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Integrated Flood Hazard Assessment Using AHP-GIS in the Pallikaranai Marshland, Buckingham Canal Corridor, India

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ABSTRACT

The resultant impact of climate change and urbanization has caused extensive disruption to natural hydrological processes, thus enhancing the flood risk in susceptible areas. This study evaluated flood processes in the Pallikaranai Marshland–Buckingham Canal corridor using detailed flood inundation modeling and risk assessment methodology. Important geospatial factors and variables, such as rainfall, Digital Elevation Model (DEM), slope, Land Use Land Cover (LULC), river distance, flow length, and Normalized Difference Water Index (NDWI), were weighed and ranked. These weighted parameters were assimilated to estimate the Flood Hazard Index (FHI), which was subsequently applied to create an intricately mapped flood hazard. The analysis and testing of the involved parameters by assessing flood susceptibility has been facilitated with hydrological modeling, Geographic Information System (GIS), as well as with remote sensing procedures. Deep-learning frameworks, particularly convolutional neural networks, have also shown high predictive capability for regional flood susceptibility (Kalantar et al. 2021). The findings suggest that urban growth has resulted in extensive wetland degradation, elevated surface runoff, and more frequent flooding, particularly during intense rainfall. The FHI-based flood hazard map identifies critical areas at risk of flooding, highlighting the explicit role of land cover changes in flood intensity and frequency. This study underscores the urgent need for sustainable urban planning, wetland conservation, and climate-resilient infrastructure to mitigate flood hazards and enhance long-term urban flood resilience in the region. These results help to better understand urban flood hazards and offer a scientific foundation for future flood management.

INTRODUCTION

Floods are among the most recurrent and devastating natural disasters affecting urban settlements worldwide, particularly in coastal cities with high population densities (Singha et al. 2025). Chennai, one of India's major metropolitan centers, has experienced severe flooding events, with the 2021 flood serving as a recent example of extreme urban inundation (Kartheeshwari & Elango 2022). Long-term climatic analyses indicate that temperature rise, precipitation extremes, and altered discharge patterns substantially increase flood occurrence globally (Alobid et al. 2024). Studies have attributed the increased flood risk in Chennai to a combination of excessive rainfall, unregulated urban expansion, and the degradation of natural drainage systems (Ramakrishnan et al. 2018). Chennai receives a significant portion of its annual rainfall from the Northeast Monsoon, making it vulnerable to waterlogging and infrastructure damage owing to inadequate stormwater management (National Institute of Disaster Management 2020). Comparable coastal systems show that climate-driven land cover changes can amplify runoff and exacerbate flood intensity (Song et al. 2024). One of the primary contributors to the flood vulnerability of Chennai is the rapid urbanization-induced loss of water-retaining ecosystems. Historically, the city has an extensive network of wetlands and water bodies that act as natural buffers against flooding. However, encroachment on these ecological systems has exacerbated the severity of flood events. The Pallikaranai Marshland to Buckingham Canal corridor, in particular, has witnessed extensive anthropogenic transformations, resulting in greater vulnerability to flooding in nearby urban areas (Sudhakar et al. 2019).

The Pallikaranai Marshland, a crucial freshwater ecosystem in Chennai, helps mitigate urban flooding by absorbing excess rainfall, functioning as a natural sponge (Ramachandran et al. 2015). However, large-scale reclamation and conversion of marshland for residential, industrial, and infrastructure development have significantly reduced its water-holding capacity. Studies indicate that nearly 90% of the original marshland has been lost over the past five decades, leading to a substantial decline in ecological functions (Jayanthi et al. 2017). The Buckingham Canal, an artificial tidal waterway running parallel to the Coromandel Coast, has historically served as an inland navigation route and stormwater drainage conduit. However, pollution, encroachment, and silt accumulation have diminished its drainage efficiency (Anand et al. 2021). Restrictions on natural flow passageways between the Buckingham Canal and Pallikaranai Marshland have led to prolonged water stagnation and urban flooding during heavy rains. This study aims to map flood-prone areas and provide insights into sustainable urban planning and flood mitigation. Hybrid ensemble flood-susceptibility models have demonstrated strong accuracy in South Asian basins that exhibit comparable terrain and hydrological variability (Ahmed et al. 2022). This research will measure the effects of climate change and urbanization on flood behavior in the study region, examine land-use patterns, drainage capacity, and rainfall trends using remote sensing and GIS applications, and create a flood hazard map by applying a weighted overlay procedure based on key hydrological and topographic factors. In addition, it will identify high-risk flood-prone areas and analyze the contribution of wetland degradation to increased flood hazards.

MATERIALS AND METHODS

The study area was selected based on three main factors: flood-prone zones, land-use changes, and drainage infrastructure. Priority was given to areas such as the Pallikaranai Marshland and Buckingham Canal, which are highly susceptible to flooding owing to their low-lying nature and poor drainage systems. Regions with significant land-use changes, particularly increased built-up land cover, were emphasized because they reduce water absorption and intensify surface runoff. Additionally, areas with inadequate or poorly maintained drainage networks were considered, highlighting the role of insufficient infrastructure in exacerbating the flood risks.

The Pallikaranai Marshland, one of the last remaining freshwater marshes in Chennai, plays a vital role in flood attenuation by acting as a natural sponge that stores excess rainwater during the monsoons. However, its drainage pathway-primarily via the Okkiyam Maduvu channel into the Buckingham Canal—has become increasingly compromised due to siltation, narrowing, and loss of channel capacity. The overall workflow adopted for flood hazard assessment is shown in Fig. 1. Notably, this hydrological linkage failed during the 2015 South India floods and more recently during Cyclone Michaung (2023), causing significant inundation in

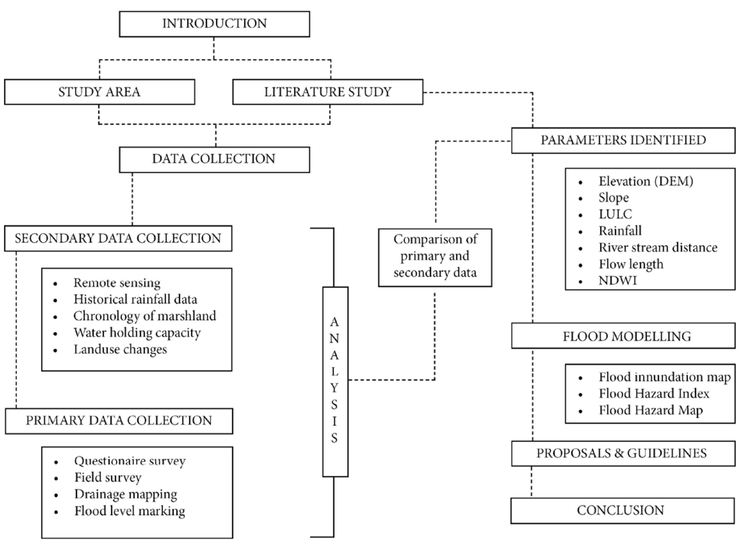

Fig. 1: Methodology.

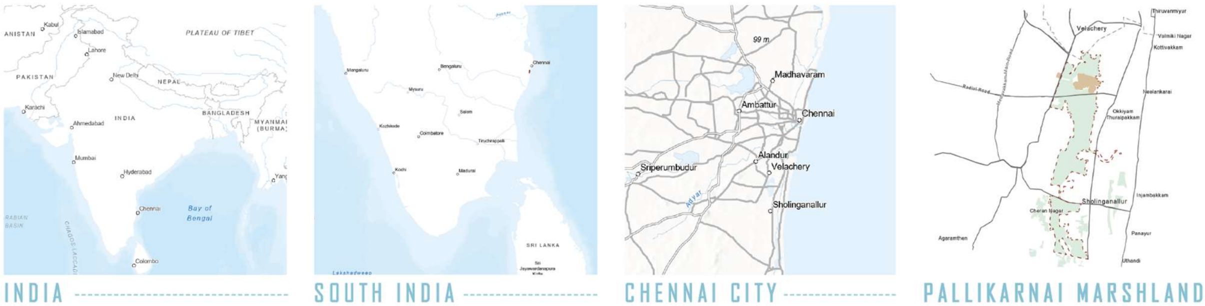

Fig. 2: Key map.

the surrounding urban areas, such as Velachery, Perungudi, and Sholinganallur.

