# Assessing the Hydrological and Ecological Impacts of River Diversion in Urbanizing Floodplains: A Case Study of the Ulwe River Basin, Navi Mumbai

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# Assessing the Hydrological and Ecological Impacts of River Diversion in Urbanizing Floodplains: A Case Study of the Ulwe River Basin, Navi Mumbai

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## Abstract
This study investigates the hydrological and ecological consequences of river diversion in the context of rapid urban development, using the Ulwe River basin near Navi Mumbai International Airport (NMIA) as a case study. The diversion of the Ulwe River has altered the region's floodplain dynamics. Through the integration of GIS, remote sensing, LULC analysis, and surface runoff modelling, this research assesses the extent to which altered flow regimes, increased impervious surfaces, and ecological disruption contribute to flood vulnerability. Findings indicate a significant increase in surface runoff between 2016 and 2024, driven by declining wetland areas and rising built-up zones. The loss of mangroves and wetlands has reduced the flood absorption capacity, while bank erosion and sediment shifts have compromised river morphology. This research provides data-driven insights into urban floodplain degradation and supports the need for policy interventions centred on ecological preservation, informed planning, and sustainable design.

## Keywords
River Diversion, Floodplain Management, Urbanisation, Surface Runoff, Hydrological Change, Geospatial Analysis.

# 1 Introduction

Floodplains are dynamic natural systems that provide essential ecological, hydrological, and socio-economic services. Their capacity to store floodwater, replenish groundwater aquifers, maintain wetland habitat, and promote biodiversity makes them vital for urban resilience and water management. Yet, in fast urbanising areas, these landscapes are being increasingly subjected to anthropogenic stressors like land reclamation, channel alteration, and the expansion of impermeable surfaces. These changes interfere with natural hydrological regimes and enhance surface run-off, thus increasing flood risk, shifting sediment transport processes, and degrading wetland environments.(Pathak et al., 2020a)

Navi Mumbai, one of India's largest planned cities,  is also experiencing accelerated infrastructural growth based on initiatives like the Navi Mumbai International Airport (NMIA) and the peripheral Navi Mumbai Airport Influence Notified Area (NAINA). The Ulwe River, which is a major coastal river in the area, has been greatly altered as part of these urban development efforts. The river, initially 25 to 30 metres in width, was artificially widened to a width of 200 metres and deepened by some 2.5 to 3 metres. The engineered diversion was done to contain flood risk and make land available for the airport construction. Such hydrological engineering impacts have far-reaching effects on the natural flow regime, sediment budget, and ecological continuity of the river.

The floodplain of the Ulwe River, previously marked by patches of connected wetlands, mangroves, and tidal mudflats, has been fragmented because of embankments, reclamation, and encroachment. This has resulted in heightened surface runoff, lowered infiltration, and lowered flood-buffering capacity. The modified flow regime has additionally altered sediment deposition patterns, with a resultant bank instability and erosion. In addition, the clearing of vegetated buffers and wetlands has reduced biodiversity and made surrounding settlements more vulnerable to climate-related hydrological processes, including intense rainfall and storm surges. (Pathak et al., 2020b)

Contrary to the scale of these changes, very little scholarly research is available to assess the cumulative effects of river diversion and urban growth on the functionality of floodplains in peri-urban Indian coastal areas. The majority of the literature targets either flood risk modelling or land use analysis alone, without considering ecological, hydrological, and spatial planning viewpoints. (Das, 2018) Additionally, while government organizations like CIDCO and NMMC conducted Environmental Impact Assessments (EIA) for certain projects, there is still a lack of longitudinal assessments that account for temporal land cover changes, runoff characteristics, and the effectiveness of mitigation measures.

This study seeks to address that gap by adopting a comprehensive geospatial framework to assess the impacts of river diversion on floodplain morphology, surface runoff, and ecological integrity in the Ulwe River basin. The research is guided by three interlinked objectives: (1) to quantify land use and land cover (LULC) changes between 2014 and 2024 using remote sensing data, (2) to evaluate alterations in surface runoff patterns resulting from urbanisation and river channel modifications, and (3) to identify ecologically sensitive zones suitable for flood mitigation interventions.

The methodology integrates multi-temporal satellite image classification, estimation of surface runoff employing the Soil Conservation Service Curve Number (SCS-CN) technique, and GIS-based spatial analysis of flood-susceptible and erosion-prone regions. Particular emphasis is placed on soil hydrologic group properties, with the study area consisting mostly of Hydrological Soil Group C, which points towards low infiltration capacities. 2016 and 2024 runoff values are computed using land cover categories and cross-checked with Strange's Tables, an official hydrological guide for Indian river basins.

Through an examination of the spatial interaction between engineered river alterations, urban land cover advancement, and hydrological reactions, this study provides sustainable floodplain management evidence-based insights. (Jain & Kumar, 2014) Results will seek to inform urban planning processes, shape zoning codes, and benefit the incorporation of ecological infrastructure in future developmental strategies in the NAINA area.

