strength and adaptability, steel is still commonly used.

Houseboats:

Houseboats came into being by the conversion of ships and fishing vessels into dwellings and therefore combined the concepts of land property with buoyant structures to support the pressure of water. Houseboats became part of American history in the early 1900s, with the first documented in Seattle in 1905, peaking at over 2,000 in the 1930s. During the 1940s, a shortage of housing in San Francisco saw laborers taking old fishing boats and decommissioned battleships and turning them into houses, many of which were moored in Sausalito Bay.

In India, houseboats are found in the backwaters: especially on Dal Lake in Srinagar and in Kerala. Figure 5 shows an example of Houseboats of Kerala in India, used for carrying grains and spices. They have now become vehicles for leisure cruises. These boats, usually 60-70 feet long, have been made from planks of wood tied with ropes and coconut fibers and covered with roofs of bamboo and palm leaves. Cashew nut oil has been used for protecting the boats. Modern day floating houses built by firms such as Waterstudio and Aquatecture of the Netherlands have gained tremendous popularity in the coastal regions around the world.

Amphibious Dwelling

Amphibious buildings utilize buoyancy in their foundation designs to mitigate the impacts of flooding. Some of them have attached mechanical systems creating buoyancy that may allow the structure to temporarily rise with floodwater and then smoothen out back to its original ground level as the water recedes.

Factor et al. (2018) define an amphibious building as one that will 'adapt' to a flood situation and float as water levels rise. English et al. (2009) define amphibious architecture as a flood mitigation strategy that allows an "otherwise-ordinary structure" to float on the surface of the rising floodwater levels. Moon (2015) defines an amphibious house as one that lies on the ground or on a structure above water but floats during a flood as water levels rise. Prosun (2011) defines an amphibious house as a structure with a buoyant foundation, constructed on solid ground with capabilities of floating up with rising water levels. Barker and Coutts (2016) define an amphibious house as a building that rests on the ground when conditions are dry but rises in its dock and floats during a flood.

Fig. 06: Amphibious Dwelling , Maasbommel Project
Source: Dura Vermeer (2020)

Examples of amphibious houses can be identified in the Netherlands; one example is the Maasbommel water dwellings along the Maas River as shown in the Figure 6. Amphibious architecture provides a flood mitigation strategy in concert with natural flood cycles of susceptible regions rather than attempting to stop it.

While there are a number of different means to deal with increased water levels, amphibious structures provide protection from flooding that is reliable and allows the community to resist calamities and get up and running much quicker rather than if their buildings were not resilient to flooding. Amphibious designs can let buildings "co-exist" with floods in sensitive environments. The floodwater lifts the structure, using its power for the benefit of the building averting any major damage. Instead of building barriers to block the water, these methods absorb floodwater while protecting the building. The experimentation with the amphibious house is common in many parts of the world where flooding occurs regularly, but not in India.

For amphibious buildings, the usage of material and construction methods lags far behind between developed and developing nations. The concept of design covers construction, land-use planning, selection of a site, policymaking, and resilience at community levels. Consideration is taken for the infrastructure needs such as the mechanical systems and utilities, system components, and the codes and certifications that are required for amphibious structures. These factors make amphibious architecture an essential tool for enhancing resilience in flood-prone areas.

Designing an amphibious dwelling is based on few main parameters that are essential to guarantee the safety, functionality, and resilience of the dwelling.

- **Capability of Floating:** The house must have the ability to float reliably during flooding events without compromising structural integrity.
- **Foundation:** The foundation must be designed to support the structure both on land and while floating, with buoyant properties that activate during rising water levels.
- **Floating Line:** This is the height at which the dwelling starts to float in relation to the level of the water.
- **Buoyant Foundation Height:** It must be buoyant enough to provide the height needed for the structure to remain well above the ground in case of a flood.
- **Structure Type:** The choice of materials and design should be suitable for both land-based living and aquatic conditions.
- **Road and Parking Conditions:** Access to roads and parking facilities should remain functional during flooding, considering the need for alternative transportation.
- **Utility Access:** Utilities such as water, electricity, and sewage systems must be able to function while the house is floating, ideally connected to municipal systems.
- **Fire Safety:** Fire safety measures must account for both land and floating scenarios.
- **Water Maintenance:** Proper drainage and water maintenance systems are needed to ensure that the structure remains stable and safe during and after flooding.

Types of Floating Foundations:

- **Expanded Polystyrene Filled with Concrete** (EPS): This type of foundation consists of an EPS foam core wrapped in concrete. It is very buoyant and unsinkable; therefore, this has a minimal draft, and it is well suited for shallower water conditions.
- **Concrete Hull**: A concrete hull foundation consists of hollow, reinforced concrete boxes. The internal airspace provides buoyancy, supporting both the structure and the concrete itself. Concrete’s resistance to corrosion and minimal condensation make this a durable option for long-term use in aquatic environments.
- **Pneumatic Stabilization Platform**: This type of foundation is composed of multiple cylinders made from materials like steel, concrete, or plastic. The buoyancy is provided by air trapped in the cylinders, with water on the bottom side and a deck on the top. This design allows for stability and adaptability in varying water conditions.
- **Plastic Bottles**: This eco-friendly foundation uses common 2-liter plastic bottles, which are inexpensive, resistant to saltwater, and widely available. The bottles are connected into hexagonal grids, stacked, and laminated to create a buoyant platform. A solid surface is then applied on top of the bottle-based flotation system to support the structure.

