

MULTI-HAZARD VULNERABILITY OF INFORMAL SETTLEMENTS IN AN URBAN AREA

A Case Study of Bhopal, Madhya Pradesh, India

*A Thesis Project submitted in partial fulfilment of the requirements for the award of
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ABSTRACT

Bhopal's informal settlements do not exist in a spatial vacuum. Over decades, they have grown precisely along the edges that the city's formal planning systems have least managed to control the railway corridor that cuts through the urban core, the sensitive margins of the Upper Lake, and the drainage channels and topographic sinks that define the low-lying quarters of the old city. These locations are not chosen randomly by the residents who live there; they are often the last available land, the most affordable, and in many cases the only spaces that remain accessible to the urban poor when formal housing provision falls short.

This thesis assesses the spatial vulnerability of informal settlements in Bhopal against three independently defined hazard categories: infrastructure edge hazards associated with railway proximity, hydrological and eco-sensitive hazards from lake buffer encroachment measured against the 50-metre National Green Tribunal standard, and topographic flood risk derived from digital elevation model analysis. The research employs a four-stage GIS-based methodology, using building footprint data from Google Open Buildings V3 (2024) intersected with hazard layers derived from NASADEM elevation data, Railway Works Manual buffer standards, and NGT wetland regulations, to classify informal settlements by priority zone and propose differentiated planning interventions.

The composite multi-hazard vulnerability analysis identifies 2,215 building footprints within one or more hazard zones across 13.6 hectares of the Bhopal Municipal Corporation area. Of these, 1,075 units (31 per cent) are classified as Untenable under the Priority Hazard Matrix and require relocation. A further 1,140 units (45 per cent) are Semi-Tenure eligible, with in-situ structural upgrading feasible through the PMAY-U 2.0 BLC vertical. Three principal vulnerability hotspots are identified: the Chola-Nishatpura belt where infrastructure edge and topographic flood conditions overlap to produce a cyclic structural decay condition; the Khanugaon-Koh-e-Fiza lakefront where Ramsar Convention obligations and drinking water contamination risks compound the housing vulnerability of 275 families; and the Bairagarh lowlands, the only confirmed triple-hazard zone in Bhopal, where all three hazard conditions simultaneously overlap for 65 building footprints.

A key analytical correction is applied throughout the study: the 50-metre NGT Ramsar buffer standard is used in place of the 33-metre Bhopal Development Plan figure for the Upper Lake Bhojtal, reclassifying 85 additional structures from the upgrade-eligible to the mandatory-relocation category. This correction has significant planning and legal implications.

Planning proposals are organised across three intervention zones. Zone A covers relocation and rehabilitation for all Untenable units, with site selection criteria, resettlement process safeguards, and new housing design standards that address the ventilation and structural deficiencies documented in existing PMAY layouts. A GIS-based vacant land identification exercise, overlaying BDP 2031 Residential General-I (RG-I) and Residential General-II (RG-II) land use zones with Sentinel-2 LULC vacancy classification and NASADEM elevation data, confirms the availability of correctly-zoned, flood-safe relocation sites within 2 kilometres of all three hotspot clusters establishing that Zone A resettlement can be achieved through existing residential land designations without requiring agricultural land conversion or long-distance displacement of affected households. Zone B covers in-situ upgrading and hazard mitigation for Semi-Tenure units, centred on a Resilience Retrofit Kit of raised plinths, cement mortar replacement, and drainage infrastructure funded through PMAY-U 2.0 and AMRUT 2.0. Zone C covers the ecological restoration of the 50-metre lakefront buffer following Zone A relocation, transforming the zone into a bioswale and public ecological park network aligned with the National Wetland Conservation Programme and the Smart City Mission Bhopal.

The study contributes a reproducible, open-data GIS methodology, a regulatory correction of significant planning consequence, and a differentiated policy framework calibrated to three distinct vulnerability profiles. Its findings are intended to serve as both a strategic diagnostic tool for Bhopal's planning authorities and an analytical foundation for the final thesis submission.

Keywords: Multi-hazard vulnerability, informal settlements, Bhopal, GIS, infrastructure edge, eco-sensitive zones, PMAY-U 2.0, topographic flood risk, ecological restoration, priority hazard matrix.

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CHAPTER 1: INTRODUCTION

1.1 Project Background and Study Context

There is a particular kind of planning problem that does not announce itself in tidy administrative categories. It lives at the edge's literal, physical edges where the city's infrastructure ends and something more provisional begins. In Bhopal, these edges are easy enough to find. Stand near the railway junction any morning and you can see them: the line of corrugated iron roofs running parallel to the tracks, close enough that conversation stops when a train passes. Walk along the Upper Lake in the early evening and you will notice where the promenade gives way to something denser and less formal, where the cleared path disappears and the structures begin, sitting lower than the neighbouring ground. These are not invisible settlements. They are simply the ones that the planning system has consistently found it easier not to think about.

Bhopal is the capital of Madhya Pradesh, a Tier-II city positioned on the Malwa Plateau in the heart of central India. It has grown considerably since its designation as a state capital, expanding outward from its historic walled core through waves of planned residential development, institutional zones, and industrial townships. But this expansion, like most Indian urban growth of the past four decades, has had an informal counterpart that has grown at least as fast, if not faster, than the formal city. The Bhopal Municipal Corporation records more than 380 notified slums within the municipal boundary. The 2011 Census documented over 1.25 lakh jhuggi families. In the Old Bhopal area alone, approximately 33 per cent of residents live in informal settlements. These are conservative figures, based on a 2011 snapshot that has been outdated by over a decade of continued growth and densification.

The spatial distribution of these settlements is not random, and it is not simply a product of poverty. It reflects a specific geography of risk and exclusion in which informal populations have occupied the marginal spaces that the formal planning system has either not managed to develop or has actively left vacant because of environmental or infrastructural constraints. The central railway corridor, the lake margins, the seasonal drainage channels: these are not neutral spaces. They are risk-generating edges. And Bhopal's informal settlements are concentrated precisely along them.

This thesis is an attempt to map that risk systematically. Using GIS-based multi-hazard overlay analysis, it assesses the spatial vulnerability of informal settlements in Bhopal

against three independently derived hazard layers infrastructure edge hazards from railway proximity, hydrological and eco-sensitive hazards from lake buffer encroachment, and topographic flood risk from digital elevation analysis and translates the composite findings into differentiated planning proposals calibrated to the specific risk profile of each zone.

The study carries immediate practical relevance. The 2022 demolition drive associated with the Bhopal-Indore third railway track project displaced over 1,000 families from the critical 30-metre NOC zone. Three hundred of those families remained unrehabilitated three months later. That event is not an aberration. It is a preview of what happens when infrastructure investment decisions outpace resettlement planning. This study is designed to help ensure that the next infrastructure decision and there will be one is not met with the same administrative unpreparedness.