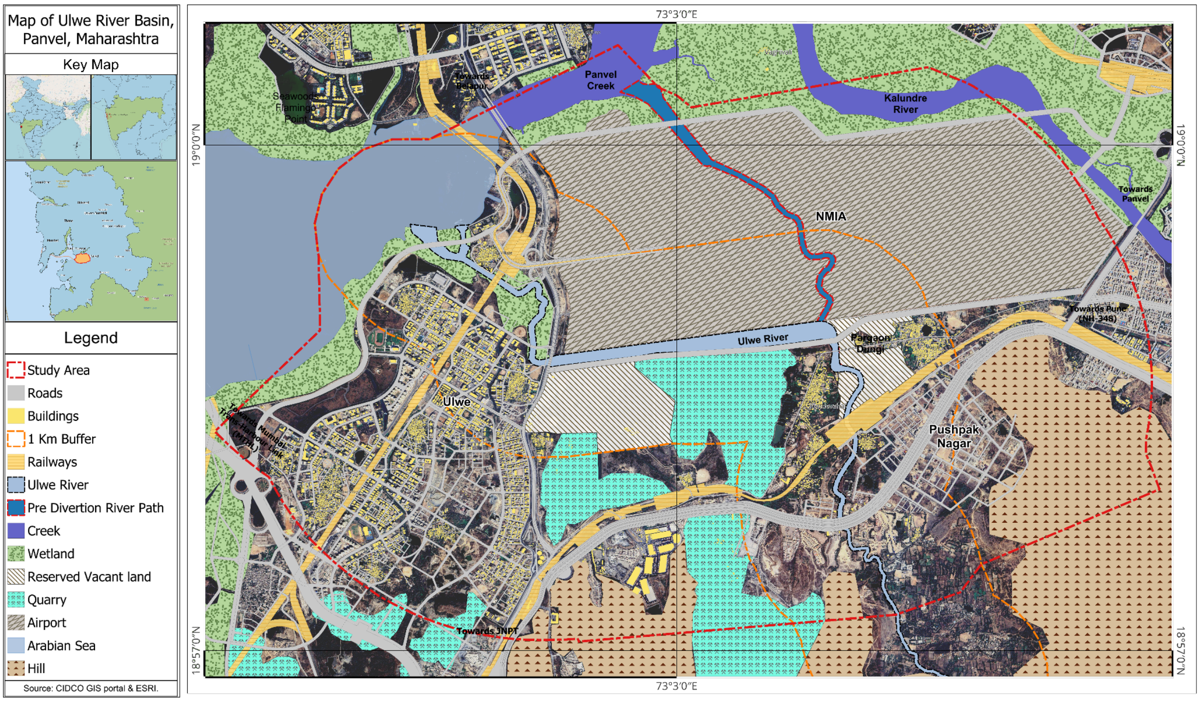


Figure 1 Study Area Map of  Ulwe River Basin

# 2 Literature Review

## 2.1 Impacts of Urbanisation on Hydrology

Urbanisation drastically modifies the natural hydrological cycle. The substitution of permeable surfaces with impermeable infrastructure like roads, buildings, and parking lots—interrupts natural infiltration and augments surface runoff. Consequently, maximum discharge rates in urban streams surge dramatically during precipitation events, increasing the hazard of flash floods and burdening drainage infrastructure. The modification of land surfaces also generates reduced lag times, reduced baseflow, and lower groundwater recharge capacity.

In coastal cities such as Navi Mumbai, urban expansion exerts further pressure on floodplains, estuaries, and wetlands ecosystems that historically played a critical role in absorbing floodwaters. The loss of vegetative buffers and soil compaction contributes to rapid hydrological responses, thereby reducing the time available for emergency management during flood events. The relationship between land use change and flood hazard has been substantiated by numerous studies, which demonstrate a direct correlation between increased impervious surface coverage and rising flood frequencies in peri-urban zones.