Each of these floating foundation types offers unique benefits, depending on the environment and design needs of the amphibious dwelling.

Case Studies

Introduction to Case Studies

This research presents three case studies as follows.

1. VSK Model House in Kuttand, India: This house has been studied directly with on-site research activities generating data.
2. Massbommel Amphibious Housing, Netherlands: This house has been studied indirectly with research activities generating data based on internet searches.
3. Water Dwelling, Ijburg in Netherlands: This house has been studied indirectly with research activities generating data based on internet searches.
4. The Float House in New Orleans, USA): This house has been studied indirectly with research activities generating data based on internet searches.

Case Study Area: Kuttanad

Kuttanad is a region in the state of Kerala, India. It lies below the sea level and often faces serious flooding. Kerala, despite having a high Physical Quality of Life Index, good governance, social equity, and spiritual harmony, was struck by one of the most disastrous floods in August 2018. Figure 07 and 08 shows a comparison between the satellite images of Kerela of before the floods and after the floods. The flood, considered as the worst in nearly a century, transformed the face of the landscape into scars and caused devastation to biodiversity, infrastructure, and livelihoods in an unparalleled manner. Over 483 lives were lost, while incalculable losses were reported to livestock, houses, roads, and bridges. The agriculture losses considerably affected the livelihood of the farmers. The tourism sector, which is one of the major contributors to the economy of the state, was also severely affected. The total estimated loss was about Rs 40,000 crore. The floods attracted international attention when United Nations, Asian Development Bank and the World Bank showed its response.

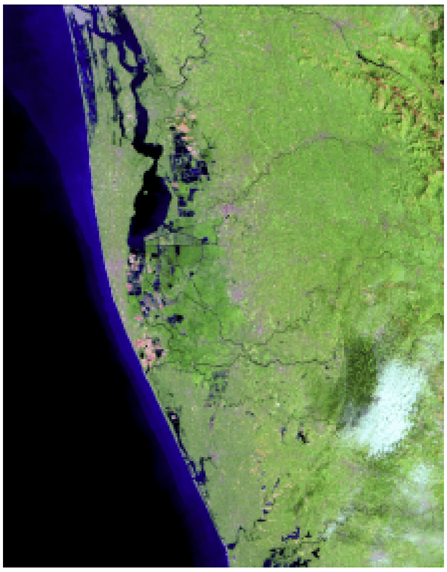


Fig. 07: Satellite image of Kerela February 6, 2018, Source: NASA

Fig. 08: Satellite image of Kerela August 22, 2018, Source: NASA

Findings from the Case Studies

According to on-site research, recovery from this calamity is believed to take a number of years, with the after-effects of the flood likely to impact the state for 5 to 10 years. The calamity brought out the vulnerability of Kerala in terms of natural hazards such as floods, droughts, landslides, coastal erosion, and lightning-all worsened due to climate change. Due to the geographical variations in Kerala, the state commonly faces all these natural threats, especially in the areas with reclaimed land below the sea level, such as Kuttanad, and the regions with steep slopes in the Western Ghats, which are prone to landslides. Apart from that, coastal erosion, slight earthquakes, and lightning strikes also contribute to the complication of the environmental problems in the region. In fact, this flood has really brought to the forefront the requirement for Kerala to rethink its development strategy and implement long-term disaster management measures. A survey conducted on the inhabitants in Kuttanad revealed that a majority thought that the lack of proper implementation of technology is one of the reasons for the aggravation of flood destruction.

Fig. 09: Damage during Kerela floods, 2018
Source: Kerela Disaster Management

Fig. 10: Damage during Kerela floods, 2018
Source: Kerela Disaster Management

While Kuttanad is well-recognized for its houseboats and floating structures, few residents are aware of amphibious architecture as a possible solution. Amphibious architecture lets the structures float during floods and relapses into their earlier positions once the water level goes down. Many residents of Kuttanad were found receptive to this concept after explanation and said they would like to use the technology due to its potential to minimize the damage caused by the floods. However, the high cost of such building structures is another serious hindrance in their widespread adoption. Despite that fact, the study "highlights amphibious architecture as one viable flood-resistant solution for the region. However, it would need more investment and technological support to make it possible to broaden its reach in the general population".

Case Study 1: VSK Model House:

The flood-prone state of Kerala has received a new solution to the issue of floods from the Gopala Krishnan VSK Model House in Chanaganessery, Vazhappally. The unassuming house at an area of 1,600 square feet floats on the waters when floods hit Kerala. Mr Gopala Krishnan himself has built this house, which is unconventional. In fact, he has made sure that stones, bricks, and cement into the construction, primarily adhering to the environmental recommendations of the Gadgil report. Figure 11 shows the floating house. His design is a result of the need for a flood-resistant design after the massive flooding experienced; hence, the house rises with the water and has the least environmental impact.

Fig. 11: VSK Modal Floating House
Source: Vastushilpi Kannan

This floating house is capable of rising several feet with water. This, it does with air tanks embedded in the foundation to raise the house as water increases pressure on the tanks. Interestingly, the house weighing approximately 6 tons floats easily. According to Gopala Krishnan, construction cost is around 30% less when compared to conventional cement-based houses and can be built within a total budget range between Rs 15-20 lakhs.