The Pallikaranai Marshland and Buckingham Canal, found in southern Chennai, Tamil Nadu, India, are incredibly important as they assist in flood management and are under threat from urbanization and severe weather events. The Pallikaranai Marshland is located at 12.93°N latitude and 80.21°E longitude and is a freshwater wetland of approximately 50 sq.km; however, the size of this wetland has been considerably reduced due to urban encroachment. Wetlands are natural flood buffers, biodiversity providers, and groundwater recharge areas with alluvial and clay soils that retain water.

The region has a tropical wet and dry climate, with an average annual rainfall of 1,200 mm, which mainly occurs during the Northeast Monsoon. Hydrologically connected to the Okkiyam Maduvu and Buckingham Canal, the marshland allows drainage into the Bay of Bengal. Isotopic hydrology studies in the Chennai region corroborate the complex interaction between shallow groundwater and surface-water systems (Natarajan 2023). However, rapid urbanization at a fast pace, landfilling operations, and alterations to the drainage system have disturbed its natural balance, increasing the risk of flooding and water contamination. The Buckingham Canal, particularly its Thoraipakkam–Karapakkam section, is one of the major drainage channels

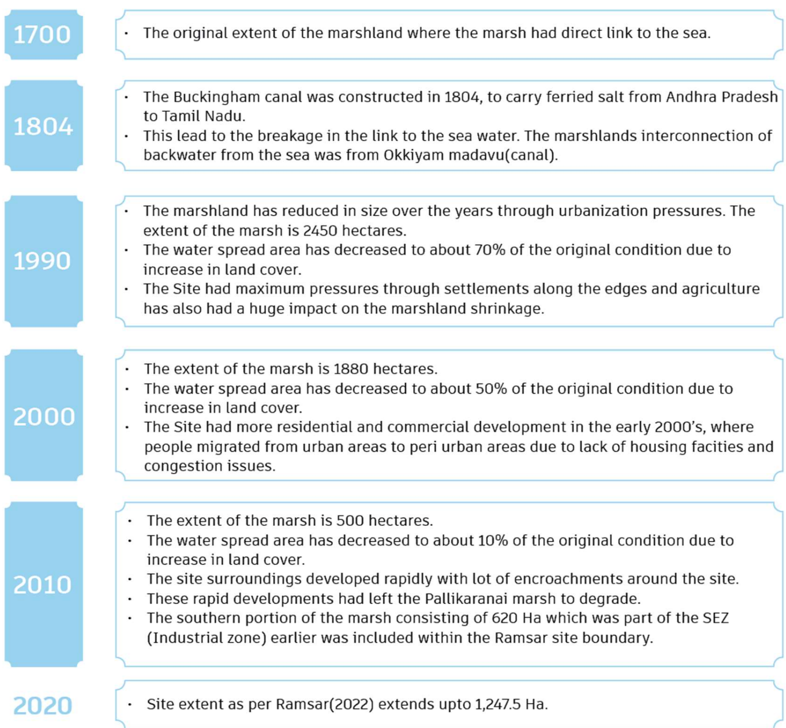

Fig. 3: Chronology of marshland timeline.

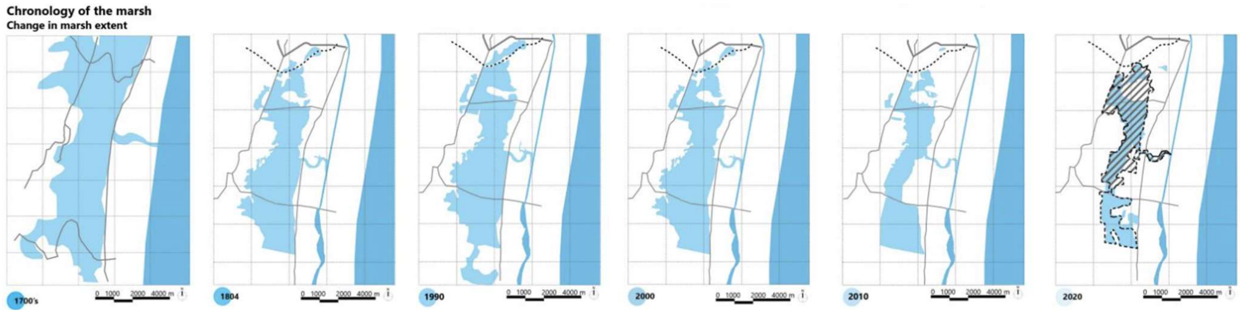

Fig. 4: Chronology of marshland.

for the city but is plagued by siltation, encroachments, and decreased flow capacity, adding to urban flooding. All these factors in unison reflect the significance of this area towards flood risk analysis and sustainable city planning (Prakriti 2025). The location and spatial extent of the study area are illustrated in Fig. 2.

Secondary Data Collection

Chronology of Marshland

The Pallikaranai Marshland initially had a direct link to the sea, with backwater inflows via the Okkiyam Maduvu (canal). The development of the Buckingham Canal in 1804 to carry salt from Andhra Pradesh to Tamil Nadu broke this natural connection, changing the hydrology of the marsh. Urbanization over the years has significantly diminished the size of the marsh. The historical evolution and timeline of marshland degradation are shown in Figs. 3 and 4.

Initially spanning an area of 2,450 hectares, the water spread area lost 70% of its land cover as settlements expanded along its boundary. By the early 2000s, when housing and commercial construction boomed with migration from overpopulated urban areas, the marsh shrank further to 990 hectares, where only 35% of its original water area remained. The development of the IT corridor in Chennai along the OMR accelerated land-use change, leading to additional reductions. The marshland now occupies an area of only 500 hectares, with scarcely 10% of its original water spread area, mainly due to rapid encroachment and illegal development. But, attempts have been made to conserve it, and 620 hectares of the south region (which was previously an SEZ industrial zone) came within the Ramsar site boundary in 2022, increasing the conserved area to 1,247.5 hectares (Prakriti 2025).

Change in Land Use Around the Region

There have been tremendous land-use changes over the years around the marshland, as illustrated in the 1990, 2000, and 2020 maps. In 1990, natural vegetation and open spaces covered most of the area around the marshland, with a few isolated built-up areas. There was a visible conversion of land by 2000, as both urban and agricultural lands started increasing in size, thereby decreasing the size of the green areas. The most drastic change took place by 2020, as significant areas of the marshland and its vicinity were taken over by urbanization and other uses. The previously wide natural habitats turned highly fragmented with serious encroachment by developed land, possibly causing the degradation of the wetland ecosystem. This trend suggests rapid urbanization, agricultural expansion, and possible environmental consequences, such as loss of biodiversity and reduced water retention capacity of the marshland. These temporal land-use changes are depicted in Fig. 5.

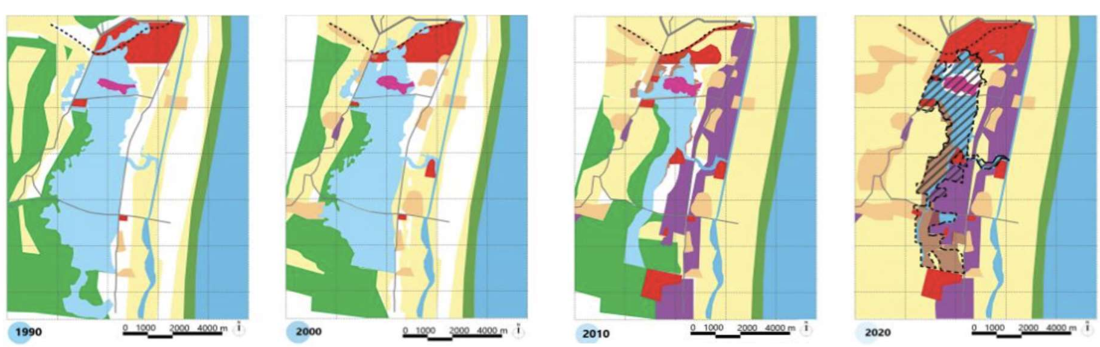

Fig. 5: Change in land use around the region.