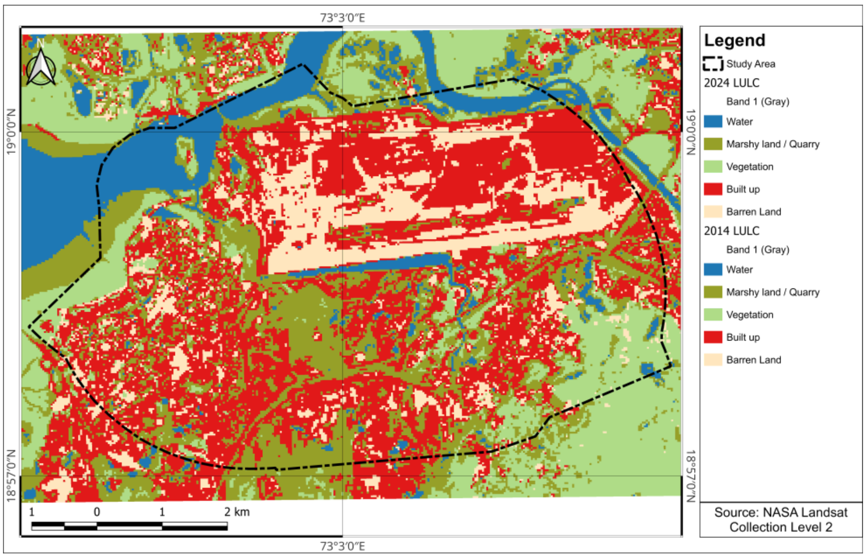


Figure 2 Land cover 2025

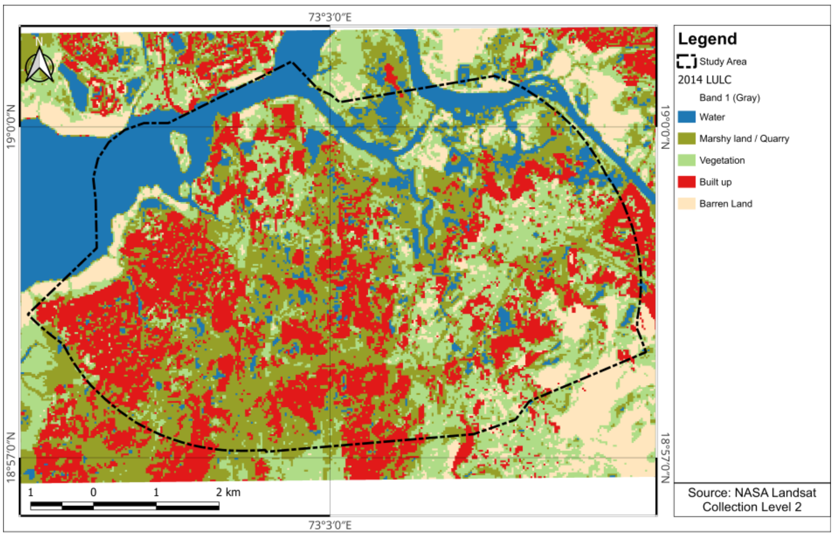


Figure 3 Land cover 2014

## 2.2 River Diversions: Global and Indian Perspectives

River diversion as a method of land reclamation, flood control, or infrastructure facilitation has a long history globally, but it is not without ecological costs. The Caernarvon Freshwater Diversion Project in south-eastern Louisiana, USA, is an internationally known case of river diversion for wetland restoration and flood hazard mitigation. Permitted by a sequence of U.S. federal legislation and built during the period from 1988 to 1991, the Caernarvon facility sits on the east bank of the Mississippi River and is intended to reintroduce as much as 8,000 cubic feet per second of freshwater, sediments, and nutrients into the bays and marshes of the Breton Sound estuary. The main goals are to increase emergent marsh plants, decrease marsh loss, and increase the productivity of commercial and recreational fisheries, especially oysters, which have been impacted by saltwater intrusion. The primary objectives are to enhance emergent marsh vegetation, reduce marsh loss, and boost the productivity of commercial and recreational fisheries, particularly oysters, which have suffered from saltwater intrusion

The project operates through controlled diversions, especially during high-flow periods, to mimic natural flood pulses and maintain salinity gradients beneficial for marsh and estuarine ecosystems. Extensive monitoring-including pre- and post-construction ecological assessments and long-term tracking of vegetation, fisheries, and water quality-has demonstrated positive outcomes. These include increased marsh stability, improved oyster production, and the mitigation of saltwater intrusion, supporting both ecological health and local livelihoods. The Caernarvon experience is frequently cited as a model for nature-based solutions in coastal restoration, emphasizing adaptive management, stakeholder engagement, and the integration of ecological objectives into river management. (Wu et al., 2023)

In the Indian context, river diversion has generally been synonymous with dam development and inter-basin water transfer schemes. For example, the Ken-Betwa link project illustrate the countrywide scale of such hydraulic alterations. (Alagh et al., 2006; Amarasinghe et al., 2008) Nonetheless, river diversion has not been addressed with much attention at the urban scale, especially in coastal environments. The diversion of Ulwe River for the NMIA is an example wherein the environmental consequences such as loss of mangroves, changed sediment transport, and tidal inflow have not sufficiently been recorded in scientific studies. A significant Indian precedent is the Mithi River in Mumbai, which was channelized after the 2005 flood disaster. (Zope et al., 2017) Notwithstanding engineering works, the river is still highly flood-prone due to poor maintenance and the lack of proper integration with land-use planning. The above parallels reiterate the imperative to study the hydrological consequences of reconfiguring rivers in urbanising settings.

**2.3 Surface Runoff Estimation and Strange’s Tables**

Estimating surface runoff is essential for understanding flood potential, especially in regions where rapid land use change alters infiltration characteristics. The Soil Conservation Service Curve Number (SCS-CN) procedure is applied extensively in urban hydrology for its simplicity and flexibility across many land cover and soil categories. The model makes use of rainfall amounts, land use type, and hydrological soil groups (HSG) in estimating runoff depth. In this research, all the three significant soil types present in the Ulwe River basin belong to Hydrological Soil Group C characterized by moderate infiltration and a high runoff capacity, especially in the absence of vegetative cover.