The house has been built with durable materials. Thus, it can be considered as an eco-friendly and flood-resistant house. The house in has all the modern amenities, including three bedrooms, a kitchen, and toilets attached to each of the bedrooms with space on the terrace for further expansions. Interestingly, Gopala Krishnan has registered a patent for floating house technology. Moreover, he has put into place houses that are resistant to earthquakes and strong coastal waves. In front of his house, there is a model of the house with reduced dimensions as a show-house Any visitor can see for themselves the innovative technology.

Findings from the VSK Modal House

This case study explained a new technique that was used to make a floating house flood-proof. It consisted of four pistons made of steel buried 25 feet underground at each corner of the house. These were concealed and could be both seen outside as well as inside the house to give the building the structural support without touching the hard ground. The pistons work with an air tank such that the house rises with a flood. As and when the water rises, so does the house with the air tank; when the water goes down, the house retreats to its old position. Figure 12 shows the conceptual section of the house. According to Acharya, the model will manage to keep the house stable and unmoving at the time of flooding, without lateral shifting.

As depicted in schematic section in figure 13, the pistons are adjustable and extend up to 15 feet above ground, which is the desired height for the house to move securely up to 10 feet. To extend the height of the pistons, their strength and length must be increased in proportion. Dirt, pebbles, tiles, cement, and wood are some of the traditional materials that are not used in this construction. Instead, it is mainly GI pipes in structure, while multi-wood sheets make up the walls, with a gap of 1.5-inch between them for cooling. The basement is also covered with multi-wood sheets, making the air tank not very prominent. The mini house itself is made from aluminum sheets, while the roofing material is flexible and one is left to one's choice.

Such a flood-resistant house may cost around Rs 1,600 per sq.ft if high-quality GI pipes are used. The building activity related to a 1,300-sft house required four months for completion with a small group of specialized workers. Four welders along with a few carpenters were required continuously for welding, carpentry, wiring, and plumbing works. Figure 14 shows all the materials used and mechanism of the house. Acharya points out that it can adopt all types of soils, ranging from loose sand to hard rock, and hence is particularly suited to low-lying areas like Kuttanad where both waterlogging and flooding prevail. The model house, called the "extra height home," has its housing elevated on multiple pistons to bear upwards. This would serve to enhance resilience in flood-prone regions.

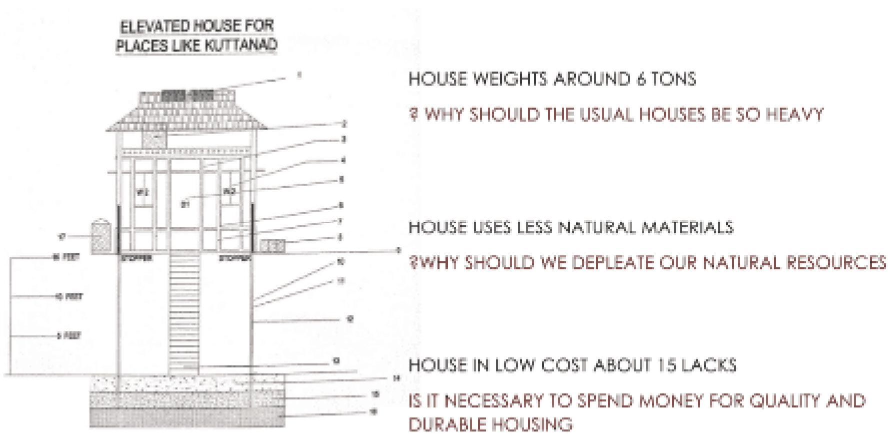
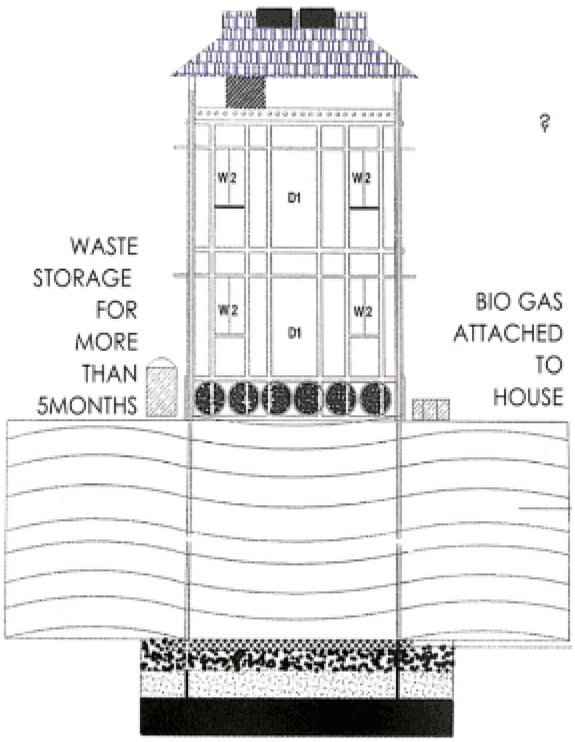


Fig. 12: Conceptual Section (Source: Vastushilpi Kanan)



