International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print); 2222-5234 (Online)
Website: https://www.innspub.net
Email contact: info@innspub.net
Vol. 28, Issue: 2, p. 28-37, 2026

RESEARCH PAPER

OPEN ACCESS

Linkages between land use change, flooding, and water quality in the Pallikaranai Marshland, Chennai, India

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Key words: Pallikaranai marshland, Urbanization, Flooding, Water quality, Land use/Land cover

Received Date: January 21, 2026 **Published Date:** February 04, 2026

DOI: https://dx.doi.org/10.12692/ijb/28.2.28-37

ABSTRACT

The Pallikaranai marshland, one of the last remaining natural wetlands in the Chennai Metropolitan Area, plays a crucial role in flood regulation and water quality maintenance. Rapid urbanization, land use/land cover (LULC) changes, wetland encroachment, and expansion of impervious surfaces have significantly altered its hydrological and environmental functions. This study evaluates the impact of urban land use changes and flooding on water quality in and around Pallikaranai during March 2025. Flood-prone areas were identified using historical satellite imagery and spatial analysis. LULC classification revealed the dominance of built-up areas, reduction in wetland extent, and increased impervious cover. Water quality analysis indicated elevated electrical conductivity, total dissolved solids, hardness, and sodium concentrations in flood-affected zones. Organic pollution indicators such as BOD and COD were also higher in highly urbanized and flood-prone areas. These trends suggest contamination from urban runoff, sewage intrusion, and landfill leachate during flood events. Parameters including pH, nitrate, sulphate, and iron largely remained within permissible limits. Despite this, overall water quality showed signs of stress in areas influenced by flooding and urban activities. Flooding was found to act as a major transport mechanism for pollutants across the landscape. The study highlights the need for wetland conservation, restoration of natural drainage systems, and sustainable urban planning to protect water resources in Chennai.

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INTRODUCTION

Wetlands provide several key ecosystem services which include flood mitigation, retain the water quality, the recharge of groundwater, and build resilience against climate change (Millennium Ecosystem Assessment, 2005; Ramsar Convention Secretariat, 2018; MoEFCC, 2020). Wetlands regulate temperature and reduce the urban heat island (UHI) effect by maintaining humidity through evapotranspiration in urban areas (Zhang *et al.*, 2019; UNEP, 2021; IIT Madras, 2020). Their preservation is thus crucial for ecological sustainability and urban resilience (IPCC, 2022; Department of Environment, Climate Change and Forests, Government of Tamil Nadu, 2022).

The Pallikaranai Wetland, on the southern edge of Chennai, is an important freshwater marsh with an aquatic buffer zone of over 65 wetlands covering approximately 250 square kilometers (Swetha *et al.*, 2025; Vencatesan and Lakshumanan, 2018). The Pallikaranai Wetland in Chennai is one of the few remaining urban wetlands in South India and a Ramsar-designated site due to its ecological importance (Ramsar Convention Secretariat, 2022; Government of Tamil Nadu, 2017). Historically it covered thousands of hectares but has drastically shrunk due to urban expansion and encroachments (Hydrology and Water Resources Management Institute, 2016; Vencatesan and Lakshumanan, 2018). The combined impact of flooding and altered land use in the Pallikaranai Wetlands degrades water quality by increasing pollutant loads, disrupting hydrological flows, and weakening the natural filtration and storage functions of the wetland (Tamil Nadu Pollution Control Board, 2019; Zedler and Kercher, 2005). Protection and restoration of wetlands, control of pollutant sources, and sustainable land-use planning are essential to improving and safeguarding water quality (Millennium Ecosystem Assessment, 2005).

As a Ramsar site, it supports biodiversity and protects the adjacent urban areas from flooding (Ramsar Convention Secretariat, 2022). However, rapid commercial activities and infrastructural growth in the vicinity has converted large tracts of natural wetlands into built environments, fragmenting habitats and hydrological flows (Vencatesan and Lakshumanan, 2018). All these shifts as led to higher pollutant runoff, increased salinity, and rising temperatures-each having negative effects on water quality and stressing aquatic ecosystems (Tamil Nadu Pollution Control Board, 2019; Swetha *et al.*, 2025).

Recent environmental issues in Pallikaranai

Impacts of floods on water quality: Flood events act as triggers that mobilize accumulated pollutants and stress the weakened wetland system (Zedler and Kercher, 2005; Tamil Nadu Pollution Control Board, 2019). Land use change is the underlying driver that has degraded the wetland's capacity to absorb, filter, and store water, leading to poorer water quality and more severe impacts from floods (Vencatesan and Lakshumanan, 2018).