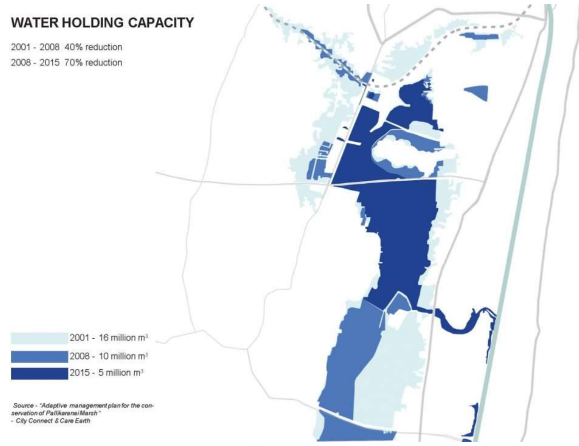

Fig. 6: Water holding capacity.

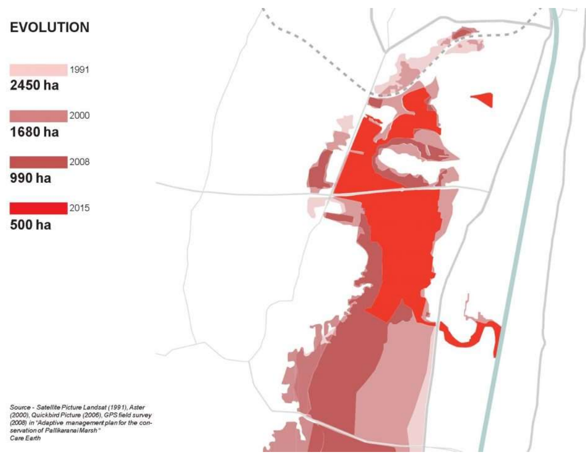

Fig. 7: Marshland degradation.

Degradation of the Marsh and Water Holding Capacity

The water-holding capacity of marshlands is influenced by the geological characteristics of the soil. Since the marshland has clayey soil that can hold water for a longer period of time and can release it during dry periods, the surrounding areas of the marsh were not much affected by the excessive rainfall during 2005. However, in 2015, some of the worst-hit areas in Chennai that suffered immensely due to flood levels of up to 1.8m were Pallikaranai, Velachery, Madipakkam, and Thoraipakkam, which are all in the vicinity of the marshland and have blocked the natural drainage network of the marshland. The encroachments include residential land use and infrastructure facilities approved by the government, namely the mass rapid transit system railway station of Velachery, which has taken up the northern part of the marsh, while the Perungudi Landfill has taken up the central part of the marsh, which takes up about 72 hectares of the marsh. In addition, the ELCOT SEZ occupies the southern part of the marsh. The spatial variations in water-holding capacity and extent of marsh degradation are presented in Figs. 6 and 7.

Historical Rainfall and Flooding in Chennai

Chennai experiences a tropical wet and dry climate, with rainfall patterns significantly influenced by the Northeast Monsoon from October to December, contributing 60-70% of the city's average annual rainfall of approximately 1,200 mm. Historical rainfall data reveal considerable variability, with some years marked by intense rainfall, leading to catastrophic flooding. Notably, the 2005 event saw over 1,000 mm of rainfall in a single day, causing widespread waterlogging and damage to infrastructure. Historical monthly and annual rainfall variability for Chennai is shown in Figs. 8 and 9. Detailed two-decadal rainfall statistics used for analysis are provided in Table 1.

Table 2 illustrates how natural rainfall extremes**,** combined with urban encroachment**,** inadequate drainage,

Table 1: Two decadal rainfall data (source: KEA weather station).

Year	Jan-May	Jun-Sep	Oct-Dec	Total
2024	87	694.2	1084.1	1865.3
2023	104	743.7	1268.8	2116.5
2022	129.8	497.7	960.3	1587.8
2021	215.9	558	1484.8	2258.7
2020	97.2	293.4	1033.5	1424.1
2019	4	492.6	605.7	1102.3
2018	5.8	432.2	390.1	828.1
2017	7.7	508.7	978.5	1494.9
2016	209.8	526.3	324.6	1060.7
2015	23.2	407.8	1663.8	2094.8
2014	23.8	518.8	752	1294.6
2013	33.6	617.4	436.8	1087.8
2012	17.8	408.2	595.2	1021.2
2011	130.8	852.4	852.4	1835.6
2010	209.4	647.6	757.6	1614.6
2009	37.8	233.2	909.8	1180.8
2008	226.8	422.6	947.6	1597
2007	7.2	677	625.6	1309.8
2006	37.4	393	892.6	1323
2005	121	337	2108	2566
2004	264.6	360	572	1196.6

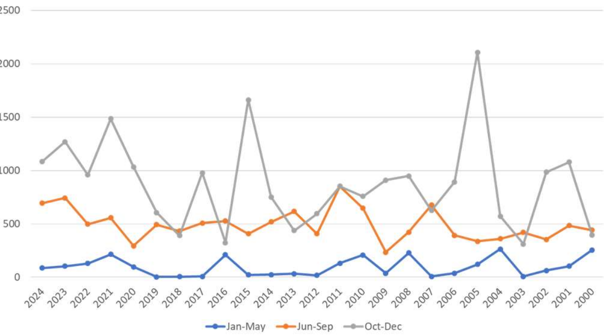

Fig. 8: Historical month-wise rainfall data.

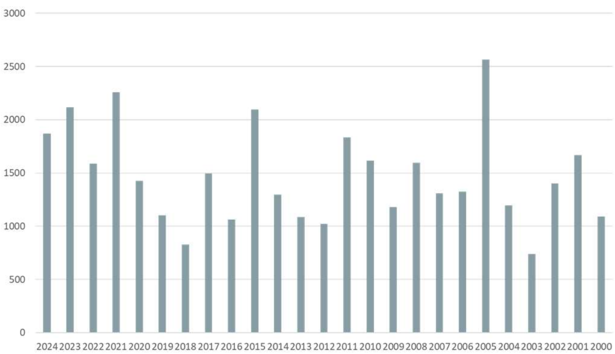

Fig. 9: Historical year-wise rainfall data.

and wetland degradation, have made the Pallikaranai Marshland a recurrent flood hotspot. Effective flood mitigation demands restoration of marsh connectivity, desilting of drainage channels, and long-term land use regulation.

Land Ownership Inside the Marshland

In the early 1900s, marshland occupied an area of 6000 ha (60 km^2), which is now 593 ha (Care Earth 2002). The National Institute of Ocean Technology (NIOT) and the Center for Wind Energy Technology (WET) have built institutions that have divided and minimized the marsh, and the Perungudi dump yards and effluent treatment plants have

Table 2: History of flooding in Palikarani Marshland and Buckingham Canal.

Year	Event/ Cyclone	Rainfall [mm]	Cause	Impact	Notes
2005	Heavy Monsoon Rainfall	~400 mm in 3 days	Prolonged NE monsoon, poor drainage	Major waterlogging in Velachery, Perungudi, Pallikaranai	Highlighted the lack of stormwater infrastructure
2008	Cyclone Nisha	~500 mm (Nov)	Cyclonic storm + encroachment in the marsh	Marsh overflowed; roads flooded	Marsh area reduced due to dumping & encroachments
2015	South India Floods	>1,200 mm in 30 days	Historic rainfall + blocked drains + Encroachments	Extensive flooding in South Chennai, airport closure	Pallikaranai overflowed; Okkiyam Maduvu failed to drain into the Canal
2017	Cyclone Ockhi (indirect)	~200 mm	Back-to-back rain events, poor marshland drainage	Moderate inundation; waterlogging in IT corridor	Drainage systems strained
2021	Northeast Monsoon	~1,000 mm (Oct–Nov)	Intense NE monsoon, high tide effects on Buckingham Canal	Partial flooding in marshland-adjacent areas	Canal outfall constrained by urban development
2023	Cyclone Michaung	~400 mm in 48 h	Cyclonic storm, silted Buckingham Canal, encroachments in marsh	Severe flooding in Sholinganallur, OMR, Perumbakkam	Okkiyam Maduvu unable to drain efficiently into the sea

(Source: *TN SDMA* (Tamil Nadu State Disaster Management Authority) Reports)