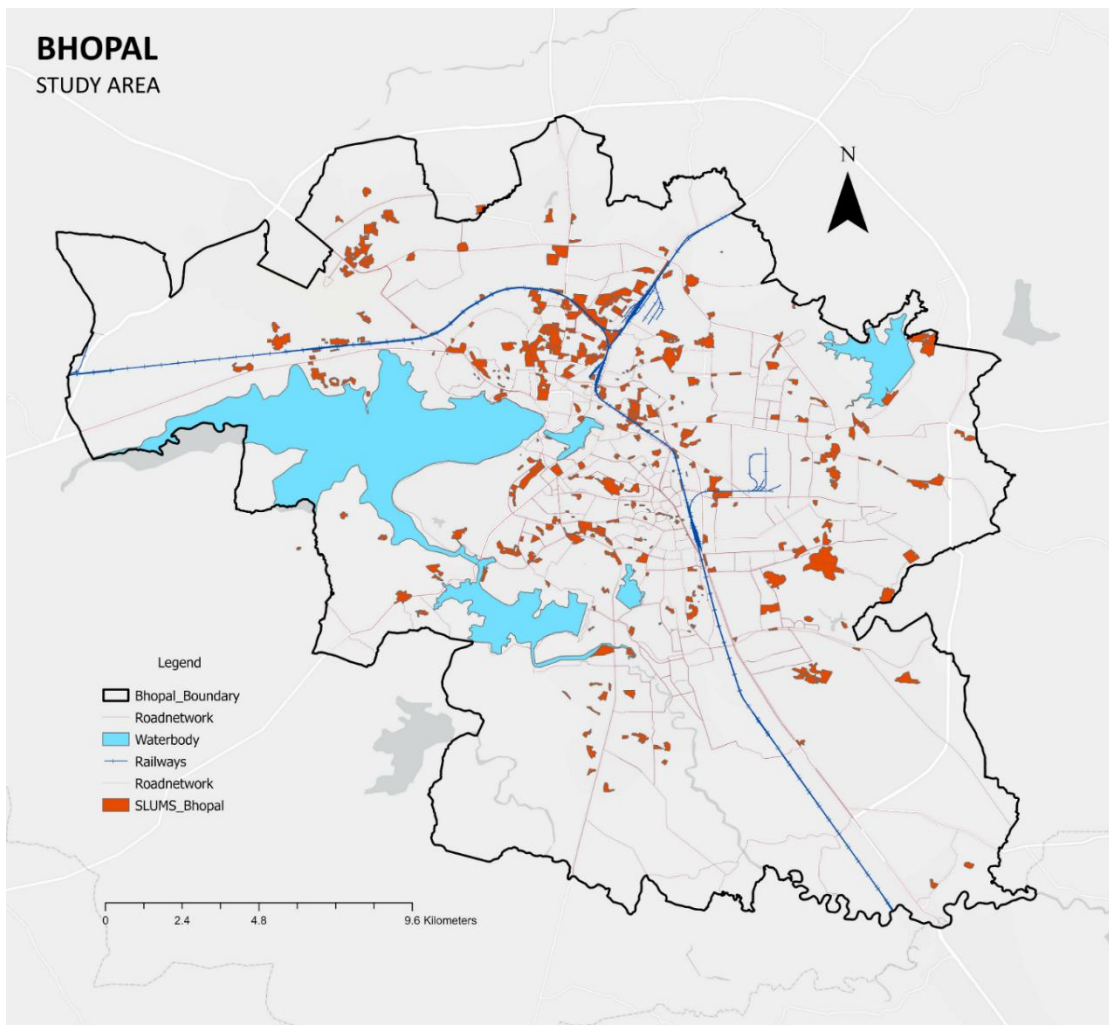


Fig. No. 1.1: Bhopal Municipal Corporation boundary showing distribution of informal settlements, railway corridor, and Upper Lake. (Source: Primary Field Survey and GIS Analysis)

1.2 Defining Multi-Hazard Vulnerability in Informal Settlements

Vulnerability, in the framework of this study, is understood through the lens of the IPCC Sixth Assessment Report (AR6, 2022), which defines it as the intersection of three interacting dimensions: exposure, sensitivity, and adaptive capacity. It is worth spending a moment on what each of these actually means in the Bhopal context, because the conceptual framework shapes every analytical decision that follows.

Exposure, in spatial terms, is relatively straightforward to measure. It is the physical proximity of a structure to a hazard-generating edge: the distance from a railway track centreline, the distance from a lake shoreline measured against the applicable NGT buffer standard, the elevation relative to the flood susceptibility threshold derived from digital terrain analysis. GIS is well suited to this dimension, and it constitutes the primary analytical layer of this study.

Sensitivity is harder to capture but no less important. It manifests here in the construction materials of informal housing kutchha clay brick walls, asbestos and corrugated iron roofing, lime mortar joints all of which respond to vibration, moisture, and cyclic loading in ways that structurally engineered buildings do not. A pucca concrete-frame house fifty metres from a railway track is exposed to the same vibration stimulus as a kutchha mud-brick house at the same distance. The sensitivity of the two structures to that stimulus is entirely different.

Adaptive capacity, for the populations of Bhopal's informal settlements, is constrained at every level. Insecure tenure the absence of a formal land Patta means that no household can obtain a building permit, access PMAY-U housing benefits, or mortgage their home to fund structural improvements. Low household income limits the ability to fund even minor self-help repairs. The absence of community insurance coverage means that post-disaster structural loss represents a permanent welfare shock rather than a recoverable setback. These constraints are not incidental; they are structural, and they compound the effect of physical exposure in ways that purely spatial analysis cannot fully capture.

The multi-hazard dimension of this study matters because the three hazard conditions are not simply additive. In compound zones where infrastructure edge vibration coincides with topographic waterlogging, a mutually reinforcing physical degradation process occurs. This study terms it cyclic decay: vibration fatigue widens mortar joint

cracks, monsoon waterlogging saturates the same cracked walls through capillary rise, post-monsoon drying shrinks the wetted clay mortars further, and the next season's vibration acts on a structurally compromised wall that is already partway to failure. This is the mechanism that makes the compound zones uniquely dangerous and uniquely resistant to incremental upgrading as a planning response.

1.3 Need for the Study

1.3.1 The Single-Hazard Planning Gap

Current planning practice in Bhopal addresses each hazard in isolation. Railway encroachments are managed through periodic eviction drives coordinated by Indian Railways and the district administration. Lake-edge settlements face sporadic enforcement action under National Green Tribunal orders. Topographic flood risk is addressed reactively through post-disaster relief. There is no existing planning framework that assesses these three hazard conditions simultaneously at the building footprint level, classifies their compound effects, and derives a unified planning response. The consequence is that the households facing the worst compound conditions those in the railway-flood overlap zone, or those in the triple-hazard Bairagarh cluster are systematically invisible to each of the agencies that has partial jurisdiction over their situation.

1.3.2 Absence of Building-Footprint-Level Hazard Quantification

Existing vulnerability assessments in Bhopal, where they exist at all, use administrative slum boundaries or ward-level enumeration as the unit of analysis. This produces significant planning inaccuracies: a single notified slum may contain structures in both the critical 30-metre railway zone and the comparatively safer 100-metre planning buffer, yet the entire slum is treated as a homogeneous risk unit. By using individual building footprints from Google Open Buildings V3 (2024) as the unit of analysis, this study achieves the spatial precision required for defensible tenability classification and targeted scheme deployment.

1.3.3 The Corrected NGT Lake Buffer Standard

Previous planning documents and vulnerability studies in Bhopal have cited the 33-metre no-construction zone from the Bhopal Development Plan 2031 as the applicable lake buffer standard. However, National Green Tribunal orders specify a minimum 50-

metre buffer for Ramsar-designated wetland sites, a standard that supersedes the BDP norm for the Upper Lake Bhojtal, which holds Ramsar Convention designation since 2002. This study applies the corrected 50-metre NGT threshold throughout, and documents the planning consequence: 85 additional building footprints fall within the non-regularizable zone under the corrected standard, reclassifying them from upgrade-eligible to mandatory relocation. This is not a minor technical adjustment; it changes the legal basis of planning intervention for nearly a hundred households.