During heavy rains, flood influx brings contaminants where the runoff carries sewage, solid waste, and urban pollutants into the wetland systems (Central Pollution Control Board, 2012).

This runoff increases nutrient loads (nitrogen and phosphorus), suspended solids, and pathogen counts in water bodies (Wetzel, 2001). Flood events can flush accumulated toxins (from earlier pollution or landfills) back into the surface and groundwater, concentrating contamination in connected lakes and channels (Millennium Ecosystem Assessment, 2005).

Further Hydrological Disruption is observed where natural drainage channels around the wetland have been clogged, blocked, or altered due to infrastructure (roads, buildings, storm drains), leading to stagnant water pockets where pollutants concentrate (Sundaramoorthy *et al.*, 2009). The wetland's reduced area and storage capacity mean it can no longer absorb or attenuate floodwaters effectively, so high pollutant loads stay longer in the ecosystem (WWF-India, n.d.).

Seasonal water quality variability: Studies show water quality fluctuates seasonally (Wetzel, 2001; Millennium Ecosystem Assessment, 2005). During the Monsoon season, dilution reduces concentrations of some pollutants (Central Pollution Control Board, 2012).

And during dry season, the pollutants become more concentrated, increasing eutrophication and degraded water quality (Wetzel, 2001; Kumar *et al.*, 2015; University of Kiel, n.d.).

Impacts of land use change

Urbanization and reduced infiltration: Around 80% of the watershed is now urbanized, increasing impervious surfaces (roads, pavements), which both boosts surface runoff and reduces natural infiltration (Vencatesan and Lakshumanan, 2018; Sundaramoorthy *et al.*, 2009). This change increases flood peak flows and limits the wetland's ability to recharge groundwater or filter pollutants (Zedler and Kercher, 2005; Millennium Ecosystem Assessment, 2005).

Pollution sources linked to land use: Untreated sewage discharge, industrial effluents, and landfill leachate (notably from the Perungudi dump yard) are major sources of contaminants entering the wetland (Tamil Nadu Pollution Control Board, 2019; Central Pollution Control Board, 2012). Adjacent residential and IT zone development has replaced natural wetlands and buffer zones that once helped filter and store water, worsening pollution loads (Vencatesan and Lakshumanan, 2018).

Expansion of the Perungudi landfill directly affects water quality through leachate (toxic liquid) entering subsurface and surface waters, raising heavy metal and chemical concentrations (TNPCB, 2019; Sundaramoorthy *et al.*, 2009). Wetland vegetation that once helped uptake nutrients and slow flows has been lost due to urban expansion and invasive species pressures, further reducing the wetland's natural cleansing functions (Zedler and Kercher, 2005).

The ecological implications are such as eutrophication where high nutrient loads from runoff and sewage promote algal blooms (Wetzel, 2001; Millennium Ecosystem Assessment, 2005).

These blooms deplete oxygen, harming fish and other aquatic organisms (Wetzel, 2001).

Rapid drying, pollution and habitat loss reduce habitat quality for fish, birds, and amphibians that depend on clean, vegetated wetland habitats leads to biodiversity decline (Ramsar Convention Secretariat, 2018). Further the pollutants infiltrate groundwater, threatening local water supplies with contaminants like nitrates, organics, and heavy metals (Central Pollution Control Board, 2012).

Floods and land-use change jointly influence water quality, hydrology, ecological health, and flood mitigation, though through distinct pathways. Floods increase surface runoff, mobilizing and redistributing pollutants, while land-use change expands pollutant sources and diminishes natural filtration. Hydrologically, floods generate rapid inflows and localized stagnation, whereas land-use change reduces natural storage capacity and amplifies peak flood flows due to altered drainage and impervious surfaces. Ecologically, floods cause short-term habitat disruption during high-flow events, but land-use change leads to long-term habitat degradation through persistent loss and pollution. In terms of flood mitigation, extreme floods can overwhelm natural buffers such as wetlands, while land-use change—particularly urbanization—reduces water absorption capacity and substantially increases flood risk.

