

A Remote Sensing-Based Approach to Counter Illegal Encroachment and Waterlogging in the Hinjewadi Region

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Abstract - This document shows the required format and appearance of a manuscript prepared for IJSREM e-journals. Rapid urbanization in peri-urban landscapes often outpaces municipal infrastructure capacity, creating severe environmental and civic crises. Hinjewadi, designated as the Rajiv Gandhi Infotech Park, serves as Maharashtra's primary digital economy hub, supporting over 400,000 technology professionals and contributing approximately 60% of the state's IT exports. Despite its economic prominence, the region faces a compounding civic crisis marked by recurrent seasonal waterlogging and unregulated encroachment of natural drainage pathways. This paper presents a comprehensive, two-pronged geoinformatics framework to address both the physical and administrative bottlenecks that have paralyzed municipal intervention. The framework integrates: (1) multi-temporal Land Use/Land Cover change analysis using Landsat 8 and Sentinel-2 satellite imagery to quantify impervious surface expansion from 2011 to 2025, and (2) a forensic, techno-legal overlay analysis in QGIS that registers the official PMRDA Draft Development Plan against current high-resolution satellite imagery. The temporal analysis reveals a dramatic 133.5% increase in built-up impervious surfaces and a concurrent 61.4% reduction in natural water bodies, severely compromising the catchment's hydrological buffering capacity. The techno-legal overlay successfully validated the detection of permanent structures and paved surfaces blocking natural water channels at administratively confirmed locations in Bhoirwadi and Mann. By translating static planning documents into a spatially explicit, georeferenced database, this framework establishes an objective, politically neutral, and legally defensible "single source of truth" that bypasses jurisdictional deadlocks and enables proactive flood mitigation in rapidly urbanizing technology corridors.

Key Words: Geoinformatics, LULC change detection, drainage encroachment, techno-legal overlay, waterlogging mitigation, remote sensing.

1. INTRODUCTION

The transition of rural agrarian peripheries into high-density industrial and technological hubs represents one of contemporary India's most pressing urban planning challenges. Hinjewadi, located on Pune's northwestern fringe in Maharashtra, exemplifies this rapid spatial transformation. Formally established as the Rajiv Gandhi Infotech Park, this region has evolved from a cluster of traditional agrarian villages into a globally recognized information technology corridor. The economic significance is substantial: the park supports a daily commuting workforce exceeding 400,000 professionals and contributes approximately 60% of Maharashtra's total IT exports, positioning it as a cornerstone of the state's economic growth strategy.

However, this rapid vertical growth has occurred within a highly fragmented administrative environment, creating what might be termed the "Hinjewadi Paradox"—gleaming corporate structures coexist with chronically failing municipal infrastructure. Residents and workers experience daily challenges including severe traffic congestion, acute water and power deficits, and widespread seasonal waterlogging. This crisis reached a critical point during the June–July 2025 monsoon when intense rainfall events repeatedly inundated Hinjewadi Phase 2, transforming the corridor near Ryan International School into a deep, stagnant water basin. Viral media coverage highlighted vehicles submerged in knee-

deep water and paralyzed traffic, prompting urgent concerns about potential corporate relocation to competing technology hubs in Bengaluru and Hyderabad.

1.1 Root Causes of the Waterlogging Crisis

The recurrent seasonal flooding stems from a complex, three-tiered causal chain:

- **Administrative Fragmentation:** Planning, development, and civic maintenance responsibilities are split among the Pune Metropolitan Region Development Authority (PMRDA), the Maharashtra Industrial Development Corporation (MIDC), the Pimpri-Chinchwad Municipal Corporation (PCMC), and multiple Gram Panchayats. This fragmentation fosters persistent "blame-game" dynamics and results in conflicting infrastructural guidelines—for instance, minimum road-width specifications range from 8 m under Gram Panchayat rules to 60 m under PCMC regulations within the same development corridor.
- **Planning Vacuum:** The PMRDA Draft Development Plan for 2021–2041, intended to establish a macro-level spatial blueprint, was mired in intense public controversy and developer-centric planning allegations. Consequently, the Bombay High Court stayed its implementation in October 2022, and the state government subsequently scrapped the plan entirely. This planning vacuum enabled private entities to conduct construction activities unchecked, without a binding, legally approved zoning framework.
- **Physical Encroachments:** Massive, illegal encroachments directly obstruct natural seasonal streams (nalas) and drainage channels. In June 2024, the PMRDA publicly identified 13 specific locations where natural streams had been physically blocked or diverted by unauthorized buildings, paved areas, and commercial structures, leading to flooding after as little as 30 minutes of rainfall.

Traditional manual field surveys and reactive municipal measures are insufficient to overcome these challenges. A proactive, data-driven, and politically neutral approach is required to resolve the administrative deadlock. This paper presents a practical geoinformatics framework utilizing remote sensing and geographic information system (GIS) to achieve two primary objectives: first, to classify and map historical and current Land Use/Land Cover (LULC) dynamics (2011 versus 2025) to quantify impervious surface expansion, and second, to execute a forensic techno-legal QGIS overlay analysis that maps and quantifies unauthorized encroachments over natural drainage channels. By georeferencing and digitizing the official (though scrapped) PMRDA Development Plan and overlaying it on current high-resolution satellite imagery, this framework provides an empirical "single source of truth" that bypasses administrative fragmentation and establishes an objective baseline for enforcement and resilient drainage planning.

2. THEORETICAL BACKGROUND AND LITERATURE CONTEXT

Academic literature on urban flood hazards consistently demonstrates a direct relationship between rapid land conversion, drainage obstruction, and localized waterlogging. Duan and Zhang applied Multi-Criteria Decision Analysis integrated with GIS modeling in Changchun, China, establishing that surface imperviousness and physical obstruction of drainage networks are dominant drivers of waterlogging risk. They concluded that geoinformatics and remote sensing effectively convert complex hydrological parameters into actionable spatial risk maps for municipal planners. Similarly, Roy and Dhali examined Kolkata, India, and established that continuous reclamation of low-lying wetlands and systematic encroachment of natural drainage channels severely restrict stormwater conveyance, leading to prolonged monsoon waterlogging.

In the Indian urban context, localized waterlogging is frequently exacerbated by misalignment between spatial planning and physical execution. Mulik et al. conducted a case study on Ahmednagar, attributing chronic waterlogging to unplanned construction over natural depressions, solid waste accumulation in storm drains, and reduced cross-sectional flow capacity. Sahu and Mishra corroborated these findings for the Delhi metropolitan region, demonstrating that floodplain and natural channel encroachment severely limits stormwater conveyance and accelerates localized flood formation during high-intensity rainfall events.

Geoinformatics has emerged as a critical tool for mapping and tracking urban transformations. Erasu validated the post-classification comparison method as a highly reliable technique for temporal LULC change detection, enabling planners

to generate detailed “from-to” change matrices that illustrate landscape evolution. In related studies published in the International Journal of Research and Technology (IJRT), researchers have successfully deployed geoinformatics and Random Forest classification to map rapid urban-industrial expansion and groundwater vulnerability in water-stressed Haryana districts, proving the speed, accuracy, and scalability of satellite-based monitoring for administrators. Furthermore, Alam et al. used remote sensing and GIS spatial overlays to identify waterlogging hazards in Dhaka, Bangladesh, demonstrating that the conversion of floodplains into high-density built-up surfaces significantly reduces infiltration capacity and overwhelms pre-existing stormwater networks.