1.3.4 Supporting Proactive Planning Under PMAY-U 2.0

The PMAY-U 2.0 scheme, launched in 2024 with a national target of one crore urban homes by 2029, requires local authorities to maintain a spatially accurate, legally defensible classification of informal settlements by tenability status. Without such a classification, the scheme's Beneficiary Led Construction vertical cannot be efficiently targeted, and relocation-eligible households cannot be identified in advance of infrastructure conflicts. This study provides the foundational spatial classification that Bhopal's BMC currently lacks for scheme-aligned proactive planning. Additionally, the study identifies specific vacant land parcels within BDP 2031 Residential General-I and Residential General-II zones that satisfy all five relocation site selection criteria demonstrating that Zone A resettlement can be achieved within existing zoning without agricultural land conversion or long-distance displacement of affected communities.

1.4 Aim and Objectives

The aim of this study is to assess the spatial vulnerability of informal settlements in Bhopal against multiple urban hazards infrastructure edges, topographic flood sinks, and eco-sensitive lake zones and to identify priority zones for planning intervention through GIS-based multi-hazard overlay analysis, with all lake buffer zones measured against the 50-metre National Green Tribunal standard.

The study is structured around four primary objectives:

- Delineate Infrastructure Edge Buffers (30m statutory NOC zone under Indian Railways Works Manual Para 827, and 100m planning safety zone under URDPFI Guidelines) and quantify the distribution of informal building footprints within each tier.

- Map Eco-Sensitive Zone Vulnerability by analysing settlement proximity to the Upper and Lower Lakes using a 50-metre inner buffer (NGT Ramsar standard) and a 100-metre outer environmental buffer, updating all spatial statistics from the corrected NGT threshold.
- Model Topographic Flood and Waterlogging Zones using NASADEM 30-metre DEM data, identifying depression-based waterlogging risk in informal clusters below 470 metres ASL relative to the Upper Lake Full Tank Level of 466.65 metres.
- Develop a composite Priority Hazard Matrix to classify all identified informal building footprints into Category 1 (Red Zone: all three hazards), Category 2 (Orange Zone: any two hazards), and Category 3 (Yellow Zone: single hazard), and propose differentiated planning interventions aligned with PMAY-U 2.0, AMRUT 2.0, and the Sendai Framework for Disaster Risk Reduction 2015-2030.

1.6 Scope of the Study

1.6.1 Spatial Scope

The study covers the Bhopal Municipal Corporation administrative area as the primary boundary. The analysis focuses on three principal vulnerability hotspot zones, identified in preliminary reconnaissance as concentration points of compound hazard conditions: the Chola-Nishatpura belt along the central railway corridor; the Khanugaon-Koh-e-Fiza lakefront along the western margin of the Upper Lake; and the Bairagarh lowlands where all three hazard conditions converge in the only confirmed triple-hazard zone in the study area. Secondary analysis covers all informal building footprints within the entire municipal boundary that fall within any of the three hazard layers.

1.6.2 Technical and Methodological Scope

The research employs a four-stage GIS methodology implemented in ArcGIS Pro: data acquisition from open satellite and building footprint sources; independent hazard layer derivation for infrastructure edge proximity, eco-sensitive lake buffer, and topographic flood elevation; spatial intersection of building footprints with all three hazard layers; and composite Priority Hazard Matrix development with tenability classification.

Analysis tools include Buffer, Con, DEM Fill, Flow Direction (D8 algorithm), Raster to Vector, and Intersect.

1.6.3 Outcome and Exclusions

The study delivers a planning-level vulnerability framework with Priority Hazard Matrix classifications, preliminary planning proposals calibrated to each zone, and policy linkages to active national schemes. It does not include detailed structural engineering designs, household socio-economic surveys at scale, or formal implementation cost estimates beyond indicative figures. The analysis is intended as a strategic diagnostic tool for planning authorities and as the analytical foundation for the final thesis submission.

1.7 Limitations of the Study

Several limitations should be kept in mind when interpreting the findings:

- The NASADEM 30-metre DEM resolution does not capture micro-level topographic variation within the densest informal clusters, where the built fabric itself modifies local drainage patterns. Sub-metre terrain variation relevant to localised waterlogging may not be captured.
- Google Open Buildings V3 (2024) represents a single temporal snapshot. Seasonal variation in settlement extent and incremental infill densification over time are not captured.
- Primary field survey coverage is limited by access constraints. Ground-truth validation is based on a sample of sites rather than comprehensive coverage of all 380-plus notified slums.
- Socio-economic vulnerability indicators, including income levels, household asset profiles, and tenure security documentation, are not incorporated into the composite hazard index, which measures physical and spatial exposure exclusively.
- Administrative data on individual unit-level Patta status and PMAY-U eligibility are not available from BMC at the building footprint level and are not incorporated in the current analysis.

1.8 Study Area Profile: Bhopal, Madhya Pradesh

1.8.1 Geographical Setting and Topography

Bhopal is situated on the Malwa Plateau in central India, at approximately 23.26°N and 77.40°E. The city's terrain is characterised by a pronounced ridge-and-valley morphology, with a recorded elevation range of 430 to 627 metres above sea level. This topographic complexity is not merely a scenic quality; it has direct planning consequences. The natural drainage system concentrates surface runoff in low-lying basins, many of which have been progressively occupied by informal settlements over the past three decades, creating exactly the kind of topographic flood exposure that the third hazard layer of this study addresses.

The city's most defining geographic feature is its system of large natural lakes. The Upper Lake, known locally as Bhojtal, covers approximately 31 square kilometres and supplies around 40 per cent of Bhopal's municipal water demand. Its Full Tank Level is fixed at 466.65 metres ASL. The Lower Lake, or Chhota Talaab, is a smaller connected water body to its east. Both lakes carry Ramsar Convention designation as internationally important wetlands. The 50-metre buffer prescribed by the NGT for Ramsar sites is the primary regulatory constraint governing settlement proximity to these water bodies in this study, and its application in place of the previously cited 33-metre BDP standard is one of this study's key analytical contributions.

The central railway spine of the Bhopal Junction passes directly through the urban core, handling both mainline intercity traffic and goods movements. It is a high-frequency corridor with continuous vibration and noise exposure. Approximately 40 per cent of Bhopal's informal settlements are estimated to lie within 500 metres of the railway tracks.



Fig. No. 1.2: Location map: Bhopal within Madhya Pradesh (Source: Survey of India)

1.8.2 Urban Structure and Informal Settlement Distribution

Bhopal has evolved from a dense historic walled core centred on the Old City into a modern polycentric urban system incorporating the New Bhopal administrative sector to the south, the BHEL industrial township to the north-west, and successive planned residential extensions to the east. This polycentric growth has left significant interstitial zones along the railway corridor, around the lake margins, and in the ravine, corridors associated with seasonal drainage channels that have been progressively occupied by informal settlements.

The BMC records 380-plus notified slums, but field reconnaissance and satellite imagery analysis confirm the presence of additional non-notified informal clusters, particularly in areas of recent growth on the urban periphery. The spatial distribution of these settlements maps closely onto the three hazard-generating edge conditions that form the subject of this study.