Extensive biomining to recover and process decades of waste has been continuously carried out in the Perungudi dumpyard since 2021, with the goal of reversing environmental contamination and restoring ecological function to the land (Greater Chennai Corporation, 2021; Tamil Nadu Pollution Control Board, 2022). While the dumpyard is not in expansion anymore, the residual impacts such as the presence of heavy metals like Cu, Cr, Ni, Zn, Pb and its higher ecological risk indicator values of its historic waste disposed alongside current urban pressures continue to affect the wetland's ecological health (Kuppusamy *et al.*, 2025; Sundaramoorthy *et al.*, 2009). Recent studies show that the loss of wetland area and its vegetation cover in Chennai also involves Pallikaranai, which has driven an average increase in land surface temperature by more than 6°C in certain urban zones (Sahithi, 2023; Mathivanan *et al.*, 2024; Zhang *et al.*, 2019), increasing the local UHI effect. This accumulated heat increases levels of pollutants due to higher evaporation rates and decreases natural water availability, further exacerbating issues related to wetland water quality, especially during summer droughts and monsoon floods (Wetzel, 2001; Millennium Ecosystem Assessment, 2005). Thus, maintaining Pallikaranai's blue-green infrastructure would be crucial for reducing heat stress and safeguarding urban water security (Ramsar Convention Secretariat, 2018; IPCC, 2022).

MATERIALS AND METHODS

Study area

The Pallikaranai Marsh is a 235 km² fresh water Wetland located at Pallikaranai in Chennai District of Tamil Nadu (12.949371 N, 80.218184 E) (Government of Tamil Nadu, 2017; Institute for Ocean Management, 2018). Pallikaranai Marsh is one of the Ramsar Conservation Site among 16 in Tamil Nadu which was declared in 08-04-2022 (Ramsar Convention Secretariat, 2022). The Ramsar Conservation site number is "2481" (Ramsar Convention Secretariat, 2022). Locally, people refer to it by the general Tamil term "Kazhuveli," which denotes a flood plain or area covered in water (Vencatesan and Lakshumanan, 2018). Pallikaranai Marshland in Chennai has a tropical wet and dry climate, influenced by its proximity to the coast (Indian Meteorological Department, 2020). The marsh receives an average annual rainfall of about 1,215 mm (Indian Meteorological Department, 2020) (Fig. 1).