Strange's Tables, which were initially constructed for Indian river basins, are a historical benchmark for the estimation of runoff in ungauged catchments. They correlate rainfall intensity, soil type, and land use to anticipated runoff coefficients. Although they represent a generalised model, their compatibility with current satellite-derived LULC data allows temporal comparison. Strange's values were utilized in this research to calculate surface runoff in the years 2016 and 2024 and found to have increased remarkably in runoff depth as a result of urban growth. (Srinivas G et al., 2020)

**2.4 Previous Hydrological and Ecological Studies in the Region**

Several assessments have examined the hydrological vulnerability of the Mumbai Metropolitan Region (MMR), including studies commissioned by CIDCO and NMMC. These reports generally focus on stormwater drainage and flood inundation mapping but often lack ecological integration. Environmental Impact Assessments (EIA) for the NMIA have acknowledged the need for compensatory mangrove plantation and wetland restoration, but ground implementation remains limited.

Recent geospatial studies have shown a consistent reduction in wetland area in Navi Mumbai, particularly in areas surrounding the Panvel-Ulwe region. Concurrently, hydrological models applied to nearby rivers such as the Gadhi and Kasadi—have demonstrated that river channel modifications result in faster time-to-peak flows and higher runoff coefficients. Moreover, ecological assessments have underscored the decline in mangrove density and wetland bird populations in the last decade, suggesting a loss of ecological services such as flood buffering and groundwater recharge.

Despite these findings, there is a conspicuous absence of integrated studies that combine hydrological modelling, land use change detection, and ecological vulnerability assessments specific to the Ulwe River basin. This research aims to address that gap by synthesising multiple datasets and proposing spatially explicit recommendations for sustainable floodplain management.

## 3. Methodology

This study employs an integrated geospatial and hydrological framework to assess the consequences of river diversion and land cover changes on floodplain dynamics in the Ulwe River basin. The methodology is organized across four primary components: land use and land cover (LULC) analysis, hydrological assessment, ecological evaluation, and susceptibility analysis. These components collectively enable a comprehensive understanding of the physical and ecological alterations resulting from anthropogenic interventions.

### 3.1 Land Use and Land Cover (LULC) Analysis

The spatio-temporal transformation of land use is a primary indicator of anthropogenic pressure on floodplain environments. Supervised classification was conducted on Landsat and Sentinel satellite imagery for the years 2014 and 2024 using the maximum likelihood algorithm within QGIS. Five key land cover classes were delineated: water bodies, marshland, vegetation, built-up area, and barren land.

Results revealed a notable increase in the built-up area from 21.99% in 2014 to 31.74% in 2024, accompanied by a decline in marshland and vegetation. This shift highlights intensified urbanization in the floodplain, particularly in proximity to the Ulwe River and within the Navi Mumbai Airport Influence Notified Area (NAINA). These land cover changes were validated through historical records, satellite-derived indices, and limited field verification.

| Sr. no. | Change | Area Change | Class_2014 | Class_2024 | %age |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| **1** | Barren - Barren | 28.07 | Barren | Barren | 0.34 |
| **2** | Barren - Built | 59.07 | Barren | Built up | 0.72 |
| **3** | Barren - Marsh Land | 44.82 | Barren | Marsh Land | 0.55 |
| **4** | Barren - Vegetation | 698.30 | Barren | Vegetation | 8.56 |
| **5** | Barren - Water | 3.95 | Barren | Water | 0.05 |
| **6** | Built up - Barren | 336.65 | Built up | Barren | 4.13 |
| **7** | Built up - Built | 1030.42 | Built up | Built up | 12.64 |
| **8** | Built up - Marsh Land | 321.93 | Built up | Marsh Land | 3.95 |
| **9** | Built up - Vegetation | 72.59 | Built up | Vegetation | 0.89 |
| **10** | Built up - Water | 31.44 | Built up | Water | 0.39 |
| **11** | Marsh Land - Barren | 270.61 | Marsh Land | Barren | 3.32 |
| **12** | Marsh Land - Built | 890.87 | Marsh Land | Built up | 10.92 |
| **13** | Marsh Land - Marsh Land | 908.82 | Marsh Land | Marsh Land | 11.14 |
| **14** | Marsh Land - Vegetation | 165.77 | Marsh Land | Vegetation | 2.03 |
| **15** | Marsh Land - Water | 80.42 | Marsh Land | Water | 0.99 |
| **16** | Vegetation - Barren | 192.97 | Vegetation | Barren | 2.37 |
| **17** | Vegetation - Built | 419.83 | Vegetation | Built up | 5.15 |
| **18** | Vegetation - Marsh Land | 463.47 | Vegetation | Marsh Land | 5.68 |
| **19** | Vegetation - Vegetation | 742.51 | Vegetation | Vegetation | 9.11 |
| **20** | Vegetation - Water | 21.33 | Vegetation | Water | 0.26 |
| **21** | Water - Barren | 64.20 | Water | Barren | 0.79 |
| **22** | Water - Built | 188.46 | Water | Built up | 2.31 |
| **23** | Water - Marsh Land | 343.23 | Water | Marsh Land | 4.21 |
| **24** | Water - Vegetation | 38.93 | Water | Vegetation | 0.48 |
| **25** | Water - Water | 736.32 | Water | Water | 9.03 |
| | Total | 8154.99 | | | 100 |

Table 1 Change in Land Cover

The implications of such land transitions include the fragmentation of natural buffers, disruption of overland flow pathways, and increased risk of urban flooding. Spatial overlay techniques were used to assess the encroachment on ecologically sensitive zones, reinforcing the need for stringent zoning and regulatory interventions.