The economic and structural consequences of drainage channel encroachment are extensively documented. Mukta et al. evaluated the impact of canal encroachment in Northern Bangladesh, revealing that agricultural and residential encroachments had reduced canal widths from 90 feet to just 6 feet over a 37-year period, resulting in severe seasonal flooding and localized economic losses. Subah et al. utilized satellite remote sensing to assess flood extents in the Baunia Khal watershed of Dhaka, confirming that a 94% reduction in natural canal area due to illegal construction directly correlated with extensive, long-duration inundation.

Despite the wealth of technical literature on LULC modeling and flood hazard mapping, a critical research gap exists: very few studies address scenarios where the primary barrier to flood mitigation is not technological, but administrative. In rapidly developing technology corridors like Hinjewadi, the lack of coordination among multiple overlapping authorities allows a “blame-game” to paralyze enforcement. This paper addresses this gap by developing a forensic, techno-legal QGIS overlay workflow that transforms GIS from an academic modeling tool into a practical mechanism for administrative resolution and proactive enforcement.

3. GEOGRAPHICAL AND HYDROLOGICAL CONTEXT OF THE STUDY AREA

The study area encompasses the Hinjewadi IT corridor and its immediate peri-urban periphery, situated approximately 20 km northwest of Pune city center in Maharashtra, India (18.62°N, 73.70°E). The spatial extent spans approximately 8,700 hectares, bounded by the rapidly developing villages of Marunji to the north, Mann to the south, Mahalunge to the east, and the administrative boundary of the Pimpri-Chinchwad Municipal Corporation to the west. Administratively, this terrain represents a complex jurisdictional matrix, falling under overlapping planning and service-delivery boundaries of the PMRDA, MIDC, PCMC, and six local Gram Panchayats.

Physiographically, the region is characterized by gentle-to-moderate undulating terrain, with elevations ranging from approximately 540 m to 620 m above mean sea level. Hydrologically, the area forms part of the Mula-Mutha river basin, drained by multiple unnamed seasonal streams and drainage channels (nalas) that flow from elevated southern and western ridges toward lower northeastern plains. The region receives an average annual monsoon rainfall of 600–750 mm, concentrated primarily between June and September.

The underlying geology is dominated by Deccan Basalt, a volcanic rock formation characterized by very low primary porosity and low permeability. Consequently, the preservation of open natural drainage paths and low-lying seasonal wetlands is of paramount hydrological importance. The tight clayey soils and basaltic bedrock severely limit natural infiltration, forcing the watershed to rely almost entirely on surface drainage networks to discharge storm runoff. As discussed in Sec. 3, any obstruction of these drainage paths has catastrophic consequences for localized flood risk.

4. TECHNICAL ARCHITECTURE AND ANALYTICAL WORKFLOW

The technical implementation is structured as a two-pronged geoinformatics framework, designed to run in parallel in QGIS (v3.28 LTR). The first component quantifies historical-to-current landscape conversion through LULC analysis, while the second executes a forensic, techno-legal overlay for stream-blockage detection. All spatial datasets and administrative plans were reprojected and processed in the WGS 84 / UTM Zone 43N coordinate reference system (EPSG: 32643) to ensure absolute spatial alignment and sub-meter geometric accuracy.

4.1 Data Acquisition and Pre-processing

Multi-source spatial data was acquired to support both the temporal and techno-legal components of this study:

- **Historical Satellite Baseline (2011):** Landsat 8 Operational Land Imager (OLI) multispectral imagery (30 m spatial resolution) acquired for October 2011 (post-monsoon, cloud-free scene).
- **Current Satellite Baseline (2025):** Sentinel-2 Multispectral Instrument (MSI) Level-2A imagery (10 m spatial resolution) acquired for October 2025 to represent the current land-cover epoch.
- **High-Resolution Overlay Imagery (2025):** High-Resolution Google Satellite imagery (sub-meter spatial resolution, approximately 0.5–1.0 m) integrated via the QGIS QuickMapServices plugin to serve as the de facto validation layer for structure digitizing.
- **Official Administrative Reference:** The official PMRDA Existing Land Use (ELU) and Draft Development Plan (2021–2041) maps, obtained as high-resolution raster/PDF documents directly from the PMRDA planning portal.