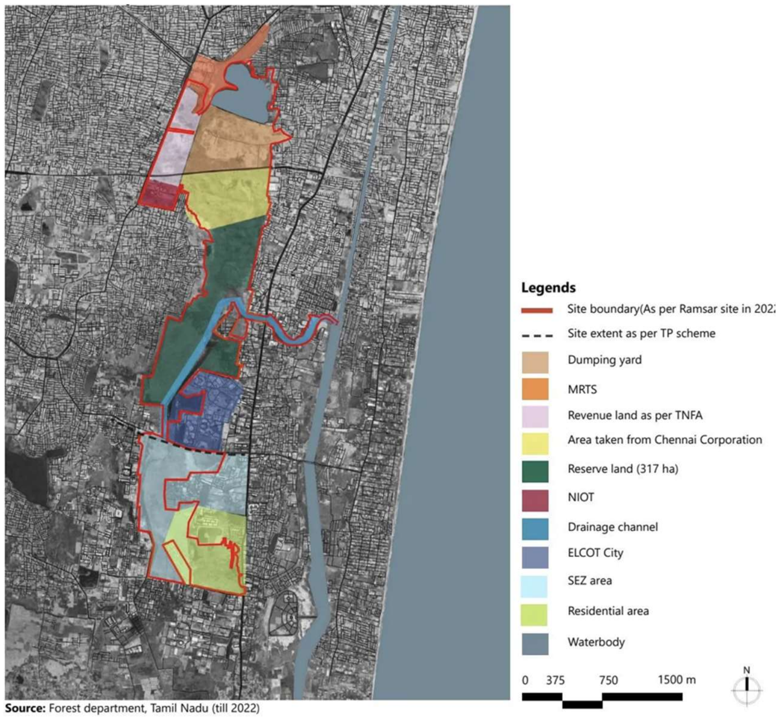

Fig. 10: Land ownership inside the marshland (source: Forest department, Tamil Nadu).

Fig. 11: Flood-affected areas.

taken over a significant area of marshland. In contrast, IT corridors and residential apartments have been developed in the area. The dumping yard comprises 173.33 Ha, land taken from Chennai Corporation is 170.405 Ha, channel of drainage is 54.21 Ha, Elcot consists of 85.43 Ha, revenue land as per TNFA is 131.55 Ha, and the SEZ comprises 445 Ha. Previously, the Palikaranai marshland was used up to the point where the Perumbakkam main road exists (Government of Tamil Nadu 2022). Subsequently, the SEZ area was also covered when it was declared a Ramsar site. The distribution of land ownership inside the marshland is mapped in Fig. 10.

Primary Data Collection

Flood-affected Areas

Fig. 11 shows the streets, residential areas, and shops in West Karapakkam, with markings indicating the water levels reached during past flood events. Specifically, the images highlight the flood levels from the 2015 Chennai floods, which were particularly devastating.

The floodwaters reached significant heights, submerging homes and businesses and causing widespread damage to infrastructure and property. The economic impact of the floods was severe, as many residents and shopkeepers lost their livelihoods and possessions due to the floods. Thoraipakkam, located below the OMR road level, has experienced recurring flooding during heavy rains due to its lower elevation. In the 2015 floods, water from the OMR flowed into the inner streets, leaving them submerged under 4 to 5 ft of water for nearly a week. A scrap shop in the area suffered severe damage, causing the owner an economic loss of approximately ₹50,000, and other residents faced similar hardships as their homes and businesses were inundated. A nearby apartment complex close to the Pallikaranai Marshland experienced severe waterlogging during both the 2015 and 2023 floods, worsened by the overflowing marshland. Residents faced numerous challenges, including stagnant water, poor sanitation, property damage, and submerged vehicles, leading to health risks and disruption of daily life. During such events, residents struggle to access essential supplies, exacerbating their difficulties. The problem of waterlogging in Thoraipakkam persists in its inner streets because of rainwater flowing from the elevated OMR road. Stagnant water often remains for approximately a week, posing significant health and sanitation challenges and increasing the risk of waterborne diseases. These prolonged floods continue to cause economic losses and disrupt community well-being.

Questionnaire

A questionnaire survey was conducted within the study area and around the Pallikaranai Marshland to assess flood susceptibility across various environmental and infrastructural settings in Chennai. A total of 247 households comprising 1,067 individuals were selected as the survey sample. The selected locations encompassed high-, moderate-, and low-risk flood zones, enabling a comprehensive evaluation of flood hazards. The data collected serve as critical indicators for analyzing the impact of climate change, drainage infrastructure, urbanization, and hydrological changes on flood occurrences.

The findings indicate that a significant proportion of residents experienced severe disruptions due to flooding, including substantial losses of property and belongings. Many households were forced to relocate temporarily for safety as floodwaters inundated residential areas and roadways. Additionally, prolonged water stagnation and poor sanitation contributed to disease outbreaks and other health issues in the affected communities. The survey offered valuable insights into the intensity and causes of flooding in the region. The primary driver was identified as overflow of the river and marshland, exacerbated by heavy rainfall exceeding the capacity of the existing drainage infrastructure, thereby intensifying the flood impact on local populations.

Drainage Infrastructure

In several parts of Chennai, including Kannagi Nagar and West Karapakkam, the convergence of stormwater and greywater within the same drainage systems poses significant challenges to urban flood management. In Kannagi Nagar, drains discharge both stormwater and untreated greywater into the Okkiyam Maduvu canal, which ultimately connects to the Buckingham Canal system. This mixing of waste and runoff water not only degrades water quality but also reduces the drainage system efficiency by increasing the risk of clogging, sedimentation, and overflow during intense rainfall events. Similarly, in West Karapakkam, the drainage outlets exhibit similar dual usage, leading to frequent overflows during the monsoon season. The accumulation of stagnant water on streets causes considerable inconvenience to residents and poses serious sanitation risks to them. Thoraipakkam faces recurring water stagnation challenges despite stormwater drains on most streets. The primary issue lies in poor maintenance, as blockages, silt buildup, and a lack of regular cleaning prevent proper drainage during heavy rains. This causes rainwater to accumulate on the streets, thereby worsening the problem. In comparison, Karapakkam

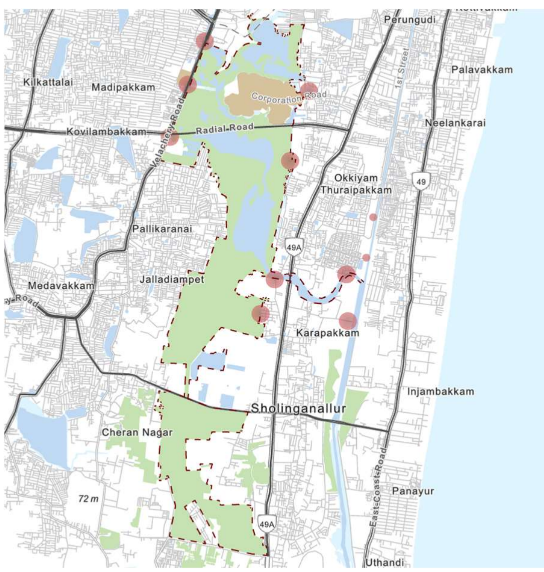

Fig. 12: Sewage outlets.

has fewer drainage facilities, intensifying the risk of flooding. Additionally, the improper use of stormwater drains for disposing of grey water in Karapakkam leads to blockages, further diminishing their effectiveness.

These cases emphasize the importance of maintaining the existing urban drainage infrastructure to ensure its continued capacity to manage water flow effectively. Integrating blue–green infrastructure into metropolitan planning has been shown to markedly improve climate adaptation and flood resilience (García Sánchez & Govindarajulu 2023). Regular maintenance, combined with the implementation of integrated drainage solutions that separate greywater from stormwater, is essential for enhancing flood resilience and promoting better environmental health.

Analysis

A detailed analysis of the existing conditions and site synthesis enabled the delineation of the marshland into three distinct zones based on environmental sensitivity and anthropogenic pressures (Fig. 12)

Environmentally Critical Zone: This parcel has undergone extensive ecological degradation due to landfill activity and infrastructural encroachments. The construction of the 200-feet radial road has disrupted natural hydrological connectivity, resulting in the stagnation and contamination of water within this segment. The proximity of the Perungudi dump yard further exacerbates the deterioration of water quality, leading to the formation of chemically polluted stagnation zones.