### 3.2 Hydrological Assessment

The hydrological analysis focused on quantifying changes in surface runoff, flow regimes, and floodplain connectivity resulting from land use transformation and river channel modification. The Soil Conservation Service Curve Number (SCS-CN) method was used to estimate runoff under varying land cover and rainfall conditions. All soil units within the study area were classified under Hydrologic Soil Group C, denoting moderate infiltration capacity and relatively high runoff potential.

To supplement the SCS-CN estimates, Strange's empirical tables were also employed to calculate runoff volumes for the years 2016 and 2024. The results indicated an appreciable increase in peak runoff in newly urbanized areas, correlating with increased impervious surface coverage. These findings substantiate the hypothesis that urban sprawl in the Ulwe basin has compromised natural infiltration, elevating the surface runoff coefficient and hydrological responsiveness during storm events.

Runoff Estimation for July 2016:

| Land Use Type | Area (Ha) | Rainfall (mm) | Runoff Coeff. (%) | Runoff (mm) | Runoff Volume (m³) | Q (m³/s) |
|---|---|---|---|---|---|---|
| **Marsh Land** | 2316.49 | 280 | 75 | 210 | 4,865,997 | 56.29 |
| **Vegetation** | 1840.12 | 280 | 65 | 182 | 3,348,021 | 38.74 |
| **Built-up** | 1793.03 | 280 | 85 | 238 | 4,267,417 | 49.39 |
| **Barren** | 834.21 | 280 | 85 | 238 | 1,985,427 | 22.97 |

Table 2 Runoff Estimation for July 2016

Runoff Estimation for July 2024:

| Land Use Type | Area (Ha) | Rainfall (mm) | Runoff Coeff. (%) | Runoff (mm) | Runoff Volume (m³) | Q (m³/s) |
|---|---|---|---|---|---|---|
| **Marsh Land** | 2082.26 | 243 | 72 | 174.9 | 3,644,561 | 42.16 |
| **Vegetation** | 1718.11 | 243 | 60 | 145.8 | 2,506,273 | 28.99 |
| **Built-up** | 2588.66 | 243 | 84 | 204.1 | 5,281,659 | 61.44 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Barren** | 892.49 | 243 | 84 | 204.1 | 1,821,677 | 21.08 |