Table No. 1.1: Key Settlement Statistics: Bhopal Municipal Corporation

Indicator	Value	Source
Notified Slums	380+ within BMC boundary	BMC Records, 2023

Indicator	Value	Source
Jhuggi Families	1.25 lakh+	Census of India, 2011
Informal Population (Old Bhopal)	Approximately 33%	Census 2011 / Field Estimate
Elevation Range	430 to 627 metres ASL	NASADEM 30m DEM
Upper Lake FTL	466.65 metres ASL	BDP 2031 / BMC Hydrology
Lake Buffer Applied (This Study)	50 metres (NGT Ramsar Standard)	NGT Orders / National Wetland Rules 2017
Informal Settlements within 500m of Railway	Approximately 40%	GIS Analysis, This Study
Study Base Year	2024	Google Open Buildings V3

Source: BMC Slum Register 2023; Census of India 2011; GIS Analysis

1.9 The Regulatory and Physical Context of Informal Settlement Hazard in India

Informal settlements occupy hazardous land not because their residents are unaware of the risk, but because the formal housing market systematically excludes them from safe alternatives. This is a structural problem, not an individual failure of judgement. The low-income migrant who builds a shelter within 20 metres of a railway track in Bhopal is not making an uninformed choice; they are making the only choice available to them within a market and policy framework that offers them nothing else. Understanding this is fundamental to designing planning interventions that can actually work.

India's urban land market is characterised by a severe affordability gap at the bottom of the income distribution. The minimum land and construction cost for a PMAY-U EWS unit, after central and state subsidies, remains beyond the means of households earning below Rs. 3 lakh per annum, which constitutes a substantial fraction of Bhopal's informal settlement population. The minimum plot sizes required under formal layout rules, combined with the statutory infrastructure provisioning obligations attached to formal development, place legal housing development structurally out of reach for this income cohort. The result is not merely informal settlement but specifically hazardous

informal settlement, because the only land available outside the formal market is the land that the formal market has rejected for its risk or regulatory constraints.

The three hazard-generating edges identified in this study the railway corridor, the lake margin, and the topographic depression are not merely physical features. They are the visible traces of formal planning exclusion. The railway line is a right-of-way in which no formal residential development is legally permissible. The lake buffer is an environmentally constrained zone in which construction requires clearances that low-income developments cannot obtain. The topographic depressions are the residual undevelopable fragments of the urban morphology that formal subdivision layouts treat as unusable. These are precisely the spaces where the urban poor find land.

This context matters enormously for the planning proposals in Chapter 6. Any intervention that simply removes people from hazardous land without providing a viable alternative replicates the conditions that created the informal settlement in the first place. A resettlement site that is affordable, well located in relation to livelihoods, and legally secure breaks the cycle. A resettlement site that is distant from employment, poorly serviced, and formally owned but practically inaccessible may simply produce a new generation of informal secondary occupation nearby.

1.10 Urban Informality in the Bhopal Context: Historical Perspective

Bhopal's informal settlement history has two distinct phases. The first, from roughly the 1960s to the 1984 Bhopal Gas Tragedy, saw the establishment of the city's primary informal settlement clusters in the Old Bhopal area and along the central railway corridor, driven by in-migration associated with the BHEL industrial township and state capital administrative expansion. These are the older, more established settlements with some degree of de facto tenure security settlements that have been notified as slums by BMC and whose residents have often lived in the same location for decades.

The second phase, from the 1990s onward, has been characterised by peripheral informal growth driven by continued in-migration and the displacement of inner-city communities by urban renewal and infrastructure projects. The settlements in the lake buffer zone and in the newer peri-urban nallah-bank areas are predominantly products of this second phase: they lack the de facto tenure stability of the older settlements, their

residents have shorter occupancy histories, and their legal position is correspondingly more precarious.

The 1984 Gas Tragedy is impossible to discuss in a Bhopal planning context without acknowledging its continuing planning legacy. The disaster and its aftermath reshaped the city's spatial development in ways that are still visible today. Gas-affected communities from the old city were in many cases displaced or disrupted, creating new informal settlement pressure in areas further from the historic core. The Union Carbide site itself remains a contested and legally complex piece of urban land that has not been resolved even four decades later, illustrating the extraordinary difficulty of managing environmentally compromised urban land in the Indian legal and political context.

This historical context shapes the tenure landscape of Bhopal's informal settlements in ways that affect the planning proposals in this study. Older settlements with longer occupancy histories have stronger de facto claims and, in some cases, partial documentation. Newer settlements, particularly those in the lake buffer and railway zones that have grown since the 1990s, have weaker claims and face greater regularisation barriers. The GIS-based tenability classification in Chapter 5 does not differentiate by occupancy history it uses purely spatial hazard criteria but the resettlement planning in Chapter 6 must take these differences in tenure trajectory into account.

1.11 Climate Change and Multi-Hazard Vulnerability

The hazard conditions mapped in this study are not static. Climate change is expected to intensify both the frequency and magnitude of extreme rainfall events in the central Indian plateau, the region in which Bhopal is located. The IPCC AR6 (2022) projects increased variability in the South Asian monsoon under all emissions scenarios, with the central plateau expected to see more intense rainfall events punctuated by longer dry spells. For Bhopal's topographic flood zones, this means that the 3-to-7-day waterlogging duration currently observed at the 465 to 470 metre ASL zone may increase in frequency and duration by the mid-2030s.

The Upper Lake's Full Tank Level relationship to surrounding informal settlements is also projected to become more variable under climate change scenarios. Years in which the lake level exceeds FTL currently occurring approximately 1 in 4 years may become

more frequent. The 95 buildings currently identified as being in the extreme flood zone below 465 metres ASL face increasing inundation risk as the monsoon pattern shifts.

The planning proposals in this study are designed to be climate-resilient in two senses. First, the Zone A relocation sites are selected above 475 metres ASL, placing them outside the flood susceptibility zone even under projected climate change scenarios. Second, the Zone C ecological restoration bioswale networks, retention ponds, and restored wetland vegetation represents a nature-based solution to peak-flow attenuation that becomes more valuable as rainfall intensity increases. These are not merely contemporary planning responses; they are investments in climate-adaptive urban infrastructure with a multi-decadal planning horizon.

CHAPTER 2: LITERATURE REVIEW AND CASE STUDY INFERENCES

Literature review in a study like this one needs to do a specific job. It is not enough to survey what has been written about urban vulnerability or informal settlements in general; the aim is to identify the frameworks, methods, and empirical findings from comparable contexts that can be directly applied to or refined for the Bhopal situation. The review presented here is therefore deliberately selective: it draws on international theoretical frameworks for vulnerability, national statutory buffer standards, and empirical case study evidence from urban contexts in India where similar hazard-settlement interactions have been studied. The synthesis identifies, at the end of the chapter, the specific research gaps that this study directly addresses.

2.1 Vulnerability Framework: IPCC AR6 and UN-Habitat

The IPCC Sixth Assessment Report (AR6, 2022) provides the foundational theoretical architecture for the vulnerability framework applied here. The AR6 defines vulnerability as a function of three interacting dimensions. This study applies them as follows:

Table No. 2.1: IPCC AR6 Vulnerability Framework Applied to Bhopal Informal Settlements

Dimension	Theoretical Definition	Manifestation in Bhopal Context
Exposure	Physical proximity of people and assets to hazard	Proximity to railway tracks, lake shores within 50m NGT buffer, topographic depressions below 470m ASL
Sensitivity	Degree to which a system is affected by hazard exposure	Kutcha and semi-pucca construction, asbestos roofing, absent drainage, foundation depth under 0.3m, high residential density
Adaptive Capacity	Ability to adjust, cope with, and recover from hazard impacts	No formal land Patta, below-poverty-line income, ineligibility for PMAY-U benefits, no community insurance, limited institutional support

Source: IPCC AR6 Working Group II Report (2022); adapted for Bhopal context

UN-Habitat's State of the World's Cities 2020 report reinforces this framework, specifically identifying informal settlement residents as the most exposure-sensitive urban population cohort, with the lowest adaptive capacity precisely because housing tenure is insecure. For Bhopal, tenure insecurity is both a cause and consequence of informal settlement in hazardous locations: households settle in hazardous locations because secure tenure elsewhere is inaccessible; settling in hazardous locations makes formal tenure even harder to achieve. This circular trap is central to the problem this study addresses.