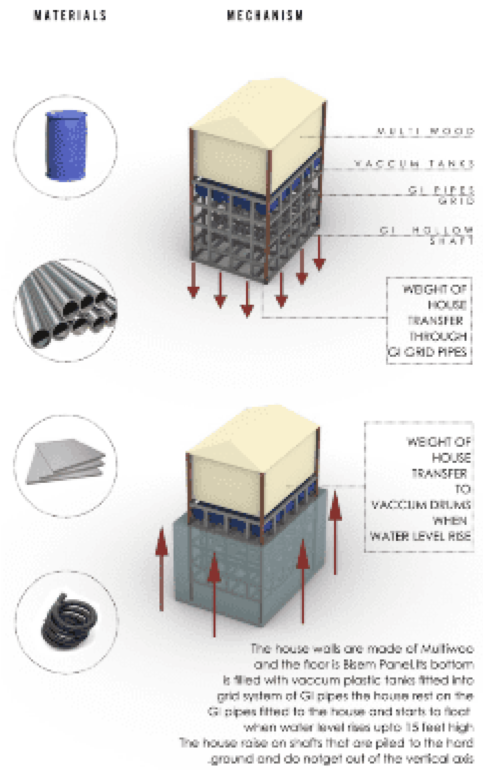


Fig. 13: Schematic Section
Source: Vastushilpi Kanan

Fig. 14: Materials & Mechanism
Source: Vastushilpi Kanan

Features:

1. Complete security from flood and rainstorm.
2. Construction cost of these houses/building will be less than that of concrete houses/building.
3. It is possible to complete the construction by less than half the time for constructing concrete houses/building.
4. Weigh less than that of concrete houses/building.
5. It has more life than that of concrete houses/building.
6. Width of the wall will be approximately 5 1/2 inches.
7. Similar to concrete houses/building these houses/ building is also resistant to wind and earthquakes.
8. These houses do not require materials such as rocks, soil, sand, blocks/bricks, cement, wood etc. Hence ensures environmental protection.
9. Even if the soil below the house gets fully eroded, it does not go down or get slanted.

10. As the flood water rises the house/building lifts up and rises to the surface of water.
11. When the flood recedes, the house/building comes down and fixes at the original position. (maximum 2 inches difference)
12. No matter how long the house/building is at the water surface, no damage will occur.
13. These types of houses/buildings can be made in any model and in any area (sqft).
14. These houses/buildings can also be constructed on seashores with specific changes.
15. It can reduce future damages and relief cost.
16. These houses/buildings can be built in any type of land as a low budget house/building.
17. The interior of this house/building is relatively less warmer compared to ordinary houses/buildings.
18. Toilet can be used during flood as the septic tank also rises with the house/building.
19. Normal life is possible during the flood by the installation of water tank, R.O System and solar panel on the terrace. It ensures the availability of pure water and electricity everyday & even during flood.
20. Any luxury facilities like tile, cupboard, gypsum, Air Conditioner etc. can be used

Case Study 2: The Massbommel Amphibious Project

The Massbommel Amphibious Housing Project as shown in Fig 15, located along the Meuse River in the Netherlands, is a pioneering example of amphibious architecture applied in flood-prone rural settings. Initiated in 2005, the project was developed in response to the vulnerability of the village of Massbommel, which lies outside the country's main dyke-protected areas (Koen, 2009). In a government-supported initiative, 34 amphibious houses and 14 floating homes were constructed based on designs by Factor Architecten and executed by the builder Dura Vermeer.

Fig. 15: Maasbommel Project
Source: https://www.factorarchitecten.nl/project/drijvende-woningen-maasbommel/

Each house is built on a watertight concrete hull weighing approximately 70 tons. These hulls serve as the buoyant foundation of the houses and are tethered by six deep-set mooring poles shown in Fig 16. As shown in Fig 17, during normal conditions, the houses rest securely on solid ground. However, when floodwaters rise as shown in Fig 18, the foundations allow the homes to float upward along the vertical mooring poles, which prevent any lateral movement or drift (Rijcken, 2013). The houses are linked to one another to reduce the structural stress caused by wave motion or strong currents.

Architecturally, the houses preserve traditional Dutch characteristics, complete with gardens, access roads, and parking spaces. Under flood conditions, the amphibious system activates automatically. Utility connections such as water, electricity, central heating, and sewage are managed via flexible connections that adapt as the house rises, ensuring uninterrupted services (Koolhaas et al., 2011). The major structural components were prefabricated, and roofing was executed on-site using a combination of steel, wood, and PVC cladding.

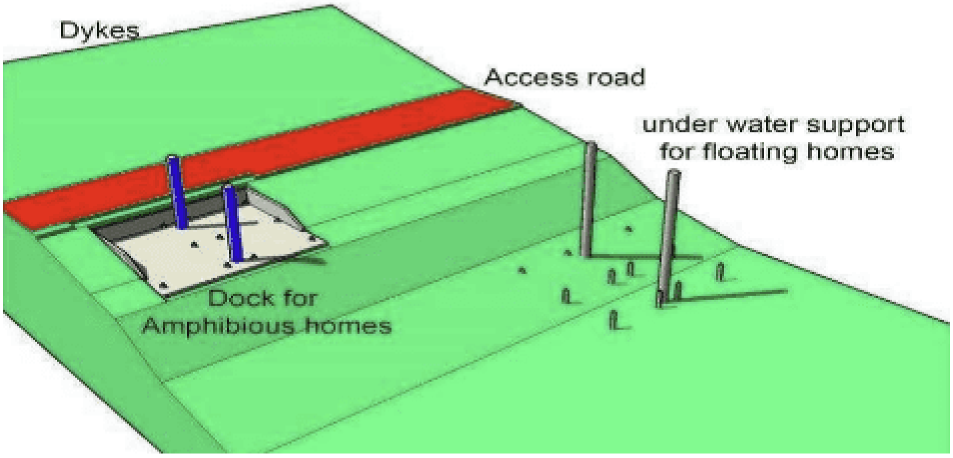


Fig. 16: Amphibious Structure dock and mooring pole
Source: https://www.factorarchitecten.nl/project/drijvende-woningen-maasbommel/