Table 3 Runoff Estimation for July 2016

**Runoff Ratio from 2016 to 2024:**

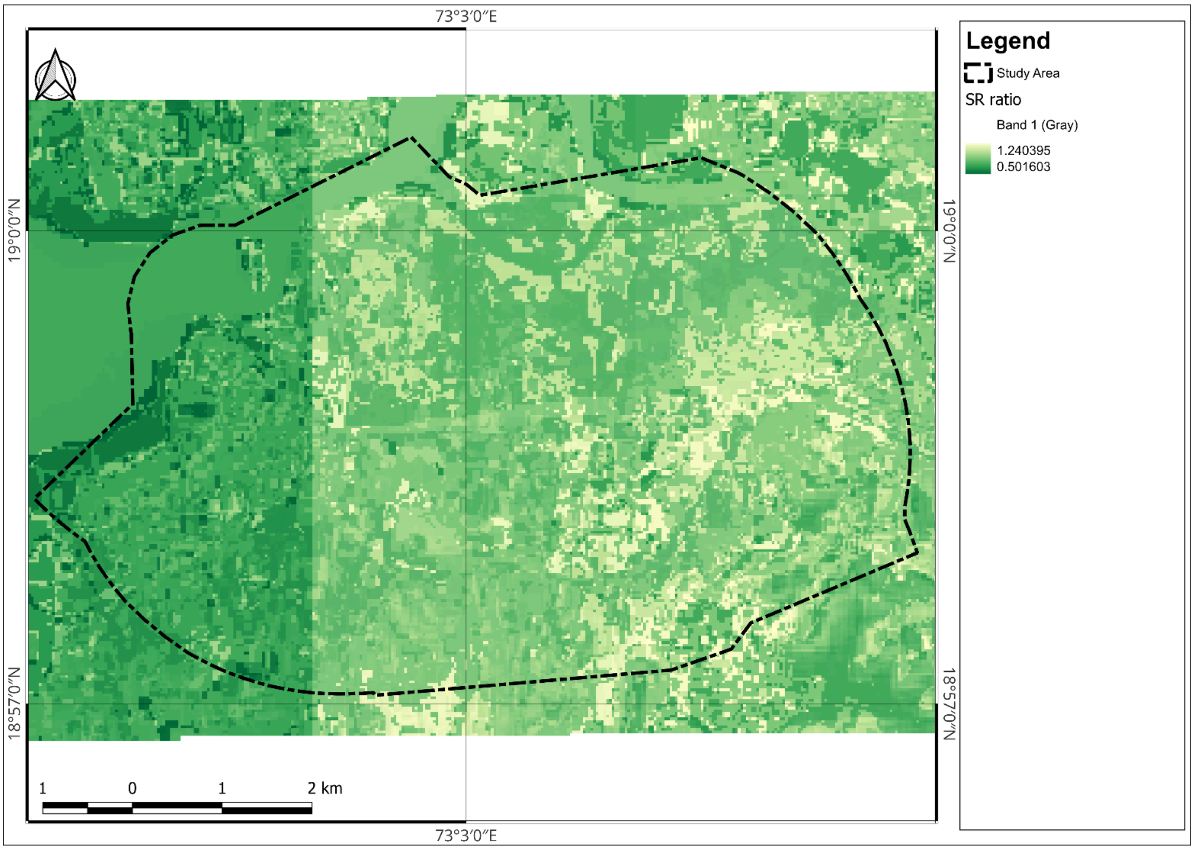


Figure 4 Surface Runoff ration from 2016 to 2024

Inference: The diversion of the Ulwe River, when coupled with intensified land development, has created a more rapid and unbuffered hydrological regime, heightening the flood vulnerability of the lower catchment areas.

### 3.3 Ecological Impact Assessment

This section examines the ecological degradation of floodplain ecosystems due to alterations in river morphology and land cover. The vegetative condition was evaluated based on the Normalized Difference Vegetation Index (NDVI), which was extracted from Sentinel-2 data. NDVI decreases between 2014 and 2024 were specifically noted in marshlands and mangrove belts, with the increasing extent of built-up areas.

Buffer zone analysis (500 m off riverbanks) was undertaken to assess the ecological sensitivity of land directly affected by river diversion and urbanization. These buffer zones, which overlap with parts of the Coastal Regulation Zone (CRZ), showed reduced vegetation cover and interruption of ecological corridors. The assessment verifies that engineered measures and extensive urbanization have caused degradation of natural floodplain habitats, with negative consequences for biodiversity, flood regulation, and water quality.