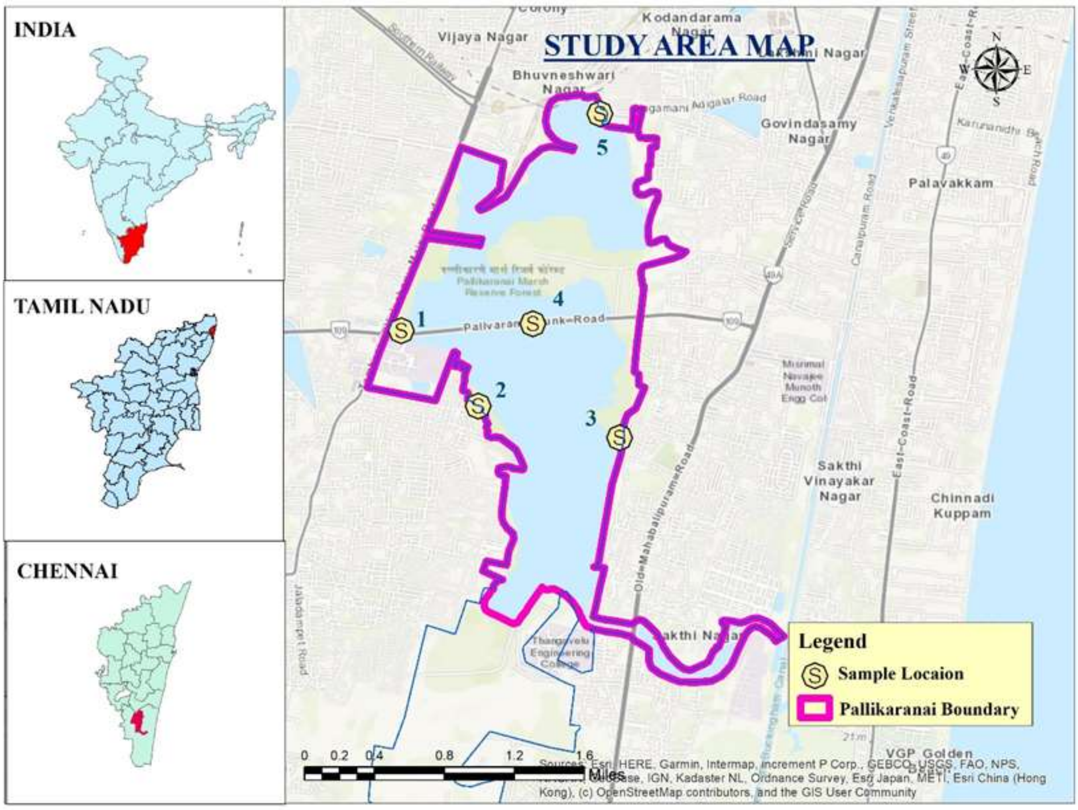

Fig. 1. Study area map

Flood area mapping

The study area boundary was delineated in Google Earth Pro, encompassing the Pallikaranai marshland, surrounding residential and commercial areas, major road networks, and associated drainage channels (Google, 2023). The delineated boundary was saved in KML/KMZ format for spatial analysis and mapping (ESRI, 2018). Historical satellite imagery available in Google Earth Pro was analyzed to identify flood events during major flood years such as 2015, 2021, and recent occurrences (Sanyal and Lu, 2004; National Remote Sensing Centre, 2016). Flood-affected locations were identified based on the presence of standing or stagnant water, submerged road networks and open spaces, and the expansion of water bodies beyond their normal extents (UN-SPIDER, 2019). The observed flood locations were digitized as points and attributed with the corresponding year and date of flooding (Jensen, 2015).

Low-lying and flood-prone areas were identified through visual interpretation of terrain characteristics, including flat topography, prolonged water retention, marshy vegetation, and proximity to wetlands (Lillesand *et al.*, 2015). Natural and man-made drainage features such as canals, stormwater drains, ponds, and marsh extents were also digitized using Google Earth Pro (Google, 2023). Particular attention was given to obstructed drainage channels, areas of drainage convergence, and encroached or modified wetland zones (Vencatesan and Lakshumanan, 2018). These features were analyzed to understand their influence on flood propagation, water accumulation, and the associated increase in contamination load (Sundaramoorthy *et al.*, 2009; Millennium Ecosystem Assessment, 2005).

Landuse landcover analysis

A visual interpretation approach was employed to classify land use and land cover within the study area using ArcGIS (ESRI, 2018; Lillesand *et al.*, 2015). The Landsat 8 satellite data was obtained from USGS Earth Explorer for the date 31st March 2025 (USGS, 2025). The major land use categories identified include built-up areas, wetlands and marshes, vegetation, open lands, and transportation networks (Jensen, 2015). Changes in land use patterns were analyzed, with particular emphasis on the conversion of wetlands and marshy areas into built-up land (Vencatesan and Lakshumanan, 2018; Sundaramoorthy *et al.*, 2009).

These changes were assessed to understand their influence on surface runoff, drainage obstruction, and the increased occurrence of flooding within the study area (Millennium Ecosystem Assessment, 2005).

Water sampling

Water samples were collected from five strategically selected locations within the Pallikaranai Wetland in March 2025 to represent variability across the study area (American Public Health Association [APHA], 2017; Wetzel, 2001). The selection of sampling sites was determined by accessibility, proximity to potential pollution sources, inflow and outflow points, and observed ecological activities, including bird congregation areas and vegetative cover (Kumar *et al.*, 2015; Vencatesan and Lakshumanan, 2018). All sites were geo-referenced using a handheld GPS device to ensure consistency in repeated seasonal sampling (Jensen, 2015). Sampling was conducted during the early morning hours to maintain uniformity in physical parameters such as temperature and dissolved oxygen (APHA, 2017). Clean polyethylene bottles which are 1-litre capacity were used for sample collection. Prior to collection, bottles were rinsed thoroughly with the sample water three times at each site to avoid contamination (APHA, 2017). In-situ parameters such as pH, temperature, dissolved oxygen (DO), and electrical conductivity (EC) were measured on-site using calibrated portable multi-parameter water quality meter (Wetzel, 2001).

Analysis of physico-chemical parameters

The water samples collected from Pallikaranai Wetland in the month of March 2025 were analysed for physico-chemical parameters such as pH, Electrical Conductivity, Total Dissolved Solids (TDS), Total Hardness, Calcium, Magnesium, Chloride, Total Alkalinity, Residual Chlorine, Sulphate, Iron, Nitrate, Sodium, Potassium, Chromium, Copper, Nickel, Manganese, Aluminium, Chemical Oxygen Demand (COD), and Biological Oxygen Demand (BOD) using the IS:3025 Standard for Water Quality Analysis in laboratory for analysis (BIS, 1983; APHA, 2017).