Sensitive Zone: The central portion of the marsh, identified as a sensitive ecological area, has been subjected to pressures from cattle grazing, debris dumping, and a lack of protective measures along its periphery. This zone is connected to the Okkiyam Maduvu drainage channel, which is approximately 15 feet above the marsh's natural elevation, creating a hydrological disconnect that affects flow dynamics.

Unprotected Zone: Previously unrecognized as part of the marsh ecosystem and falling within a Special Economic Zone (SEZ) before its RAMSAR designation, this area exhibits potential for ecological restoration. It can serve as a terrestrial habitat for diverse faunal and avifaunal species.

Furthermore, the low-lying regions within the study area (Fig. 13) have been officially designated as aquifer recharge zones by the Chennai Metropolitan Development Authority (CMDA), underscoring their hydrological significance in urban water management strategies.

Data Sets

In this research, Digital Elevation Model (DEM) and slope information were collected from the United States Geological Survey (USGS) based on the Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global dataset. This data set captures high-resolution elevations with a near 30-meter spatial resolution to ensure that precise topographic presentation is accomplished. Recent studies combining machine-learning models with geospatial datasets have further strengthened flood-risk prediction in

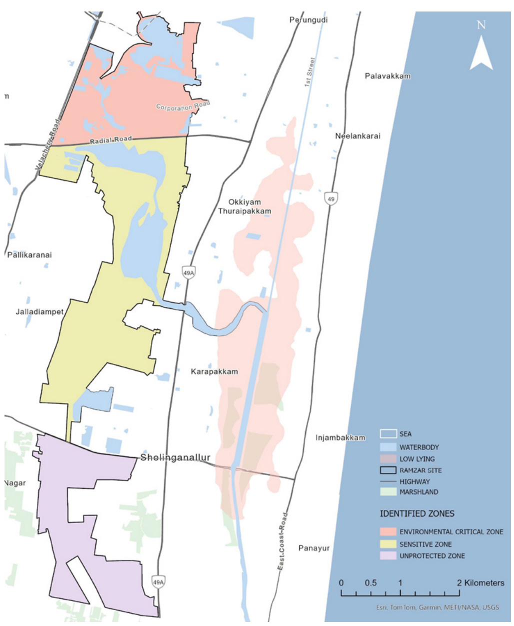

Fig. 13: Identified Zones.

urban catchments (Miranda et al. 2023). The DEM has been applied in terrain analysis and slope computed employing GIS-based image processing to provide surface gradients, as well as landscape differences assessment. Important spectral indices like the Normalized Difference Water Index (NDWI) were collected from the United States Geological Survey (USGS) based on the Landsat 8-9 OLI/TIRS C2L1 (30 Meter Spatial Resolution) dataset. Their merge enabled reliable characterization of the terrain, thereby making it viable to apply to applications in hydrology, geomorphology, as well as the environment's modelling.

Sentinel-2 (S2) multispectral imagery was used for land use classification and analysis. The high spatial and spectral resolution of Sentinel-2 (10 m resolution) data allowed precise discrimination of different land cover types, such as vegetation, water bodies, urban, and bare land.

Flood Inundation Model

Flood inundation modeling in QGIS using a Digital Elevation Model (DEM) involves a systematic methodology for identifying flood-prone areas based on topographic characteristics and hydrological analysis.

Flood Depth = Water Surface Elevation – DEM

The process begins by importing a high-resolution DEM, such as SRTM or LiDAR, into QGIS, followed by preprocessing with the Fill Sinks (Wang & Liu) tool to remove depressions and ensure accurate water flow representation. Hydrological flow analysis was then conducted using Tau DEM, which generates flow direction and accumulation maps to delineate drainage patterns and potential flood pathways. To estimate the flood extent, the Floodplain Delineation Plugin or Raster Calculator was used to subtract DEM elevations from predefined water surface levels, identifying inundated areas. Flood depth was calculated using the equation, producing a raster layer that represents varying flood depths across the terrain.

A flood inundation map was generated to assess flood depths of 1 and 2 m. As shown in Fig. 14, this resulted in severe damage, particularly in low-lying areas. Notably, regions within 500 m on either side of the Buckingham Canal experienced significant flooding, severely impacting the residents of Thoraipakkam. Additionally, the institutional and industrial zones of Karapakkam were affected, with flood impacts varying according to land use patterns. Furthermore, Velachery, Perungudi, and Medavakkam faced extensive inundation owing to inadequate drainage infrastructure and disruptions to natural water flow, exacerbating the flood severity in these regions.

Flood Hazard Index

The FHI is a multi-criteria decision analysis method that uses the Analytical Hierarchy Process (AHP) to evaluate different factors contributing to flood hazards.

Analytical Hierarchy Process

The AHP process for flood assessment and mapping involves using a multi-criteria decision-making method to evaluate various factors influencing flood risk and then assigning weights to the factors based on their relative importance. The weights were then used in a weighted overlay analysis within a GIS environment to create a flood susceptibility or hazard map. Maximum entropy modelling has also been successfully applied in

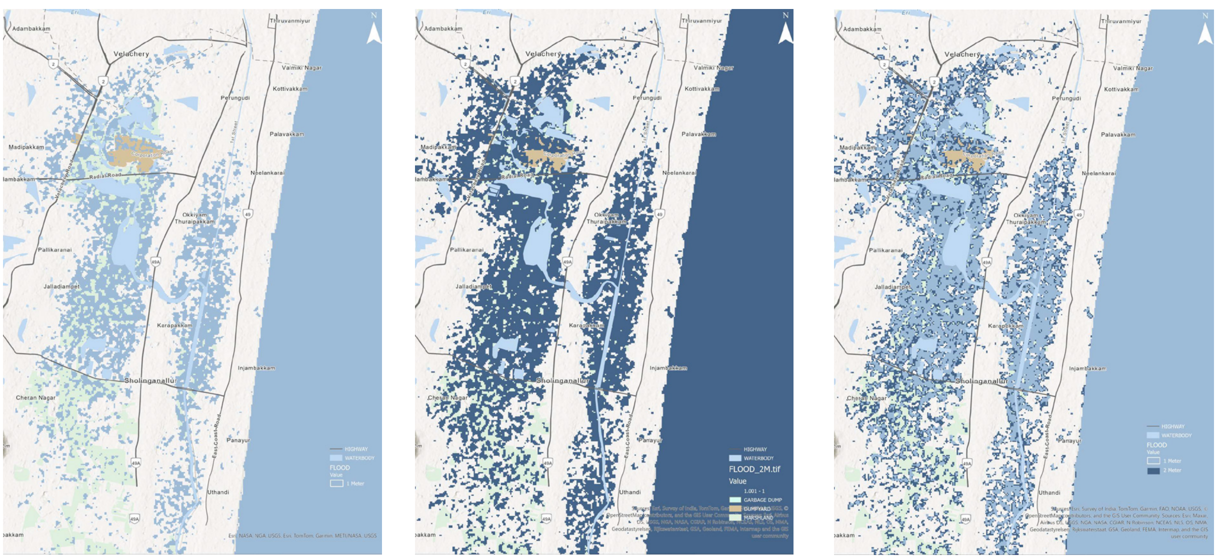

Fig. 14: a) 1 meter flood depth. b) 2 meter flood depth c) Flood inundation map.

Indian catchments for delineating flood-hazard zones (Kalita et al. 2025).

Identifying Key Factors and Criteria

The AHP focuses on identifying and structuring the factors that contribute to flooding, as shown in Table 2. Recent advancements that integrate remote sensing with machine-learning models highlight improved accuracy in identifying flood-susceptible zones (Ahmed et al. 2024). In this study, the seven most effective FCFs were selected for processing: elevation, slope, rainfall, NDWI, LULC, river distance, and flow length (Fig. 15). The metadata sources and descriptions of all FCFs are listed in Table 3.

Weight Assignment Using Pairwise Comparison

To evaluate the relative importance of various factors influencing flood hazard, a pairwise comparison matrix was constructed using the Analytic Hierarchy Process (AHP) methodology. The pairwise comparison values are calculated as:

$$PCMij = Wj/Wi$$

Where Wi and Wj are the weights of factor *i* and factor *j*, respectively.

In this approach, each factor is systematically compared with every other factor based on its contribution to flood susceptibility. The comparisons were made using the Saaty scale (1–9), which allows experts to quantify how much more important one factor is over another factor. This scale ranges from 1 (equal importance)

Fig. 15: Flood hazard index.