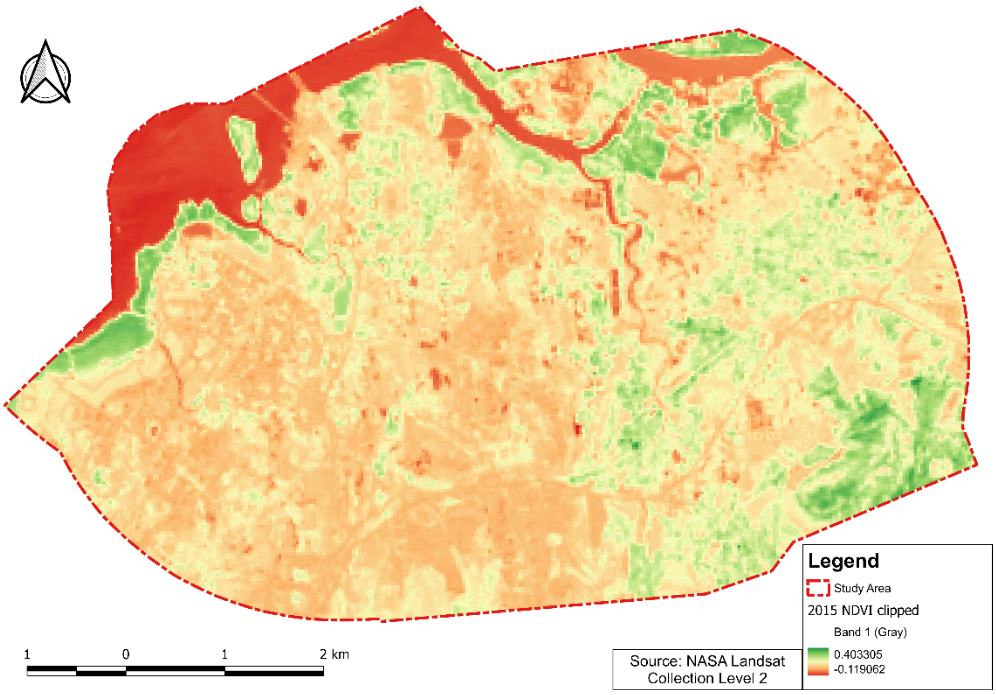


Figure 5 Normalized Difference Vegetation Index (NDVI) of 2014

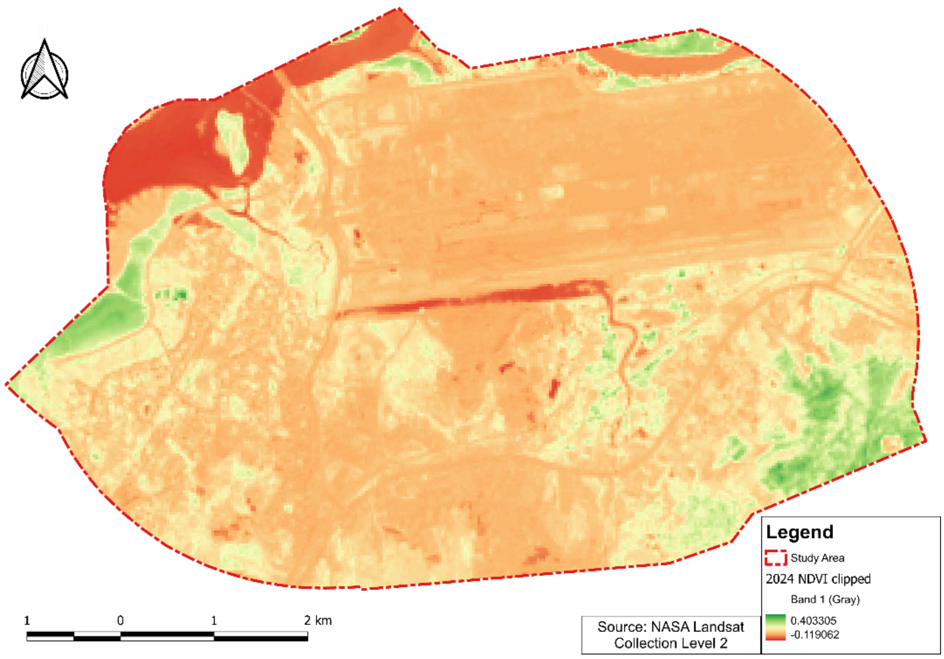


Figure 6 Normalized Difference Vegetation Index (NDVI) of 2024

### 3.4 Susceptibility Analysis

A composite susceptibility assessment was carried out using weighted overlay analysis in a GIS environment. Five criteria were considered: land ownership status (30%), land use (25%), flood risk (20%), land cover (15%), and distance from the river (10%). Each category was assigned a risk score ranging from 0 to 9, with higher values denoting greater vulnerability.

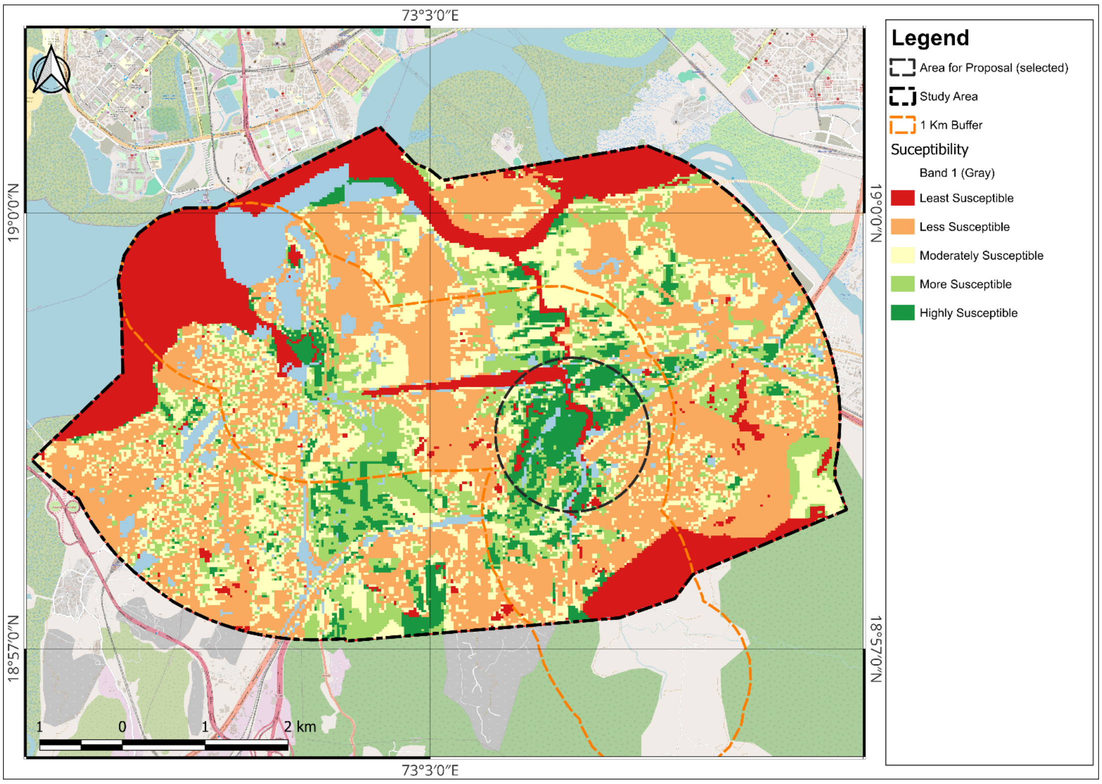


Figure 7 Composite Susceptibility Map of Study Area

For example, marshlands and unacquired private lands near the river were classified as high-risk zones, while open water and government-acquired areas were assigned lower risk scores. The output was a spatial risk map that visualizes zones requiring targeted intervention.This map will serve as a decision-support tool for regulatory agencies and urban planners to prioritize conservation, zoning restrictions, and flood mitigation strategies.