It is worth noting that the IPCC's vulnerability framework, while universally applied, was developed primarily with climate change adaptation in mind. Its application to urban infrastructure and ecological hazards in a developing-country city like Bhopal requires certain adaptations. In particular, the adaptive capacity dimension in the AR6 framework emphasises institutional and financial resources at the national and sectoral scale. For individual household-level informal settlements, adaptive capacity is better understood as the capacity to access formal tenure, government schemes, and community-organised risk-reduction mechanisms. The vulnerability profile in Chapter 5 incorporates this reframing.

2.2 Statutory Buffer Standards in India

The three hazard layers in this study are grounded in statutory regulatory standards that carry legal force in India. Understanding these standards, their hierarchy, and their relationship to one another is prerequisite to interpreting both the hazard layer boundaries and the tenability classification that follows from them.

Table No. 2.2: Statutory Buffer Standards Applicable to This Study

Hazard Type	Buffer Distance	Regulatory Instrument	Legal Implication
Infrastructure Edge: Critical Zone	30 metres	Indian Railways Works Manual, Para 827 (NOC Zone)	No permanent structure permissible; NOC compulsory for any intervention; mandatory relocation zone
Infrastructure Edge: Safety Buffer	100 metres	URDPFI Guidelines: Noise and Vibration Attenuation Zone	Noise above 65 dB; vibration risk; in-situ upgrade feasible with

Hazard Type	Buffer Distance	Regulatory Instrument	Legal Implication
			structural retrofitting and NOC
Eco-Sensitive Zone: Inner Buffer (Applied)	50 metres	NGT Orders on Ramsar Sites; National Wetland Rules 2017	Supersedes BDP 2031's 33m standard for Upper Lake Bhojtal (Ramsar designated since 2002)
Eco-Sensitive Zone: Environmental Buffer	100 metres	NGT General Wetland Norms; BDP 2031 Environmental Zone	Environmental sensitivity zone; semi-permanent structures face chronic dampness; may be regularizable with environmental clearance
Previous Standard (Reference Only)	33 metres	Bhopal Development Plan 2031: No-Construction Zone	Applies to non-Ramsar water bodies only. All references in this study corrected to 50m for Upper Lake.

Source: Indian Railways Works Manual (Current); URDPFI Guidelines (2014); National Wetland Rules 2017; BDP 2031 (BMC)

A note on regulatory hierarchy is important here. In India's federal structure, NGT orders carry the force of judicial pronouncements and supersede state and local government regulations on matters of environmental protection. The BDP 2031 is a statutory planning document of Bhopal Municipal Corporation, a local authority. Where it conflicts with NGT orders on buffer standards for Ramsar-designated wetlands, the NGT standard prevails. This is why the 50-metre threshold is applied in this study in place of the 33-metre BDP figure for the Upper Lake Bhojtal.

2.3 National and International Case Study Inferences

Four case studies are reviewed in detail, each chosen for its direct relevance to one or more of the hazard conditions or planning challenges addressed in this study. The selection prioritises recent empirical research over descriptive accounts, and preference is given to studies that provide quantitative data comparable to the Bhopal analysis.

2.3.1 Mumbai: Railway Slum Belt: Dharavi-Sion Corridor

The research conducted by Risbud (2009) and the Hazard, Risk and Vulnerability Assessment by the Municipal Corporation of Greater Mumbai documents physical and

safety conditions of informal settlements within and immediately beyond the 30-metre railway Right of Way in Mumbai's Dharavi-Sion corridor. The findings are directly applicable to Bhopal:

- Settlements within 15 metres of tracks record fatality rates three times the city-wide urban average, with accident risk from derailments and near-miss incidents representing the dominant mortality pathway.
- Beyond 30 metres, in-situ improvement becomes structurally feasible, though NOC compliance from Indian Railways remains the primary bureaucratic barrier to formal intervention.
- Physical morphology in the railway-adjacent zone is characterised by linear elongation parallel to the track boundary, blind walls on the rail-facing side, and zero setback. These patterns replicate exactly in Bhopal's Chola-Nishatpura belt.

The Mumbai case provides the most direct empirical precedent for the infrastructure edge hazard layer in this study, and the 50-metre buffer applied in Mumbai's railway slum resettlement under the SRA (Slum Rehabilitation Authority) framework provides a useful planning benchmark for comparison with Bhopal's 30-metre threshold.

2.3.2 Surat: Flood Resilience of Informal Settlements

Ahmad et al. (2023), in their study published in *Natural Hazards* by Springer, present an indicator-based resilience assessment of informal settlements in Surat following the 2006 and 2013 urban flood events. Several findings directly inform this study's approach to the topographic flood hazard layer and Zone B upgrading proposals:

- Physical and institutional resilience of informal settlements is significantly lower than that of formal areas across all flood-risk indicators measured.
- Drainage infrastructure quality and tenure security are identified as the two strongest predictors of household-level flood resilience stronger even than elevation above flood level.
- Settlements where raised plinth construction has been adopted whether through community initiative or partial government support show measurably lower post-flood structural damage rates.

These findings provide the empirical justification for the mandatory raised-plinth standard proposed in Zone B of this study. If Surat's data shows that a simple physical intervention like plinth raising has measurable structural resilience benefits, that evidence should inform the design of retrofit programmes in Bhopal's moderate-risk flood zones.

2.3.3 Bhubaneswar: Cyclone Vulnerability of Slum Dwellers

Patra and Peri (2022), published in the *International Journal of Disaster Risk Reduction*, develop a multidimensional vulnerability model for informal settlements in Bhubaneswar based on primary survey data from cyclone-affected communities. Their key theoretical contribution is the demonstration that physical exposure alone cannot predict disaster impact. Socio-economic sensitivity and governance gaps compound hazard effects in ways that structural intervention alone cannot address.

Most relevant to this study is their finding on tenure and recovery: communities with even partial Patta documentation show significantly higher rates of post-disaster government support access and faster recovery timelines. This finding directly motivates the GIS-based tenure regularisation pathway proposed for Zone B in Chapter 6, and the Community Resilience Micro-Insurance proposal in Chapter 7.

2.3.4 Bhopal: Annu Nagar and Arif Nagar Eviction (2022)

The eviction of over 1,000 families from the 30-metre railway NOC zone in Bhopal during the 2022 Bhopal-Indore third track construction project is the most directly relevant local case for this study. Reported by the *Free Press Journal* in January 2023 and documented through IRSDC SPV records, the event reveals the systemic gap between infrastructure investment decisions and resettlement planning capacity in the city:

- More than 1,000 families were displaced under Section 4 of the Railways Act, which permits removal of encroachments on railway land without notice.
- Three hundred families remained unrehabilitated three months after displacement, with no permanent resettlement site identified in advance.
- The eviction drive did not extend to the 30 to 100 metre safety buffer zone, leaving a further cohort of structurally at-risk households without intervention.

- No compensation or Patta transfer was offered to displaced households, reflecting the legal untenability of railway-land settlement that makes PMAY-U access structurally impossible without a prior resettlement arrangement.

This case is a cautionary precedent that directly shapes the Zone A resettlement process design in Chapter 6. The failure mode demonstrated in 2022 demolition without advance resettlement is specifically addressed in the phasing and process framework of the planning proposals.