RESULTS AND DISCUSSION

The analysis of water samples collected from five locations (Sample 1 to Sample 5) across the Pallikaranai wetland revealed notable variations in physico-chemical characteristics as shown in Table 1.

The pH values of all samples ranged between 6.67 and 7.07 which were within the permissible limit, indicating neutral conditions favourable for aquatic life. However, high Electrical Conductivity (1758–3380 µS/cm) and Total Dissolved Solids (1030–1990 mg/L) were recorded in Samples 1, 3, and 4, indicating higher ionic concentrations possibly due to municipal or urban runoff. Similarly, Total Hardness values exceeded the permissible limit (600 mg/L) in Samples 1, 3, 4, and 5 mainly due to elevated calcium (up to 235 mg/L) and magnesium (up to 103 mg/L) levels. Chloride concentrations ranged between 313 and 893 mg/L, remaining within the acceptable limit but indicating moderate salinity in Samples 1 and 3. Total Alkalinity between 312 and 543 mg/L remained within the permissible range, showing adequate buffering capacity of wetland water.

Table 1. Water quality parameters data of five sample location (all values are in milligram/litre)

Sl	Parameters	Permissible limit	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
1	pH	6.5-9.0	6.68	6.93	7.07	6.83	6.67
2	Electrical Conductivity		3380	1950	3230	3236	1758
3	Total Dissolved Solids in mg/l	1500	1990	1146	1905	1900	1030
4	Total Hardness in mg/l	600	759	385	638	881	658
5	Calcium in mg/l	180	134	73	117	235	109
6	Magnesium in mg/l	70	103	49	84	71	93
7	Chloride in mg/l	1000	893	383	814	740	313
8	Total Alkalinity in mg/l	600	312	543	442	352	462
10	Sulphate In mg/l	400	59	8	25	92	24
11	Iron in mg/l	0.5	0.15	0.17	0.08	0.11	0.09
12	Nitrate in mg/l	45	32	29	13	13	16
13	Sodium in mg/l	100	512	238	515	482	169
14	Potassium in mg/l	250	48	22	50	46	16
20	COD in mg/l	250	130	94	108	124	90
21	BOD for 3 days at 25°C in mg/l	30	34	26	33	37	25

Nitrate concentrations, though within the acceptable limit, were relatively higher in Samples 1 and 2, ranging from 13 to 32 mg/L, indicating nutrient enrichment due to wastewater inflow. The sodium ion concentration was high in Samples 1, 3, and 4 (as high as 515 mg/L), indicating salinity stress and mixing of wastewater. High COD and BOD values across all samples, ranging between 90–130 mg/L and 25–37 mg/L. The contamination levels of Samples 1, 3, and 4 were higher than those of Samples 2 and 5. Therefore, it is apparent that the ongoing discharge of domestic wastewater with inadequate flushing is causing moderate to severe anthropogenic stress in the Pallikaranai wetland (Fig. 2).

Fig. 2. Flood zone and land use land cover of Pallikaranai wetland region

A comparative assessment of the flood inundation map and the land use/land cover (LULC) map reveal a strong spatial relationship between flooding patterns and land use characteristics within the Pallikaranai region (Sanyal and Lu, 2004; Vencatesan and Lakshumanan, 2018). The flood zones, when overlaid on the LULC classification, show that a significant proportion of flooded areas coincide with wetlands, marshland vegetation, waterlogged areas, and low-lying open lands (Sundaramoorthy *et al.*, 2009; Millennium Ecosystem Assessment, 2005).

These areas naturally act as water retention zones and exhibit prolonged inundation during heavy rainfall events (Ramsar Convention Secretariat, 2018). The spatial concentration of flood zones along the central marsh corridor highlights the hydrological significance of the Pallikaranai wetland system (Vencatesan and Lakshumanan, 2018).

The comparison further indicates that built-up areas and impervious surfaces located adjacent to wetlands and drainage channels are increasingly affected by flooding (Zedler and Kercher, 2005; Lillesand *et al.*, 2015). Urban expansion into marshland and conversion of permeable surfaces into impervious layers have disrupted natural drainage pathways, leading to surface runoff accumulation and localized flooding (Sundaramoorthy *et al.*, 2009; Jensen, 2015). Areas characterized by drainage convergence, encroached wetlands, and proximity to water bodies exhibit higher flood susceptibility (UN-SPIDER, 2019). This relationship underscores the impact of land use transformation—particularly wetland loss and increased impervious cover—on flood propagation and waterlogging, thereby increasing flood risk and contamination load in the study area (Millennium Ecosystem Assessment, 2005; Vencatesan and Lakshumanan, 2018).