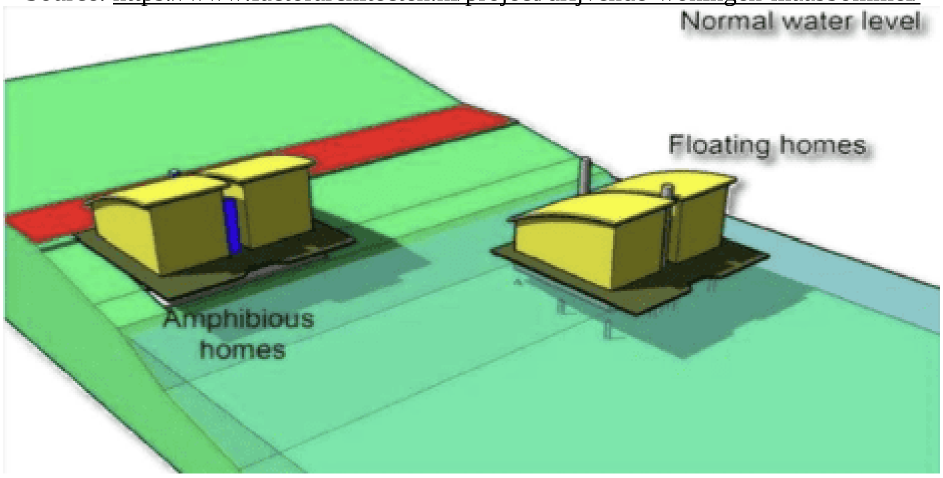


Fig. 17: Amphibious homes during normal water level
Source: https://www.factorarchitecten.nl/project/drijvende-woningen-maasbommel/

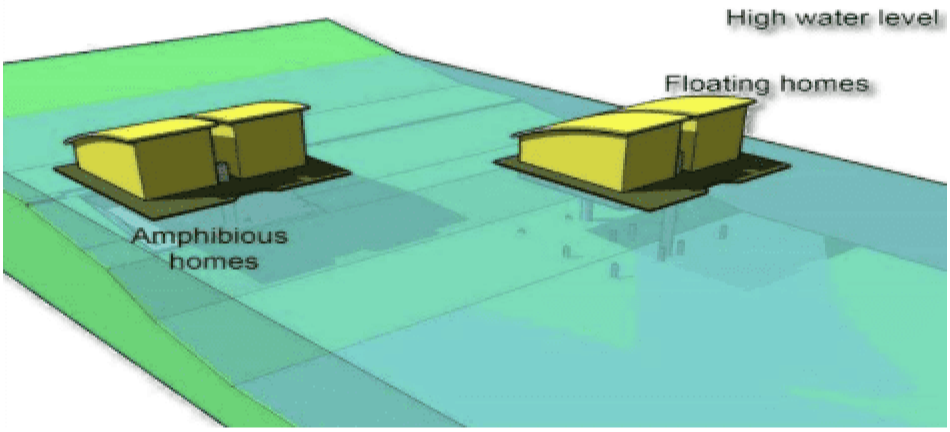


Fig. 18: Amphibious homes during flood conditions
Source: https://www.factorarchitecten.nl/project/drijvende-woningen-maasbommel/

Findings from Massbommel Amphibious Project

Amphibious houses in Massbommel have already been tested for some flood events, including that of 2011 when the water rose to over 7 meters.

The residents had received prior notification and had shifted their vehicles from the parking site. When the water reached its peak, the houses successfully floated; residents were able to reach them by boats. When the flood waters receded, the houses moved smoothly back into their original position without any structural damage or damage to the docking systems.

The Massbommel Project shows how amphibious architecture can be an effective solution for flood-prone regions. Since 2005, the floating and amphibious houses function very well, needing only slight maintenance. For this reason, these homes present a prospect for integrating amphibious architecture into urban and rural planning that can be one of the sustainable ways of living harmoniously with water.

A review of the amphibious architecture in the Netherlands provides valuable insight into how similar flooding problems elsewhere in regions like Kuttanad have been tackled. Its implementation in India could, thus, be the effective and practical long-term measure toward flood resilience by assuring the safety of a community while keeping it functional against rising waters.

Case Study 3: Water Dwelling, Ijburg (Netherlands):

Perhaps the most prominent example of contemporary amphibious buildings in flood-prone city centers is the Ijburg residential complex between Zeeburger Island and Haven Island on the IJ Lake in Amsterdam, Holland as shown in Figure 19 and 20. Constructed beginning in 2001, Ijburg is a series of water homes that contain over 15,500 residents. The first island in the chain, Steigereiland, incorporates two distinct neighborhoods comprising prefabricated floating houses and dwellings built on platforms (de Graaf & van Buuren, 2010).