2.4 Research Gaps and Insights

The synthesis of reviewed literature and local policy context identifies five critical gaps that this research directly addresses. Being explicit about these gaps is important because it clarifies what the study contributes that existing work does not:

- Gap 1: No Bhopal-specific study has simultaneously quantified infrastructure edge proximity, eco-sensitive lake buffer encroachment, and topographic flood risk at the individual building footprint level. Existing assessments treat each hazard in isolation and use administrative settlement boundaries rather than individual building units as the unit of analysis.
- Gap 2: The NGT-mandated 50-metre Ramsar buffer standard has not been applied in existing BDP 2031 compliance assessments in Bhopal. All prior vulnerability references citing a 33-metre lake standard undercount the number of structures in the non-regularizable zone.
- Gap 3: The compound effect of infrastructure edge vibration coinciding with topographic waterlogging the cyclic decay condition has not been identified or mapped as a distinct extreme-risk category in the Bhopal context. This study identifies and quantifies it.
- Gap 4: There is no publicly available GIS-based tenability classification of informal settlements in Bhopal that could support PMAY-U 2.0 scheme deployment. This study provides the foundational spatial dataset for such a classification.
- Gap 5: Post-eviction resettlement planning in Bhopal has consistently lagged infrastructure decisions. A pre-emptive vulnerability and tenability

assessment, such as this study provides, is necessary to enable proactive resettlement planning before the next infrastructure conflict arises.

Table No. 2.3: Case Study Inferences and Their Relevance to Bhopal

Case Study	Primary Finding	Application in This Study
Mumbai Railway Slum Belt (Risbud, 2009)	Fatality rates 3x average within 15m of tracks; linear morphology pattern; NOC barrier	Validates 30m threshold; informs morphological vulnerability profile for Hotspot A
Surat Flood Resilience (Ahmad et al., 2023)	Drainage and tenure are strongest flood resilience predictors; raised plinth reduces damage	Justifies mandatory raised plinth (0.6m) in Zone B; drainage as primary infrastructure intervention
Bhubaneswar Cyclone Vulnerability (Patra & Peri, 2022)	Physical exposure alone insufficient; tenure enables recovery; insurance gap matters	Motivates tenure regularisation pathway; Community Resilience Micro-Insurance proposal in Ch.7
Bhopal Annu Nagar Eviction (Free Press Journal, 2023)	Demolition without advance resettlement: 300 families unrehabilitated after 3 months	Directly informs Zone A resettlement process safeguards: resettlement site must be 80% complete before demolition

Source: Primary case study sources as cited in Section 2.3

2.5 Theoretical Frameworks: Urban Morphology and Hazard Interaction

Beyond the IPCC AR6 vulnerability framework, two additional theoretical perspectives inform the analytical approach of this study. The first is urban morphological analysis, as developed by Conzen (1960) and applied to informal settlements by Dovey (2012) and others. Morphological analysis examines the physical form of settlements their street patterns, plot structures, building types, and open space configurations as both a product and a determinant of social and environmental processes. In the context of this study, morphological analysis is used to explain why the same regulatory buffer zone contains structures with very different vulnerability levels: the variation is not random but reflects systematic differences in the morphological pattern that can be read from satellite imagery and field observation.

The second theoretical contribution is from urban political ecology, which examines how environmental hazards and the social distribution of risk are jointly produced through unequal urban development processes (Swyngedouw and Heynen, 2003). This

framework is particularly relevant to the eco-sensitive zone analysis, where the dual victim-polluter status of lakefront informal settlements themselves flooded by the lake they are simultaneously polluting is a product of the political economy of urban land allocation rather than natural environmental conditions. The zone is contaminated and at risk not because of any inherent ecological property of the location, but because formal planning decisions have allocated this hazardous margin to informal occupation through the simple mechanism of ignoring it.

2.6 Indian Urban Policy Framework: Relevant Instruments

The study operates within a specific Indian urban policy framework that shapes both the hazard standards applied and the planning response options available. A review of the most relevant instruments provides the regulatory context that the methodology chapter builds on:

The URDPFI Guidelines (2014) provide the national framework for urban and regional development plan formulation. Their noise and vibration attenuation zone specification the basis for the 100-metre infrastructure edge safety buffer in this study reflects a planning principle that informal settlements should be protected from chronic environmental health hazards even where the critical safety threshold is not crossed. The URDPFI document is advisory rather than statutory at the local level, but it provides the planning justification for buffer-based intervention.

The National Wetland Rules 2017, implementing the Environment Protection Act 1986, establish the regulatory framework for Ramsar site buffer protection that produces the 50-metre lake buffer applied in this study. These Rules are binding, not advisory, and their precedence over local development plan provisions is established by the constitutionally mandated hierarchy of legislation.

The Sendai Framework for Disaster Risk Reduction 2015-2030, to which India is a signatory, provides the international alignment for the study's multi-hazard approach. Priority 1 of the Sendai Framework specifically calls for building the evidence base for multi-hazard risk assessment in urban settings. This study directly implements that priority in the Bhopal context.

Table No. 2.4: Relevant Indian Urban Policy Instruments and Their Application

Instrument	Type	Key Provision Relevant to This Study	Application
URDPFI Guidelines 2014	Advisory (MoUD)	100m infrastructure edge noise/vibration attenuation zone; hazard buffer standards	Basis for 100m infrastructure edge outer buffer; in-situ upgrading threshold
National Wetland Rules 2017	Statutory (MoEFCC)	50m minimum buffer for Ramsar-designated wetlands; prohibits structures within buffer	Primary basis for 50m NGT lake buffer applied throughout; supersedes BDP 2031
Ramsar Convention (2002)	International Treaty (India signatory)	Buffer zone protection for internationally important wetlands; ecological function maintenance	Upper Lake Bhojtal Ramsar designation grounds the 50m buffer obligation
Railways Act (Relevant sections)	Central Legislation	Section 4: removal of encroachments from railway land without advance notice; no statutory rehabilitation obligation	Legal basis for 30m NOC zone and eviction authority; motivates pre-emptive resettlement planning
PMAY-U 2.0 Scheme (2024)	Central Scheme (MoHUA)	BLC vertical: Rs. 2.5L per EWS household; Patta or BMC notification required for eligibility	Primary funding mechanism for Zone A and Zone B; eligibility preparation challenge
NDMA Urban Flood Guidelines 2010	Advisory (NDMA)	Hazard zone mapping standards; emergency evacuation protocols; temporary shelter standards	Phase 1 emergency relocation protocol; transit accommodation standards for Zone A
Sendai Framework 2015-2030	International Framework	Priority 1: Understanding disaster risk; Priority 4: Build Back Better	Framework alignment for multi-hazard approach; Build Back Better principle in Zone A housing

Source: Ministry of Urban Development (2014); MoEFCC National Wetland Rules (2017); Ramsar Convention (2002); UNDRRR (2015)

2.7 Review of GIS-Based Vulnerability Assessment Methods in Indian Cities

GIS-based vulnerability mapping has been applied in several Indian urban contexts that provide methodological benchmarks for this study. Three examples are reviewed briefly:

Srivastava et al. (2012) applied multi-hazard overlay analysis to informal settlements in Lucknow, combining flood susceptibility, air quality, and infrastructure proximity as hazard layers. Their approach of using building footprints as the unit of analysis rather than administrative boundaries is directly adopted in this study. The Lucknow study's primary limitation the use of population survey data for vulnerability scoring that is not spatially transferable motivated the present study's decision to use purely spatial and statutory criteria for tenability classification.

The Greater Mumbai Development Plan's Slum Rehabilitation Authority (SRA) has developed a GIS-based tenability classification system for Mumbai's informal settlements that uses buffer distances from infrastructure and environmental constraints as the primary eligibility criterion. This system provides the closest Indian precedent for the methodology applied here. Its limitation in the Mumbai context that building footprint data quality was insufficient for plot-level classification has been substantially resolved by the 2024 release of Google Open Buildings V3, which is the dataset applied in this study.