Table 3: Metadata of the utilized datasets for flood hazard susceptibility mapping.

Main factor	Sub Factor	Data description	Source	Data Acquired
Topographical factor	Elevation [m]	Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global dataset (30 Meter Spatial Resolution)	https://earthexplorer.usgs.gov/	2024
	Slope	Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global dataset (30 Meter Spatial Resolution)	https://earthexplorer.usgs.gov/	2024
Terrain factor	LULC	Sentinel 2 - S2, The high spatial and spectral resolution of Sentinel-2. (10 m resolution) (2024)	https://livingatlas.arcgis.com/landcoverexplorer/	2024
Hydro logical factor	Rainfall [mm]	India Meteorological Department Spatial resolution: 0.25° × 0.25° (~25 km × 25 km)	https://mausam.imd.gov.in/	2024
	River distance	Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global dataset (30 Meter Spatial Resolution)	https://earthexplorer.usgs.gov/	2024
	Flow length	Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global dataset (30 Meter Spatial Resolution)	https://earthexplorer.usgs.gov/	2024
	NDWI	USGS - Landsat 8-9 OLI/TIRS C2L1 (30 Meter Spatial Resolution)	https://earthexplorer.usgs.gov/	2024

Table 4: Pairwise Comparison Matrix.

Factors	Rainfall	Elevation	LULC	Slope	River Distance	Flow Length	NDWI
Rainfall	1	1.2	1.5	3	6	6	6
Elevation	0.83	1	1.25	2.5	5	5	5
LULC	0.67	0.8	1	2	4	4	4
Slope	0.33	0.4	0.5	1	2	2	2
River Distance	0.17	0.2	0.25	0.5	1	1	1
Flow Length	0.17	0.2	0.25	0.5	1	1	1
NDWI	0.17	0.2	0.25	0.5	1	1	1

Table 5: Derived weights.

Factors	Derived Weight	Derived Weight [%]
Rainfall	0.3	30%
Elevation	0.25	25%
LULC	0.2	20%
Slope	0.1	10%
River Distance	0.05	5%
Flow Length	0.05	5%
NDWI	0.05	5%

to 9 (extreme importance of one over the other) (Table 4).

Weights were then assigned to each factor based on expert judgment, considering the relative influence of each factor in determining flood hazards. The resulting matrix captures the preferences and priorities in a structured form, providing the basis for calculating the normalized weights and ensuring consistency in the decision-making process. The normalized weights for each factor are presented in Table 5.

Derived Weights and Consistency Check

To find the Weighted Sum Vector, multiply the Pairwise Comparison Matrix (PCM) by the weight vector (the derived weights from normalization). The results are shown in Table 6 and the consistency evaluation results are detailed in Table 7.

Let's denote:

A = Pairwise Comparison Matrix (7x7)

W = Weight Vector (7x1)

Now compute: WSV = A x W

The principal eigenvalue (λ_m) is computed by averaging the values of WSV/W:

$\lambda_m = (7.15 + 7.06 + 7.11 + 7.05 + 7.04 + 7.04 + 7.04)/7 = 7.071$

The Consistency Index (CI) is calculated as:

$$CI = (\lambda_m - n) / (n - 1) = (7.071 - 7)/6 = 0.0118$$

The Consistency Ratio (CR) is calculated using the Random Index (RI), which for n = 7 is 1.32:

$$CR = CI/RI = 0.0118/1.32 = 0.0089$$

Because the calculated Consistency Ratio (CR = 0.0089) is significantly less than 0.1, the judgments in the pairwise comparison matrix are considered consistent. This validates the reliability of the weight derivation and confirms that the matrix is suitable for further analysis in the AHP.

Flood Hazard Map

Using the collected spatial and environmental data, a Flood Hazard Map was developed in GIS through reclassification and standardization. Each input raster was first normalized and then reclassified on a scale of 1–5, where 1 represents a very low flood hazard, and 5 represents a very high flood hazard (Table 8).

Table 6: WSV Calculation.

Factor	WSV Calculation	WSV
Rainfall	(1×0.30) + 1.2×0.25 + 1.5×0.20 + 3×0.10 + 6×0.05 + 6×0.05 + 6×0.05	2.145
Elevation	0.83×0.30 + 1×0.25 + 1.25×0.20 + 2.5×0.10 + 5×0.05 + 5×0.05 + 5×0.05	1.764
LULC	0.67×0.30 + 0.8×0.25 + 1×0.20 + 2×0.10 + 4×0.05 + 4×0.05 + 4×0.05	1.421
Slope	0.33×0.30 + 0.4×0.25 + 0.5×0.20 + 1×0.10 + 2×0.05 + 2×0.05 + 2×0.05	0.705
River Distance	0.17×0.30 + 0.2×0.25 + 0.25×0.20 + 0.5×0.10 + 1×0.05 + 1×0.05 + 1×0.05	0.352
Flow Length	0.17×0.30 + 0.2×0.25 + 0.25×0.20 + 0.5×0.10 + 1×0.05 + 1×0.05 + 1×0.05	0.352
NDWI	0.17×0.30 + 0.2×0.25 + 0.25×0.20 + 0.5×0.10 + 1×0.05 + 1×0.05 + 1×0.05	0.352

Table 7: Weight Consistency.

Factor	Weight [W]	Weighted Sum	WS/W
Rainfall	0.3	2.145	7.15
Elevation	0.25	1.764	7.06
LULC	0.2	1.421	7.11
Slope	0.1	0.705	7.05
River Distance	0.05	0.352	7.04
Flow Length	0.05	0.352	7.04
NDWI	0.05	0.352	7.04

Table 8: Flood criteria ranking of the thematic layer.

Factors/criterion	Class value range	Reclassified value	Type
Elevation [m]	-7.99 – 1	5	Numerical
	1.01 – 3	4	
	3.01 – 6	3	
	6.01 – 9	2	
	9.01 – 19	1	
Slope [°]	0.01 - 0.36	5	Numerical
	0.37 - 1.29	4	
	1.3 - 3.67	3	
	3.68 - 9.8	2	
	9.81 - 25.57	1	
LULC	Bare Ground	5	Categorical
	Built area	4	
	Crops	2	
	Flooded Vegetation	3	
	Range land	5	
	Trees	2	
	Water	1	
River Distance [m]	0 – 100	5	Numerical
	100 - 223.05	4	
	223.05 - 316.31	3	
	316.31 - 576.34	2	
	576.34 - 1548.68	1	
Flow length [m]	100 - 230	5	Numerical
	230 – 510	4	
	510 – 790	3	
	790 – 1080	2	
	1080 – 1210	1	
NDWI	(-0.43) - (-0.25)	5	Numerical
	(-0.25) - (-0.18)	4	
	(-0.17) - (-0.13)	3	
	(-0.12) - (-0.03)	2	
	(-0.02) - (0.07)	1	

The individual thematic layers contributing to the FHI like DEM, slope, LULC, river distance, flow length, and NDWI are illustrated in Fig. 16. Elevation and slope are significant parameters that significantly impact flood risk. Gentle slopes and low elevations allow for water accumulation, making the area more susceptible to floods (Vojtek & Vojtekova 2019). Elevation also influences river inundation and atmospheric conditions, such as precipitation (Najibi & Devineni 2023). In this study, elevation and slope were extracted from the 30 m SRTM-DEM in GEE. In this study, elevations varied from -7.99 m to 19 m, where lower elevations were more susceptible to flooding than steeper, higher regions. A mean