Influence of land use/land cover and flooding on water quality

The water quality analysis indicates a clear influence of land use/land cover (LULC) patterns and flood inundation on the physico-chemical characteristics of surface and groundwater samples collected from the study area (APHA, 2017; Wetzel, 2001; Sundaramoorthy *et al.*, 2009). The pH values across all samples ranged from 6.67 to 7.07, remaining within the permissible limits, indicating neutral conditions (BIS, 1983; APHA, 2017). However, elevated electrical conductivity (EC) and total dissolved solids (TDS) were observed in Samples 1, 3, and 4, exceeding the permissible limit of 1500 mg/l for TDS (BIS, 1983).

These locations coincide with flood-prone zones dominated by built-up areas, impervious surfaces, and proximity to marshland and dumpyard sites, suggesting enhanced dissolution of salts and pollutants during flood events (Vencatesan and Lakshumanan, 2018; Sundaramoorthy *et al.*, 2009).

Total hardness, calcium, magnesium, and sodium concentrations were notably higher in samples collected from areas characterized by dense urban development, impervious layers, and wetland encroachments (Wetzel, 2001; Millennium Ecosystem Assessment, 2005). Total hardness exceeded permissible limits in Samples 1, 3, 4, and 5, indicating leaching of minerals and domestic waste inputs during flooding (BIS, 1983). Elevated sodium levels, particularly in Samples 1, 3, and 4, reflect contamination from urban runoff, sewage intrusion, and landfill leachates transported through floodwaters (Tamil Nadu Pollution Control Board, 2019; Kuppusamy *et al.*, 2025). The presence of higher magnesium and calcium further indicates prolonged water–soil interaction in waterlogged and marsh-adjacent areas (Wetzel, 2001).

Chloride and alkalinity values remained within permissible limits but showed higher concentrations in flood-affected zones, suggesting mixing of domestic wastewater and surface runoff (APHA, 2017). Nutrient parameters such as nitrate were within limits across all samples; however, slightly elevated values in urbanized zones point toward agricultural runoff and sewage influence during inundation (BIS, 1983; Vencatesan and

Lakshumanan, 2018). Sulphate and iron concentrations were within acceptable limits, indicating limited industrial contribution (BIS, 1983).

Organic pollution indicators-Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)—show elevated BOD values exceeding permissible limits in Samples 1, 3, and 4 (APHA, 2017; Wetzel, 2001). These samples correspond to areas with high flood exposure, wetland encroachment, and proximity to dumpyards and sewage treatment facilities (Kuppusamy *et al.*, 2025; Sundaramoorthy *et al.*, 2009). Floodwaters facilitate the transport of organic waste, sewage overflow, and decomposing vegetation into water bodies, leading to increased oxygen demand and deterioration of water quality (Millennium Ecosystem Assessment, 2005; Vencatesan and Lakshumanan, 2018).

Overall, the results demonstrate that flooding acts as a major transport mechanism, redistributing pollutants from built-up areas, dumpyards, impervious surfaces, and encroached wetlands into surrounding water bodies (Sanyal and Lu, 2004; Ramsar Convention Secretariat, 2018). The LULC pattern—particularly increased urbanization, loss of marshland, and expansion of impervious surfaces—has significantly amplified flood-induced contamination, resulting in elevated salinity, hardness, sodium content, and organic pollution in the study area (Vencatesan and Lakshumanan, 2018; Sundaramoorthy *et al.*, 2009).

CONCLUSION

The study concludes that unplanned urban expansion and degradation of the Pallikaranai marshland have intensified flood vulnerability and contributed to the deterioration of water quality. Flood events act as a critical pathway for contaminant transport, leading to elevated salinity, hardness, sodium levels, and organic pollution in flood-affected zones. The findings emphasize the urgent need for wetland conservation, restoration of natural drainage networks, and regulation of impervious surface expansion to mitigate flood-induced water contamination. Integrating sustainable land use planning with flood management strategies is essential for improving water quality and ensuring long-term environmental resilience in the Pallikaranai region.

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