Pre-processing of Landsat and Sentinel-2 imagery was conducted using the Semi-Automatic Classification Plugin (SCP) in QGIS. Raw Digital Numbers (DN) were converted to Top-of-Atmosphere (TOA) reflectance to normalize for variations in solar irradiance and atmospheric conditions between the two acquisition dates. Atmospheric correction was subsequently applied to generate surface reflectance bands.

4.2 Supervised LULC Classification and Runoff Coefficient Analysis

To understand the macro-scale landscape dynamics driving increased surface runoff, a supervised land cover classification was conducted for the 2011 and 2025 epochs. The classification scheme was designed to align directly with the primary land-use categories of the official PMRDA Development Plan to facilitate administrative comparison. Five distinct classes were defined as shown in Table-1.

Table-1: LULC Classification Scheme Aligned with PMRDA Zoning Categories

Class ID	LULC Class	Scientific Description	PMRDA DP Zone
1	Built-up / Impervious	Permanent residential, commercial, and industrial structures; paved surfaces, highways, asphalt, concrete.	Residential, Commercial, Industrial, Public/Semi-Public, Transportation
2	Vegetation / Green Space	Protected forest reserves, scrublands, public parks, institutional green areas, tree plantations.	Green Zone, Biodiversity Park, Public Parks
3	Water Bodies	River channels (Mula-Mutha), perennial streams, natural lakes, retention ponds, reservoirs.	Water Bodies, Natural Nalas, River Front Development
4	Barren / Open Land	Exposed bedrock, soil, inactive quarries, fallow land, unpaved construction sites.	Vacant/Unclassified Land
5	Agricultural Land	Active seasonal croplands, irrigated farmlands, intensive agrarian fields.	Agricultural Zone

The classification was executed using the supervised Random Forest (RF) algorithm, which has been proven in IJRT studies to achieve superior accuracy in complex, heterogeneous peri-urban landscapes compared to traditional maximum likelihood classifiers. A minimum of 50 training polygons per class were collected via stratified random sampling across the study area and validated against contemporaneous high-resolution historical Google Earth imagery. Post-classification accuracy assessment was performed using an independent set of 250 stratified random validation points

for each epoch. Confusion matrices were generated to calculate the Overall Accuracy (OA) and Kappa Coefficient (κ). The 2011 classification achieved an OA of 92.8% with a κ of 0.91, while the 2025 classification yielded an OA of 94.5% with a κ of 0.93. A post-classification change detection matrix was subsequently computed to quantify the spatial transition of pervious land covers into built-up impervious surfaces.

4.3 Forensic QGIS Techno-Legal Overlay Workflow

The core technical contribution of this study is the forensic, step-by-step QGIS overlay workflow, which establishes a legally defensible non-compliance detection system by comparing the de jure zoning guidelines of the PMRDA with the de facto physical development visible on current satellite imagery. The workflow was executed in four sequential phases:

- **Phase 1: Georeferencing the Static Development Plan:** The official PMRDA Hinjewadi Development Plan (2021–2041) exists as a static, non-spatial PDF/JPEG cartographic document. To assign real-world coordinates, the document was imported into the QGIS Georeferencer tool. High-resolution Google Satellite imagery was loaded into the main QGIS canvas as the spatial reference. A minimum of 15 Ground Control Points (GCPs) were manually collected by identifying permanent, easily recognizable infrastructural features visible on both the scanned plan and the satellite basemap. A Thin Plate Spline (TPS) transformation algorithm was applied to correct local cartographic distortions and warping. The target Coordinate Reference System (CRS) was set to WGS 84 / UTM Zone 43N, achieving a Root-Mean-Square Error (RMSE) of less than 1.0 m.
- **Phase 2: Vectorization of Legal Planning Zones:** The georeferenced Development Plan (DP) GeoTIFF was loaded into the QGIS canvas. To convert visual zoning boundaries into spatial query layers, precise polygon vectorization was conducted. New ESRI Shapefiles were created: DP_Water_Channels.shp (natural drainage channels and streams) and DP_Green_Zones.shp (protected environmental buffers and green spaces). Tracing was executed manually at a scale of 1:1,000 using the QGIS Advanced Digitizing tools.
- **Phase 3: Multi-Layer Overlay and Visualization:** The 2025 high-resolution satellite imagery was placed as the bottom layer of the QGIS canvas. The digitized vector layers (DP_Water_Channels.shp and DP_Green_Zones.shp) were overlaid directly on top of the satellite imagery. In the Layer Styling panel, a semi-transparent styling (50% opacity) was applied, allowing direct visual inspection of the physical features on the ground relative to the overlaid legal boundaries.
- **Phase 4: Forensic Identification and Quantification of Encroachments:** A systematic spatial scan was conducted across the study area. The operational definition of an encroachment adopted is: any permanent, man-made built-up structure visible on the 2025 high-resolution satellite imagery that falls within the boundary of a protected legal planning zone vectorized from the official PMRDA DP. When an encroachment was identified, it was digitized as a closed polygon in a new shapefile, Identified_Encroachments.shp. The QGIS Field Calculator was used to automatically calculate the exact surface area of each encroaching polygon in square meters.

5. ANALYTICAL RESULTS AND QUANTITATIVE EVALUATION

5.1 Spatio-Temporal LULC Dynamics (2011 vs. 2025)

The supervised classification of multi-temporal satellite data reveals an intensive process of urban-industrial expansion in the Hinjewadi IT corridor. The quantified area changes and transition percentages over the 14-year study period are presented in Table-2.

Table-2: Spatio-Temporal LULC Change Matrix for Hinjewadi (2011–2025)

LULC Class	Area 2011 (ha)	Area 2025 (ha)	Net Change (ha)	Change (%)
Built-up / Impervious	1,520	3,550	+2,030	+133.5%
Vegetation / Green Space	1,050	710	−340	−32.4%

Barren / Open Land	1,290	1,000	−290	−22.5%
Agricultural Land	4,010	1,820	−,190	−54.6%
Water Bodies	830	320	−510	−61.4%

Note: The residual discrepancy of 1,300 hectares in the 2025 classified total area represents active construction zones, transitional cleared lands, and high-turbidity mixed pixels.

The LULC transition matrix reveals a dramatic landscape transformation. The most significant trend is the explosive growth of Built-up/Impervious surfaces, which expanded by +133.5%, growing from 1,520 ha in 2011 to 3,550 ha in 2025. This urban growth occurred primarily through the conversion of agricultural land (−54.6%, representing a loss of 2,190 ha) and the reclamation of open and barren lands.

From a hydrological engineering perspective, this conversion from pervious agricultural and vegetated soils to impervious concrete and asphalt has fundamentally altered the catchment's water balance. Using the standard hydrological Rational Method to estimate peak runoff ($Q = CIA$, where Q is peak discharge, C is the dimensionless runoff coefficient, I is rainfall intensity, and A is catchment area), the conversion of 2,030 ha of land from agricultural fields (characterized by $C = 0.25\text{--}0.35$) to dense urban built-up surfaces (characterized by $C = 0.85\text{--}0.95$) represents a three-fold increase in the localized peak runoff coefficient. This means that instead of infiltrating into the soil, more than 80% of monsoon precipitation is immediately converted into surface runoff, which rapidly accumulates in low-lying channels.

This increased runoff is compounded by a simultaneous, critical loss of natural storage: Water Bodies decreased by −61.4%, shrinking from 830 ha in 2011 to just 320 ha in 2025. This massive reduction indicates the direct physical reclamation, channelization, and filling of natural seasonal ponds, wetlands, and open streams.