The Odisha JAGA Mission, cited in Chapter 7 as the precedent model for the GIS-based Hazard Eligibility Portal proposal, provides the most significant Indian precedent for translating GIS-based slum mapping into land rights outcomes. The JAGA Mission's demonstration that GIS mapping can be operationalised as an administrative tool for mass Patta issuance, rather than remaining a planning analytical product, is the key innovation that the portal proposal draws on.

CHAPTER 3: METHODOLOGY

The methodology of this study is built around a single organising principle: that the evidence base for planning intervention must be as spatially precise as the planning decisions it supports. If the aim is to classify individual buildings by tenability, the unit of analysis must be individual buildings, not administrative slum boundaries. If the regulatory standard for a lake buffer is 50 metres, then 50 metres must be the threshold applied in the spatial analysis, not 33 metres because a local development plan happens to cite a different figure. This chapter documents the four-stage GIS methodology through which that principle is translated into analytical practice.

3.1 Methodology Framework Overview

Table No. 3.1: Methodology Framework Overview: Four Stages

Stage	Process	Primary Tools	Output
Stage 1: Data Acquisition	Collection of satellite imagery, building footprint polygons, DEM raster, vector datasets, and regulatory documents	Sentinel-2, LISS-IV, Google Open Buildings V3, NASADEM, Railway and Waterbody Vectors	Georeferenced spatial dataset covering Bhopal Municipal Corporation area
Stage 2: Hazard Layer Mapping	Independent derivation of three spatial hazard layers from primary datasets	ArcGIS Pro: Buffer tool (Infrastructure Edge, Eco-Sensitive Zones), Con tool on DEM (Flood), DEM Fill, Flow Direction D8	Three independent hazard layer polygons: Infrastructure Edge Buffer, Eco-Sensitive Buffer (50m NGT), Topographic Flood Zone
Stage 3: Spatial Intersection	Overlay of building footprints with all three hazard layers to classify exposure	ArcGIS Pro: Intersect tool, Select by Attribute, Field Calculator	Composite attribute table: each building flagged for infrastructure tier, eco-sensitive tier, flood risk, and overlap category
Stage 4: Vulnerability Synthesis	Priority Hazard Matrix development, tenability classification, planning proposal derivation	Weighted overlay; policy benchmarking against PMAY-U	Composite Multi-Hazard Vulnerability Map; Priority Hazard Matrix; Tenability

Stage	Process	Primary Tools	Output
		2.0, AMRUT 2.0, Sendai Framework	Classification; Planning Proposals

Source: Author's GIS methodology framework; ArcGIS Pro 3.1

3.2 Stage 1: Data Acquisition

Dataset selection for this study prioritised open-access, reproducible sources to ensure that the analytical framework could be replicated for other Indian cities facing comparable compound hazard conditions. The following datasets constitute the primary spatial inputs:

Table No. 3.2: Primary Data Sources and Their Applications

Dataset	Resolution / Scale	Source	Application
Google Open Buildings V3 (2024)	Individual building footprint polygons	Google Research, Open Buildings Dataset	Primary unit of analysis for all hazard intersection and tenability classification
NASADEM Digital Elevation Model	30 metres	NASA JPL via Open Topography	Topographic flood and waterlogging analysis; DEM fill-flow-con workflow
Sentinel-2 LULC (2023-24)	10 metres	ESA via Esri Planetary Computer	Land use classification; informal settlement boundary delineation
LISS-IV Satellite Imagery	5.8 metres	NRSC Bhuvan (ISRO)	High-resolution settlement boundary verification and morphological analysis
Railway Network Vectors	1:10,000	Digitised from SOI Toposheets, satellite-verified	Track centreline for infrastructure edge buffer generation
Water Body Polygons	Derived	LULC classification, verified against BDP 2031 FTL boundary	Shoreline for 50m and 100m eco-sensitive buffer generation
Bhopal Development Plan 2031	1:25,000	Bhopal Municipal Corporation (BMC)	Statutory land-use reference, no-construction zone baseline

Dataset	Resolution / Scale	Source	Application
BMC Slum Notifications	Ward level	Bhopal Municipal Corporation, Slum Register	Ground-truth reference for notified slum boundaries
Indian Railways Works Manual	National standard	Ministry of Railways, Government of India	Para 827 NOC zone specification (30m threshold)
NGT Wetland Buffer Orders	Judicial standard	National Green Tribunal, National Wetland Rules 2017	50m Ramsar site buffer standard for Upper Lake

Source: Multiple sources as listed; accessed 2023-24

A word on the Google Open Buildings V3 dataset, since it is the analytical backbone of this entire study: the V3 release (2024) provides building footprint polygons derived from satellite imagery using a machine learning model trained on high-resolution aerial data. Its coverage of Indian cities has improved substantially from earlier versions. For Bhopal, estimated coverage exceeds 95 per cent of the municipal area for pucca and semi-pucca structures. The main limitation is the representation of very small katcha structures, below approximately 30 square metres footprint, where model detection is less reliable. This limitation is noted in the data quality assessment in Section 5.5.5.

3.3 Stage 2: Hazard Layer Mapping

3.3.1 Hazard Layer I: Infrastructure Edge (Railway Proximity)

Dual buffer zones were generated around the centreline of all railway track segments within the Bhopal Municipal Corporation boundary using the ArcGIS Pro Buffer tool. Parameters: Side Type = FULL; End Type = FLAT; Dissolve Type = DISSOLVE ALL. The 30-metre buffer represents the critical NOC zone under Indian Railways Works Manual Para 827. The 100-metre buffer represents the planning safety zone under URDPFI Guidelines. A 30 to 100 metre annular ring was derived by erasing the 30-metre buffer from the 100-metre buffer, producing mutually exclusive hazard tier polygons for the intersection analysis.

Track centreline accuracy was validated against high-resolution LISS-IV imagery and field observation at three locations: the Bhopal Junction mainline, the Nishatpura goods

yard sidings, and the Bairagarh section. Minor discrepancies in the SOI toposheet digitisation were corrected against satellite imagery before buffer generation.