## 4. Results and Discussion

### 4.1 Spatio-Temporal Trends in Land Use and Land Cover

The LULC analysis revealed a significant transformation in land cover patterns between 2014 and 2024. Built-up areas increased from 1,793.03 hectares (21.99%) in 2014 to 2,588.66 hectares (31.74%) in 2024, indicating a 44% rise. Conversely, marshlands declined by approximately 234.23 hectares, and vegetative cover reduced marginally from 22.56% to 21.07%.

These findings highlight accelerated urban encroachment into ecologically sensitive floodplain regions. Urban expansion, particularly in proximity to the diverted Ulwe River and proposed infrastructure such as NMIA and MTHL, has resulted in substantial loss of natural buffers, reduced infiltration zones, and increased surface sealing. Spatial overlays confirm that high-intensity urbanization aligns with areas previously classified as wetlands or riparian buffers, implying compromised ecological functionality and flood resilience.

### 4.2 Surface Runoff and Hydrological Response

Surface runoff estimates calculated using the SCS-CN method and validated with Strange's Tables underscore a marked increase in runoff potential due to land cover changes. The hydrologic response of the catchment has shifted toward higher peak discharge events.

In 2016, the average runoff coefficient for the basin was computed at approximately 0.51, whereas by 2024, it rose to 0.61. This increase reflects a reduced infiltration rate and an enhanced overland flow pattern, particularly in newly built-up zones and impervious surfaces such as roads and commercial clusters.

The shift in hydrological behavior is further compounded by the morphological modification of the Ulwe River. The expansion of its cross-sectional area widening from 25–30 meters to 200 meters has increased flow velocities. While intended to improve drainage and reduce upstream inundation, these changes have led to localized erosion, unstable banks, and sediment imbalance in downstream reaches.

### 4.3 Ecological Impairment in Buffer Zones

NDVI values across the 500-meter buffer zone indicate a decline in vegetative health between 2014 and 2024. Several mangrove and marsh patches, previously exhibiting NDVI values above 0.4, now register between 0.2 and 0.3, signifying stress or degradation. Field validation and literature corroborate that such shifts are associated with infilling activities, channel modification, and salinity fluctuations triggered by altered flow regimes.

The ecological impact is not limited to vegetation loss. The disconnection of the river from its floodplain has reduced habitat continuity, increased edge effects, and disrupted nutrient exchange mechanisms. These processes threaten biodiversity and reduce the adaptive capacity of the ecosystem in the face of climate variability and tidal influences.

### 4.4 Integrated Interpretation and Planning Implications

Areas with high flood susceptibility generally overlap with parcels showing both high runoff potential and ecological sensitivity. The spatial distribution confirms that poor land-use planning and piecemeal development have intensified vulnerabilities in the basin. For example, sectors near the airport periphery and upcoming SEZs scored high on both hydrological and ecological risk parameters.

These results provide actionable insights for regulating development, revising zoning frameworks, and allocating resources for ecological restoration and nature-based flood mitigation. The convergence of LULC dynamics, hydrological alterations, and ecological stressors presents a compelling case for integrated floodplain management. The increase in surface runoff and reduction in vegetative buffers implies that traditional engineering-based drainage solutions may be insufficient without complementary ecological strategies. Furthermore, the dissonance between land acquisition status and risk classification indicates the need for regulatory coherence. Areas marked for future development are currently the most vulnerable, which necessitates urgent zoning revisions to include eco-sensitive overlays and enforce development control regulations.

## 5. Conclusion

This study investigated the hydrological, ecological, and urban consequences of river diversion in the Ulwe River basin using an integrated geospatial and hydrological approach. The analysis reveals that large-scale infrastructure development particularly the expansion of the Navi Mumbai International Airport and related projects has substantially altered the natural floodplain dynamics of the Ulwe River.

A temporal comparison of land use and land cover data between 2014 and 2024 demonstrates a sharp increase in impervious surfaces, predominantly due to built-up expansion, alongside a corresponding reduction in wetlands and vegetative areas. These changes have directly contributed to increased surface runoff, as shown by rising runoff coefficients calculated through SCS-CN methods, particularly in zones with compacted soils classified as Hydrological Soil Group C. The heightened runoff, in combination with the deepening and widening of the Ulwe River channel, has disrupted natural hydrological functions such as sediment transport and floodplain connectivity. The findings establish a clear link between rapid urban transformation, loss of natural flood-absorbing landscapes, and an increase in both hydrological and ecological vulnerabilities. The river's engineered reconfiguration, though intended to improve flood management, has resulted in unintended consequences such as erosion, sediment imbalance, and disconnection from adjacent ecosystems.

In sum, the Ulwe River case exemplifies how infrastructural ambition, when not harmonized with ecological considerations, can generate long-term risks to urban resilience. The study underscores the critical need for spatially-informed, ecosystem-sensitive approaches to floodplain planning in rapidly urbanizing contexts like Navi Mumbai.

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