These houses were manufactured over 30 miles from the site, with structural components such as floors and walls being cast simultaneously in concrete to ensure a smooth, water-tight base. Wall thicknesses were carefully calibrated to accommodate the combined weight of the furniture and inhabitants. Once assembled and secured to the floating foundations, the dwellings were transported and positioned at the site. This prefabrication approach enhanced construction precision and provided resilience against fluctuating water levels. As a result, Ijburg has become a model for sustainable, amphibious urban housing in the face of climate-induced flood risks (de Graaf & van Buuren, 2010).

Fig. 19: Water Dwellings Ijburg
Source: archdaily

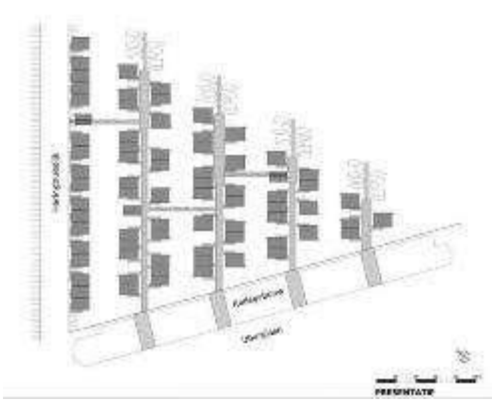


Fig. 20: Overall Plan, Water Dwellings Ijburg
Source: archdaily

Case Study 4: The Float House, New Orleans (USA)

New Orleans Float House is a prefabricated, inexpensive house type for the flood areas. Figure 21 shows the float house of New Orleans. This house has been designed by the students and faculty at University of California, Los Angelos with the architects from Maynes and Morphosis. It follows the traditional shotgun style houses in New Orleans. The house has been built on a foundation of expanded polystyrene foam sprayed with glass fiber-reinforced concrete, incorporating a front porch that allows easy accessibility for elderly and disabled individuals, maintaining the cultural charm of the town. A 4-foot foundation also houses the electrical and plumbing systems; the house is able to float during floods as shown in Figure 22. It is one of the major steps toward affordable resilient housing in the most vulnerable communities (Morphosis Architects, 2009).

Fig. 21: The Float House, New Orleans (Source: archdaily)

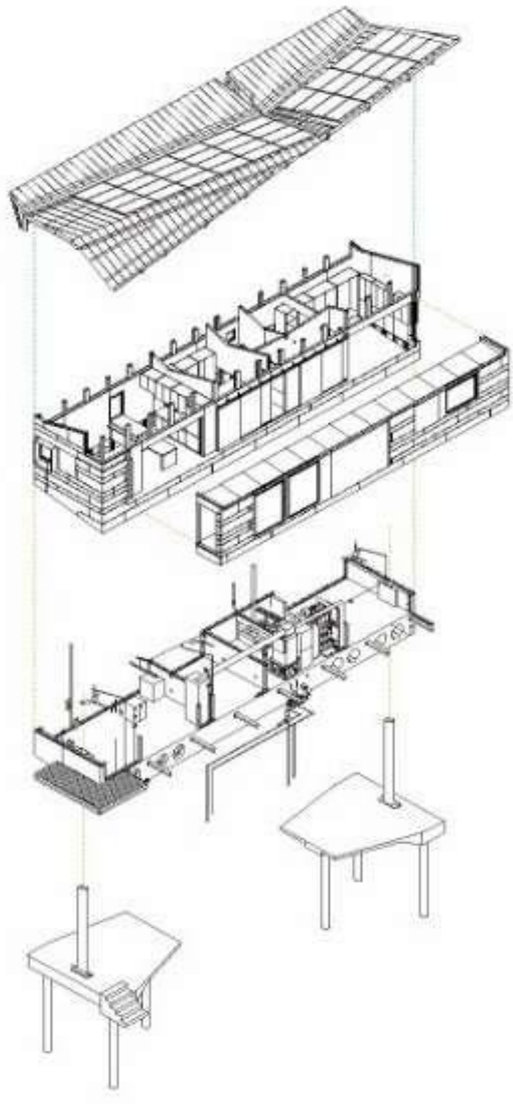


Fig. 22: The Float House, New Orleans
Source: archdaily

Analysis and Discussion

The 2018 Kerala floods have been the worst ever recorded in the history of the region (Government of Kerala, 2018). The calamity has come with severe impacts on human life and infrastructure. Between August 7th and 20th, the floods have killed 504 people and have directly affected 23 million others (NDMA, 2018). Economic losses have been estimated at $2.85 billion, hence the third costliest flood in India (EM-DAT, 2019). Further, more than 110,000 houses have been damaged or destroyed, while over 60,000 hectares of agricultural land has been affected, and considerable livestock has been lost (UNDP India, 2018). Flooding has damaged over 130 bridges and a combined total of 83,000 km of roads, leaving many communities isolated (Kerala State Disaster Management Authority, 2018).