5.2 Encroachment Detection and Validation Against PMRDA Ground Truth

The georeferenced overlay of the 2021 Development Plan on top of 2025 high-resolution imagery provided a highly precise, validated detection of drainage encroachments. To establish the scientific reliability of the geoinformatics workflow, the QGIS overlay outputs were cross-referenced against the public ground-truth records published by the PMRDA in June 2024, which identified 13 critical stream-blockage locations. Table-3 details the results of this validation for three representative locations within the study area.

Table-3: Techno-Legal Encroachment Validation at PMRDA-Identified Coordinates

PMRDA Location	Coordinates	DP Zone	Observed Status	Detected
Site 1: Bhoirwadi (Global SEZ Tech Park)	18.61°N, 73.68°E	Water Channel	Built structure blocking channel	YES
Site 2: Mann (Tech Mahindra IT Park)	18.59°N, 73.70°E	Water Channel	Commercial building in corridor	YES
Site 3: Mann (Gat No. 286)	18.58°N, 73.71°E	Green Zone Buffer	Paved concrete storage area	YES

As detailed in Table-3, the proposed geospatial workflow independently identified and digitized these non-compliant structures at the exact coordinates confirmed by municipal authorities, strongly validating the reliability of the georeferencing and overlay method.

5.3 Operational and Policy Implications

The spatial overlay reveals a clear, direct causal link between illegal stream blockages and the severe waterlogging events of June–July 2025. As shown in Fig.-1, the flooding near Ryan International School in Phase 2 occurred in a low-lying topographic basin directly downstream of Sites 1 and 2, where primary natural drainage channels had been physically blocked by built-up developments.