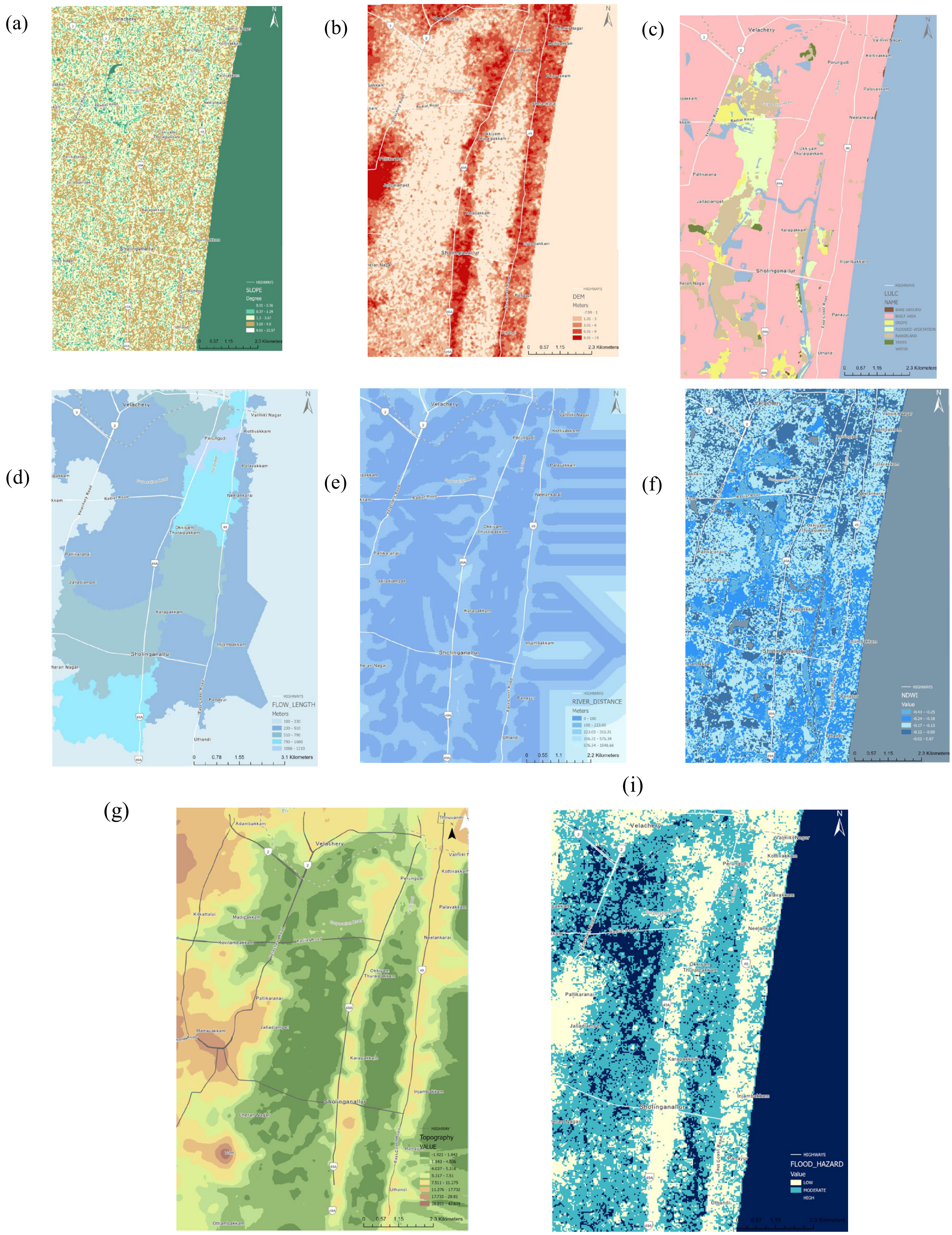

Fig. 16: a) DEM b) Slope c) LULC d) River distance e) Flow length f) NDWI g) Topography h) flood hazard map.

slope of 2.36° justifies the higher risk of flooding on flat slopes. The NDWI is a remote sensing index used to identify water bodies and moisture levels in vegetation. It is used for the important task of flood hazard mapping by delineating regions with high water content, which could be flood risk areas. It is computed using near-infrared (NIR) (Band 3 in Landsat 8) and Shortwave Infrared (SWIR) or green bands (Band 5 in Landsat 8) of satellite data. Water absorbs NIR and reflects green light; therefore, water features appear as high positive NDWI values.

$$NDWI=(Green+NIR)/(Green-NIR)$$

The NDWI values for the study area varied between -0.43 and 0.07, with a standard deviation of 0.10, showing changes in the submerged or waterlogged zones. The distance to rivers and streams controls the probability and magnitude of flood occurrences through proximity to water courses. Flow length is the path length that water moves across the land to flow to the closest stream or river. The flow length of our study area varied from 0.01 to 0.12 sq km, resulting in shorter flow lengths, which contributed to quicker runoff and increased flood risk, thereby boosting the FHI score. The 2024 LULC was obtained from ESA Sentinel-2 imagery at a 10 m resolution. Land cover differences are vital when explaining water storage and hydrological processes, as they have an immediate effect on flooding (Ma et al. 2023). The land use and land cover in this study encompassed seven prominent classes: tree cover, rangeland, flooded vegetation, cultivated crops, buildings, exposed land, and water surfaces.

Flood Hazard Index

The Flood Hazard Index (FHI) was derived using these standardized layers. The FHI serves as a composite indicator to assess flood risk, integrating a range of physical and environmental parameters, including rainfall, slope, elevation, land use/land cover (LULC), drainage density, Normalized Difference Water Index (NDWI), stream order, river distance, and flow length.

Each parameter was assigned a weight based on its relative importance, which was determined using the Analytic Hierarchy Process (AHP) (Table 9). The final FHI was computed using a weighted overlay technique, where the reclassified and normalized values were multiplied by their corresponding AHP-derived weights and summed across all factors.

$$\text{Normalized Value } (X) = (Raw - Min)/(Max - Min)$$

$$FHI = \sum (Wi \times Xi)$$

$$FHI = 0.1650+0.1750+0.1500+0.0400+0.0100+0.0275+0.0350=0.6025$$

A Flood Hazard Index (FHI) score of 0.60 signifies a moderate to high flood hazard potential within the study area. This outcome reflects the combined influence of key parameters, such as intense rainfall, low elevation, and vulnerable land use/land cover (LULC) types. A comprehensive weighted overlay analysis was conducted in a GIS environment using the Analytic Hierarchy Process (AHP), wherein each factor was assigned a weight based on its relative importance on a 1–5 scale. Seven critical factors–rainfall, slope, elevation, LULC, NDWI, river distance, and flow length–were normalized and integrated to compute the FHI. Hazard zones were classified using the Natural Breaks (Jenks) method, which effectively distinguishes areas with varying flood risks. The resulting FHI map identified the study area as being highly susceptible to flooding.

RESULTS AND DISCUSSION

The Pallikaranai Marshland and Buckingham Canal, once integral components of Chennai's natural drainage and flood mitigation systems, have been severely degraded due to rapid urbanization, encroachments, and inadequate drainage infrastructure. The marshland, historically functioning as a natural flood buffer, has experienced a significant decline in its water-holding capacity. This is primarily attributed to extensive land reclamation for residential, commercial, and industrial purposes, resulting in excess stormwater inundating

Table 9: Flood Hazard Index.

Factor	Raw Value	Min Value	Max Value	Normalized Value [X]	Weight [W]	Weighted Score [W × X]
Rainfall [mm]	891.4	264.6	1663.8	0.55	0.3	0.165
Elevation [m]	2	-8	19	0.7	0.25	0.175
LULC	5.5	1	7	0.75	0.2	0.15
Slope [°]	5	0.4	25.57	0.4	0.1	0.04
River distance [m]	300	0	1548.68	0.2	0.05	0.01
Flow Length [m]	700	100	1210	0.55	0.05	0.0275
NDWI	-0.05	-0.44	0.07	0.7	0.05	0.035

adjacent urban areas during periods of intense rainfall. Similarly, the Buckingham Canal, originally engineered as a critical stormwater drainage channel, has been compromised by siltation, encroachments, and pollution. These factors have drastically reduced its hydraulic capacity, limiting its ability to effectively convey floodwaters. As a consequence, low-lying areas such as Thoraipakkam and Karapakkam are increasingly susceptible to severe waterlogging during monsoonal events.

A comprehensive analysis of the Pallikaranai Marshland has delineated distinct ecological zones (Fig. 13) based on prevailing environmental conditions. The marshland's chronology (Figs. 3&4) shows a consistent pattern of degradation, directly increasing flood vulnerability in the region. To mitigate further deterioration and preserve the marsh's ecological and hydrological functions, a series of strategic interventions is proposed. To prevent future encroachments and monitor anthropogenic activities, geo-fencing of the marshland boundaries is recommended (Fig. 17(a)). This digital perimeter surveillance system will enable real-time monitoring of unauthorized vehicular movement and construction activities, transmitting instant alerts to enforcement authorities. Integrated with GIS-based databases, the system will also support automated land use change detection and generate actionable reports for regulatory intervention.