Satellite images on the 21st of August 2018 indicate a 90% increase in water cover in the areas affected by the flooding. In many places, such as Kuttanad and the Kole lands of Thrissur, water has reached up to 5 to 10 meters high (ISRO, 2018). The discharge of floodwater in Kuttanad has been obstructed due to heavy rainfall, the opening of shutters from upstream dams, and high tidal action in the Arabian Sea (Iyer et al., 2019). Field observations indicate that the embankment breakages around Vembanad Lake further worsens the flooding with the inflow of lake water into paddy fields and residential areas (Thomas and Varghese, 2020).

A significant factor here is the sudden release from dams across the state. Changes in land-use patterns, such as deforestation and encroachment in catchment areas, over the past two to three decades have given a greater dimension to the scale of this disaster (Roxy et al., 2019). Landslides, silt deposition, and soil erosion has further reduced the effective storage capacities of the dams, increasing the magnitude of the flood. These findings point out the immediate need for better flood management and land-use practices in the region (Nair et al., 2020).

Impact of floods

The state of Kerala stands second only to Tamil Nadu in terms of urban development with an urbanization rate of 47%. As far as the quality of its housing is concerned, Kerala boasts of a very good stock of buildings: 83.5% of them are pucca, 12.7% semi-pucca, and only 2.6% kutcha. As many as 66% of its dwellings were rated as excellent, 28% rated as habitable, and only 5% rated as deteriorating. Moreover, 94% have electricity in their houses, and 95% have latrines, out of which 93% from rural households have latrines on their premises. The main sources of water are wells, at 62%, and tap water, at 30%. Kerala has quite a low poverty rate, with less than 12% of the population living below the poverty line. On the other hand, human settlements experienced high destruction during the 2018 Kerala Monsoon Floods in both the urban and rural settings. (Census of India, 2011).

As depicted in Table 1, about 22,132 houses have been completely destroyed while 104,636 have been partially damaged. The kutcha houses, being fragile in nature, accounted for 30% of the severely and 20% of the marginally damaged ones. The destruction has been witnessed at a range from tribal hamlets, riverside villages, to peri-urban areas. Consequently, the elderly, disabled, female-headed households, and ST/SCs have been especially constrained in reconstructing houses (Government of Kerala, 2018).

Table 1: Housing damages
Source: Kerela Disaster Management

District	Fully damaged			Partially damaged			Total
	Kutcha	*Pucca*	*Total (A)*	*Kutcha*	*Pucca*	*Total (B)*	(A+B)
	Units	Units	Units	Units	Units	Units	Units
Alappuzha	2,830	2,056	4886	4,519	17,517	22,036	26,922
Ernakulam	6	3,619	3625	8	23,110	23,118	26,743
Idukki	632	1,716	2348	1,437	3,920	5,357	7,705
Kannur	0	11	11	113	397	510	521
Kasaragod	0	0	0	0	26	26	26
Kollam	49	7	56	414	80	494	550
Kottayam	95	946	1031	1,737	9,582	11,319	12,360
Kozhikode	118	237	355	1,126	4,726	5,852	6,207
Malappuram	784	296	1080	2,824	2,734	5,558	6,638
Palakkad	539	231	770	2,265	971	3,235	4,005
Pathanamthitta	463	669	1132	2,052	9,233	11,285	12,417
Thiruvananthapuram	16	73	89	107	546	653	742
Thrissur	916	4,412	5328	2,184	10,561	12,745	18,073
Wayanad	514	897	1411	1,494	3,606	5,100	6,511
Sub-total	**6,962**	**15,170**	**22,132**	**20,280**	**87,009**	**107,288**	**129,420**

Table 2 Cost for Repair of partially damaged and Reconstruction of the Fully Damaged Houses
Source: Kerela Disaster Management

District	Fully Damaged		Partially Damaged		Total		
	Number of units	INR million	Number of units	INR million	Number of units	INR million	USD million
Alappuzha	4,886	2,201	22,036	2,183	26,922	4,384	62.63
Ernakulam	3,625	1,884	23,118	2,404	26,743	4,288	61.26
Idukki	2,348	1,145	5,357	523	7,705	1,668	23.83
Kannur	11	6	510	50	521	56	0.8
Kasaragod	0	0	26	3	26	3	0.04
Kollam	56	23	494	41	550	65	0.92
Kottayam	1,041	530	11,319	1,135	12,360	1,665	23.79
Kozhikode	355	170	5,852	582	6,207	752	10.74
Malappuram	1,080	468	5,558	510	6,638	978	13.97
Palakkad	770	336	3,235	282	4,005	618	8.83
Pathanamthitta	1,132	533	11,285	1,124	12,417	1,657	23.68
Thiruvananthapuram	89	44	653	65	742	110	1.57
Thrissur	5,328	2,661	12,745	1,273	18,073	3,934	56.2
Wayanad	1,411	672	5,100	495	6,511	1,167	16.67
Total	**22,132**	**10,673.20**	**107,288**	**10,671.24**	**129,420**	**21,344.44**	**304.92**

Table 3: Relocation - Total cost of basic services, land required for relocation, cost of land acquisition, and transition shelters arrangements
Source: Kerela Disaster Management