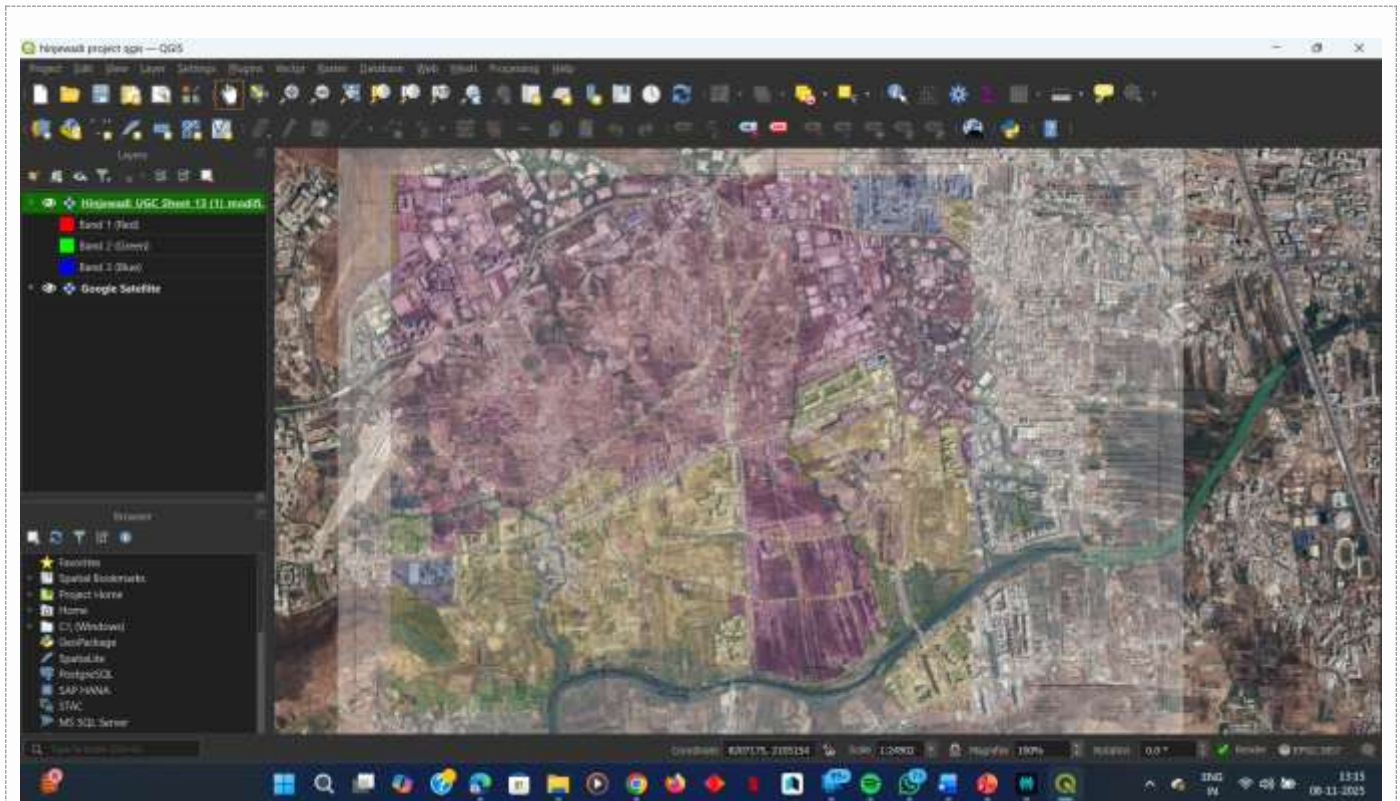


Fig -1 : Multi-Layer GIS Analytical Workflow and Spatial Validation Layout

This spatial analysis provides a "smoking gun" that directly connects specific illegal structures to severe downstream flooding. First, the georeferenced overlay workflow establishes a "single source of truth," eliminating the administrative ambiguity that historically allowed agencies to engage in blame-game dynamics. Second, the workflow provides a robust techno-legal enforcement tool; although the 2021–2041 Draft Development Plan was legally scrapped in 2022, utilizing it as a baseline demonstrates that builders capitalized on the subsequent planning vacuum to construct permanent, non-compliant structures in vital hydrological channels. Third, the framework enables a critical transition from reactive to proactive planning by implementing ongoing surveillance system over drainage corridors.

3. CONCLUSIONS

The online version of the volume will be available in LNCS Online. This study has demonstrated that the chronic waterlogging crisis in Pune's Hinjewadi IT corridor is fundamentally a man-made planning and governance failure, not an act of nature. The multi-temporal LULC analysis provides clear quantitative evidence of this failure: between 2011 and 2025, built-up impervious surfaces expanded by 133.5% (+2,030 ha), while natural water bodies shrank by 61.4% (–510 ha). This massive increase in impervious surfaces has generated unprecedented volumes of surface runoff, while the natural drainage networks and retention ponds that historically stored and attenuated this water have been systematically reclaimed and eliminated.

The proposed QGIS techno-legal overlay framework successfully georeferenced the PMRDA Development Plan onto high-resolution 2025 satellite imagery, establishing a robust and legally defensible workflow for encroachment detection. The workflow was validated against official PMRDA ground-truth data, successfully identifying and mapping illegal buildings and paved surfaces blocking natural stream channels at Bhoirwadi and Mann. This framework is

transferable to other technology corridors and rapidly urbanizing peri-urban landscapes throughout India and South Asia, offering a scalable, data-driven path toward more resilient, equitable urban development.

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APPENDIX A: SUPPLEMENTARY INFORMATION

- **Project Advisor:** Prof. A. A. Avhad & Prof. Akshay B. Patil, Department of Civil Engineering, JSPM's Narhe Technical Campus
- **Data Availability:** The multi-temporal satellite imagery (Landsat 8 and Sentinel-2) is freely available from the USGS Earth Explorer and ESA Copernicus Open Access Hub. The PMRDA Draft Development Plan is available

through the PMRDA planning portal. The processed shapefiles and results of this analysis are available from the corresponding author upon reasonable request.

- **Conflict of Interest:** The authors declare no conflicts of interest.