In parallel, ecological edge restoration (Fig. 17(b)) is proposed to rehabilitate the marsh's degraded margins. Wetland restoration has proven effective in strengthening regional flood resilience in similar urban–wetland systems (Sundaram et al. 2022). This measure aims to stabilize marsh boundaries, mitigate erosion, and reinforce habitat

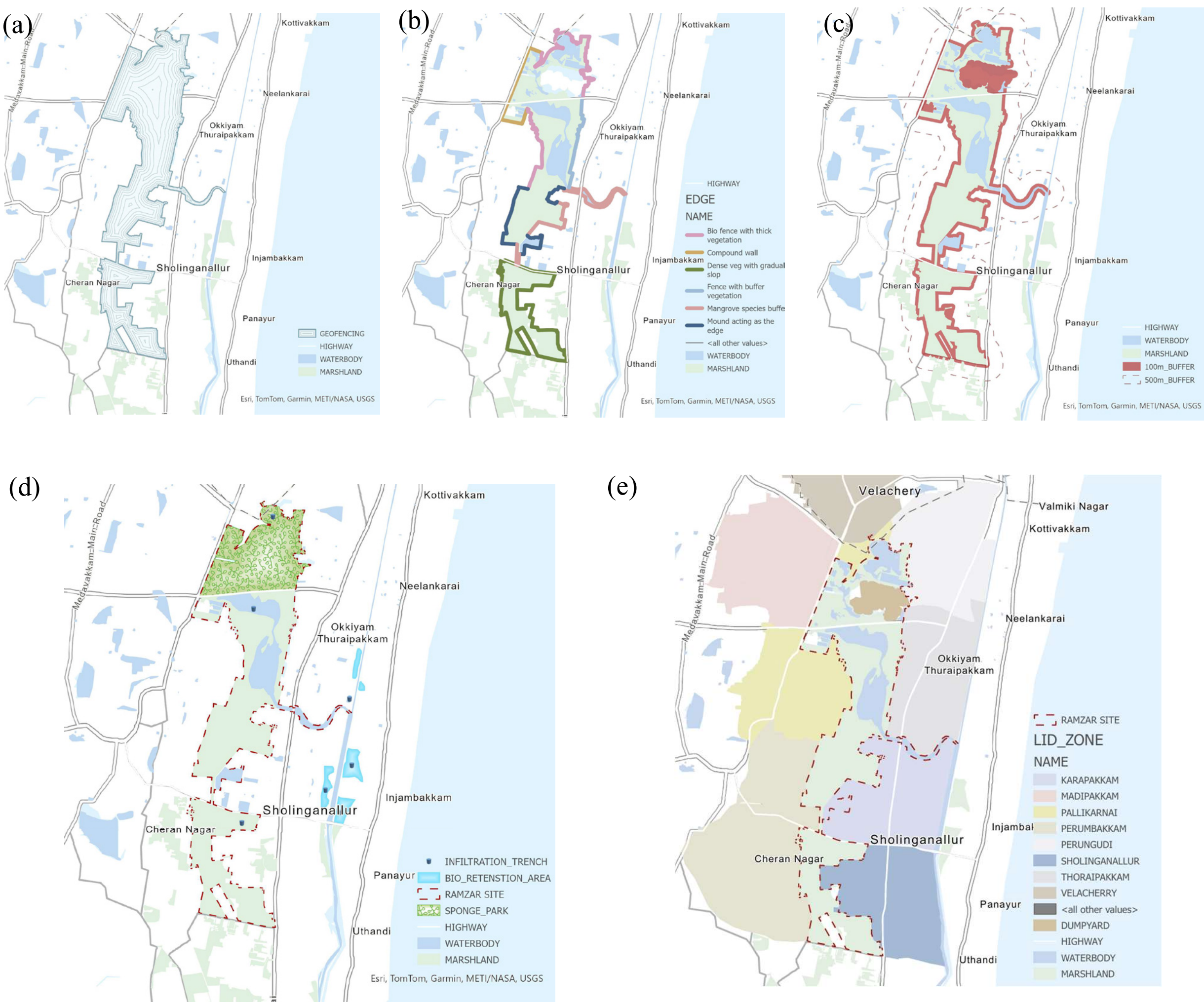

Fig. 17: a) Geo-fencing, b) Edge restoration, c) No development zone, and d) Recharge wells, bio retention ponds, bioremediation and Sponge Park, e) low-impact development zones.

conditions for native biodiversity. The restoration strategy will be tailored to the specific ecological character of each edge zone. To regulate future development, the enforcement of a 100-meter "No Development Zone" (Fig. 17(c)) around the marshland is strongly advocated, in accordance with the Wetland (Conservation and Management) Rules, 2017. This regulatory buffer will protect the marsh's core zones from further urban intrusion. The installation of recharge wells is proposed in both the designated Aquifer Recharge Area (ARA) near the Buckingham Canal and in regions of greater water depth within the marshland. These interventions will enhance groundwater recharge, mitigate seasonal water shortages, and support aquifer sustainability.

To complement these hydrological strategies, bio-retention ponds will be established in identified low-lying areas with high percolation potential. These ponds will serve as decentralized stormwater treatment systems, filtering runoff and improving water quality through natural processes (Fig.17(d)). A critical long-term intervention is the bioremediation of the Perungudi landfill (Fig. 17(d)), which currently poses severe environmental risks to the adjacent marshland. The proposal seeks to transform the degraded dump site into a sponge park, facilitating stormwater absorption, reducing surface runoff, and enabling ecological regeneration. This concept draws on a successful precedent in Indore, where a similar intervention was implemented over three years (John Snow Inc 2022).

Land-use policies should promote sustainable practices, such as green roofs, rainwater harvesting, and rain gardens, across residential, commercial, and institutional developments, with mandatory compliance with LEED or GRIHA certification standards. Low-density, non-polluting industries, such as those classified as white-category industries, may be permitted. Additionally, the installation of Decentralized Wastewater Treatment Systems (DEWATS) should be made mandatory to treat wastewater locally and prevent its discharge into ecologically sensitive areas, such as the Pallikaranai Marshland and the Buckingham Canal.

These guidelines recommend designating surrounding urban areas, Karapakkam, Madipakkam, Pallikaranai, Medavakkam, Perungudi, Perumbakkam, Sholinganallur, and Thoraipakkam as Low-Impact Development (LID) zones (Fig. 17(e)) to preserve ecological integrity. Furthermore, a 100-meter buffer zone should be established as a no-development area to curb further urban encroachment and maintain the flood mitigation capacity of the marshland. Implementing these measures is essential to enhance urban flood resilience and promote long-term environmental sustainability.

CONCLUSIONS

In conclusion, this study underscores the crucial roles of the Pallikaranai Marshland and Buckingham Canal in flood mitigation and urban water management. The application of geospatial modelling and hydrological analysis provides critical insights into flood hazard risks, facilitating the identification of vulnerable areas and the formulation of effective mitigation measures. Nature-based solutions, including wetland restoration and bioremediation, coupled with stringent land-use policies, can significantly enhance flood resilience in the region.

The compounded effects of climate change and urbanization have intensified flood risks in the Pallikaranai Marshland–Buckingham Canal corridor, highlighting the urgent need for sustainable urban planning in the region. The progressive shrinkage of marshlands due to land conversion, waste dumping, and infrastructure expansion has diminished their natural flood-buffering capacity. Similarly, the Buckingham Canal has suffered from siltation, pollution, and unregulated development, which has exacerbated urban flooding. Historical flood events, such as those in 2015 and 2021, underscore the increasing vulnerability of low-lying areas, such as Thoraipakkam and Karapakkam, owing to intensified rainfall, rising sea levels, and reduced drainage efficiency.

To mitigate these challenges, it is imperative to adopt holistic urban planning strategies that emphasize wetland conservation, the restoration of natural drainage systems, and the remediation of degraded areas. The implementation of Low-Impact Development (LID) principles, integration of green infrastructure, and reinforcement of stormwater management policies are essential steps toward reducing flood risks. A comprehensive, ecosystem-based approach that aligns climate resilience with sustainable urban expansion is critical for ensuring long-term flood mitigation and environmental sustainability in Chennai.

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