District	Cost of Basic Services	Area of land required	Cost of land acquisition	Cost of transition shelters	Total Cost of Land for Relocation	
	INR million	Acre	INR million	INR million	INR million	USD million
Alappuzha	166.03	30.2	755.08	49.15	970.25	13.9
Ernakulam	113.13	17.39	434.76	28.3	576.19	8.2
Idukki	76.29	12.77	319.24	20.78	416.31	5.9
Kannur	0.34	0.05	1.32	0.09	1.75	0
Kasaragod	-	-	-	-	-	0
Kollam	1.98	0.39	9.65	0.63	12.26	0.2
Kottayam	32.94	5.22	130.44	8.49	171.87	2.5
Kozhikode	11.64	1.98	49.61	3.23	64.48	0.9
Malappuram	37.46	7.06	176.4	11.48	225.34	3.2
Palakkad	26.61	4.98	124.57	8.11	159.29	2.3
Pathanamthitta	37.54	6.54	163.39	10.64	211.57	3
Thiruvananthapuram	2.85	0.46	11.62	0.76	15.23	0.2
Thrissur	170.63	27.73	693.36	45.13	909.12	13
Wayanad	46.49	8	199.88	13.01	259.38	3.7
Total	**723.94**	**122.77**	**3,069.32**	**199.78**	**3,993.04**	**57.0**

Table 4: Total Cost of Reconstruction of Houses
Source: Kerela Disaster Management

District	Reconstruction and Repair Cost	Relocation Cost	Total Cost	
	INR million	INR million	INR million	USD million
Alappuzha	4,384.41	970.25	5,354.66	76.5
Ernakulam	4,288.36	576.19	4,864.55	69.49
Idukki	1,667.76	416.31	2,084.07	29.77
Kannur	56.05	1.75	57.8	0.83
Kasaragod	2.7	0	2.7	0.04
Kollam	64.68	12.26	76.94	1.1
Kottayam	1,665.41	171.87	1,837.27	26.25
Kozhikode	752.02	64.48	816.51	11.66
Malappuram	977.78	225.34	1,203.11	17.19
Palakkad	617.81	159.29	777.1	11.1
Pathanamthitta	1,657.47	211.57	1,869.04	26.7
Thiruvananthapuram	109.7	15.23	124.94	1.78
Thrissur	3,933.70	909.12	4,842.83	69.18
Wayanad	1,166.58	259.38	1,425.97	20.37
Total	**21,344.44**	**3,993.04**	**25,337.48**	**361.96**

Even structural damages have occurred in buildings with structured foundations, such as RC-framed structures with cement-mortared masonry. As depicted in the table, extensive collateral damage has been caused to many structural components, including electrical systems, plumbing, flooring, doors, windows and compound walls. The total estimated damage and loss is Rs. 26,718 crores, as depicted in table 2,3 and 4 while the recovery needed is estimated at Rs 31,000 crores. Infrastructure sectors affected included transportation, water and sanitation, electricity, and irrigation. However, notably, the long-term economic loss has been huge: as nearly as 2.6% of the GSDP of Kerala has been lost owing to flood-related damage, accompanied by wage and livelihood losses.

Conclusion

The emerging evidence of rising sea levels coupled with catastrophic events of 2018 such as recurrent floods in Kuttanad demands a different kind of resilient infrastructure that are rooted in local traditions of India. With the loss of over 483 human lives, extensive loss of infrastructure, agricultural crops, and houses, and estimated losses of over ₹40,000 crore, the floods have irreversibly transformed the geography and exposed the inadequacies of the conventional methods of flood mitigation. In this context, this paper explored Amphibious architecture as a sustainable and adaptive solution to address the peculiar environment of Kuttanad, which lies below sea level. Its intention was to offer ways to mitigate the impacts of flooding and thus improve the quality of life of its residents.

The paper demonstrated that amphibious constructions rely on vernacular architecture design principles in offering effective alternative options to conventional flood defenses through locally sourced materials, community-led designs, and flexibility within a natural environment. The study recommends adopting locally available, sustainable materials; designing buoyant foundations with vertical guidance posts; and ensuring infrastructure flexibility to adapt to water levels. It emphasizes involving local communities and vernacular knowledge in the design process and integrating amphibious solutions into Kerala's long-term coastal resilience plans.

The research met its objectives by assessing the severe impact of floods in Kuttanad through surveys and interviews, revealing inadequate flood management and prolonged recovery. Case studies and expert consultations confirmed that amphibious designs are technically and economically feasible. The research examined the case study of India's first floating house in Changanassery and continued with similar examples from across the world—from the Netherlands and USA. These proved the viability of amphibious architecture over traditional elevation-based flood defenses. Insights from the VSK Model House provided practical architectural references. The paper argues that the VSK Model House in Kuttanad represents the best model wherein the low-cost, sustainable, and locally sourced materials provide all resilience against floods with the least dependence on state support. Based on these, context-specific design guidelines were developed, considering local hydrology, culture, and economic factors. Amphibious housing was shown to offer safety, reduce reliance on aid, and support community continuity.

Embracing amphibious architecture which honors the resilience embedded in vernacular architecture can transform India's approach to water-based living, fostering a shift from seeing rising waters as threats to adapting to these changes with resilience and confidence. Adding such amphibious designs into development plans allows for sustainable living that adapts easily with floods and solidifies the stability of the community. Amphibious architecture is creating an attainable solution for adaptive and sustainable quarters within a country like India, facing unforeseeable increase in climatic uncertainty in the future. This design can redefine our relationship with water and assembles an existent resilient future in harmony with the rhythms of nature.

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