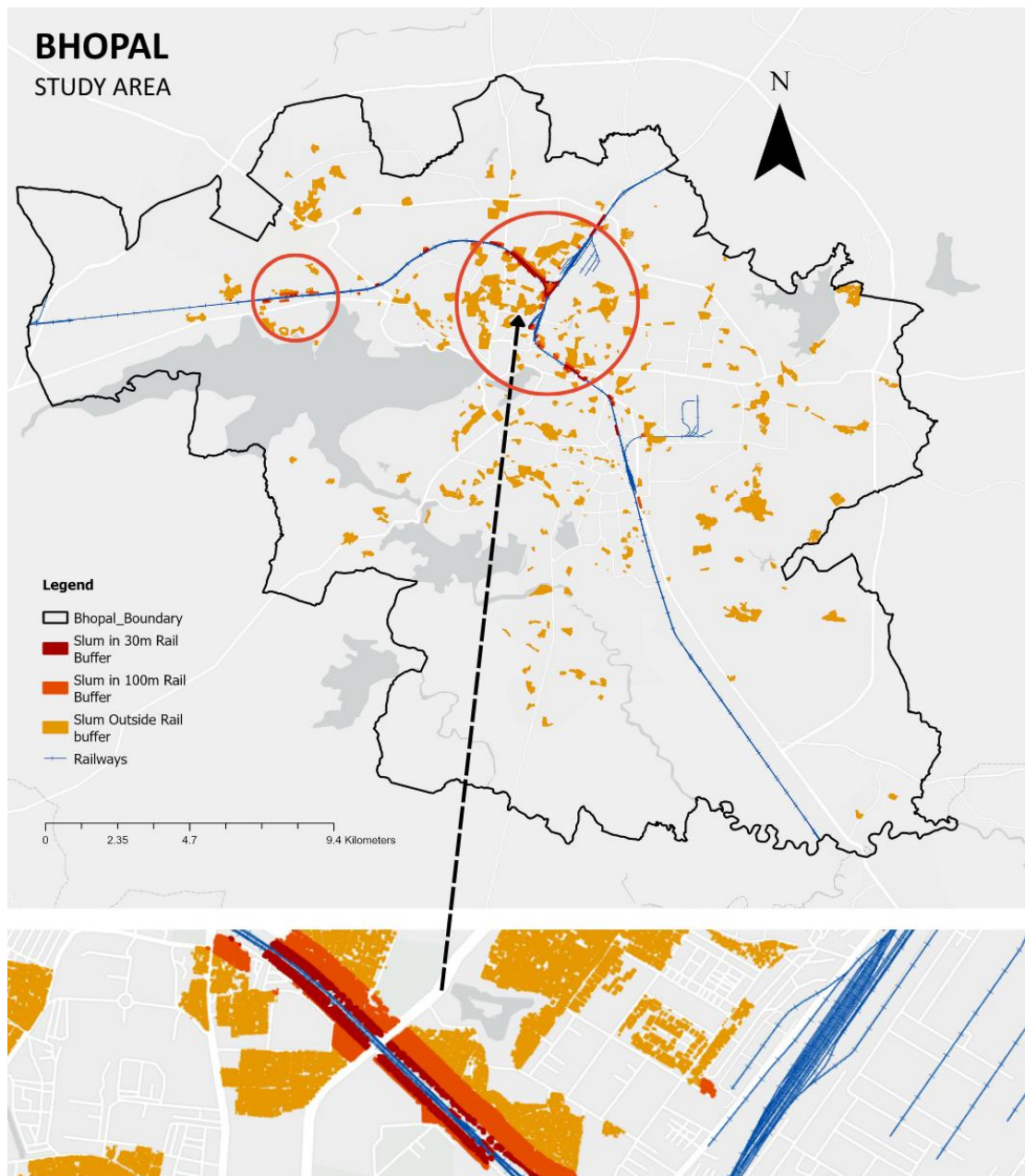


Fig. No. 3.2: Infrastructure edge buffer zones: 30m NOC zone (dark red) and 30-100m safety zone (orange), informal building footprints overlaid (Source: Primary Field Survey and GIS Analysis)

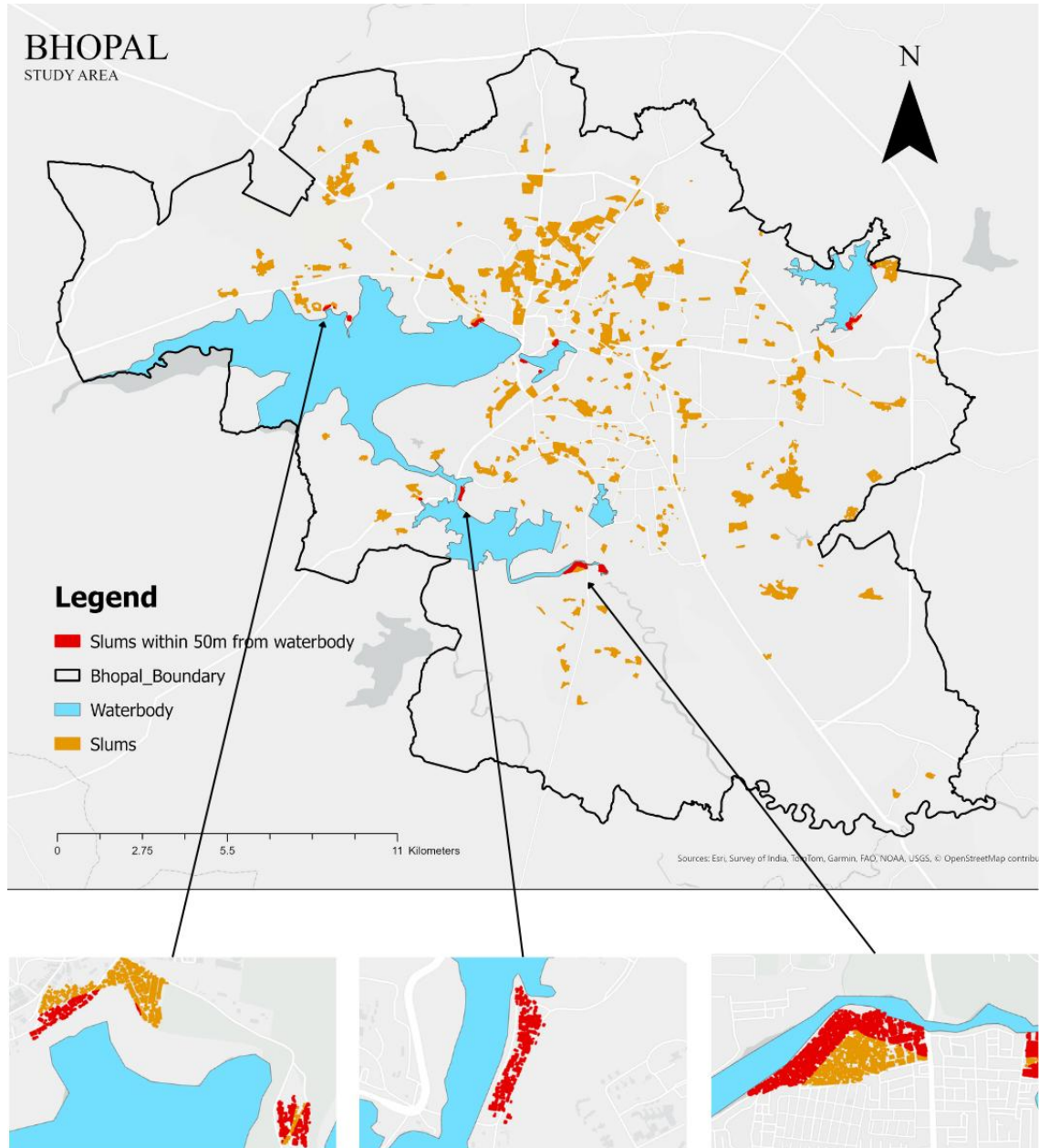


Fig. No. 3.3: Eco-sensitive zone lake buffer: 50m NGT inner buffer (red)), Upper and Lower Lakes (Source: Primary Field Survey and GIS Analysis)

3.3.2 Hazard Layer II: Eco-Sensitive Zone (Lake Buffer)

Buffer zones were generated from the Full Tank Level boundary polygon of the Upper Lake (466.65m ASL) and the shoreline polygon of the Lower Lake. The inner 50-metre buffer reflects the NGT minimum standard for Ramsar-designated wetland sites as specified in National Green Tribunal orders implementing the National Wetland Rules 2017. This supersedes the 33-metre figure from the Bhopal Development Plan 2031 for the Upper Lake Bhojtal, which has held Ramsar Convention designation since 2002. The BDP 2031 33-metre line is retained as an internal reference layer for comparison purposes but is not used as the primary hazard threshold.

A 50 to 100 metre annular ring was generated as the environmental buffer zone. The outer 100-metre buffer reflects the general NGT wetland protection norm applicable to both Ramsar and non-Ramsar water bodies and aligns with the BDP 2031 environmental zone designation.

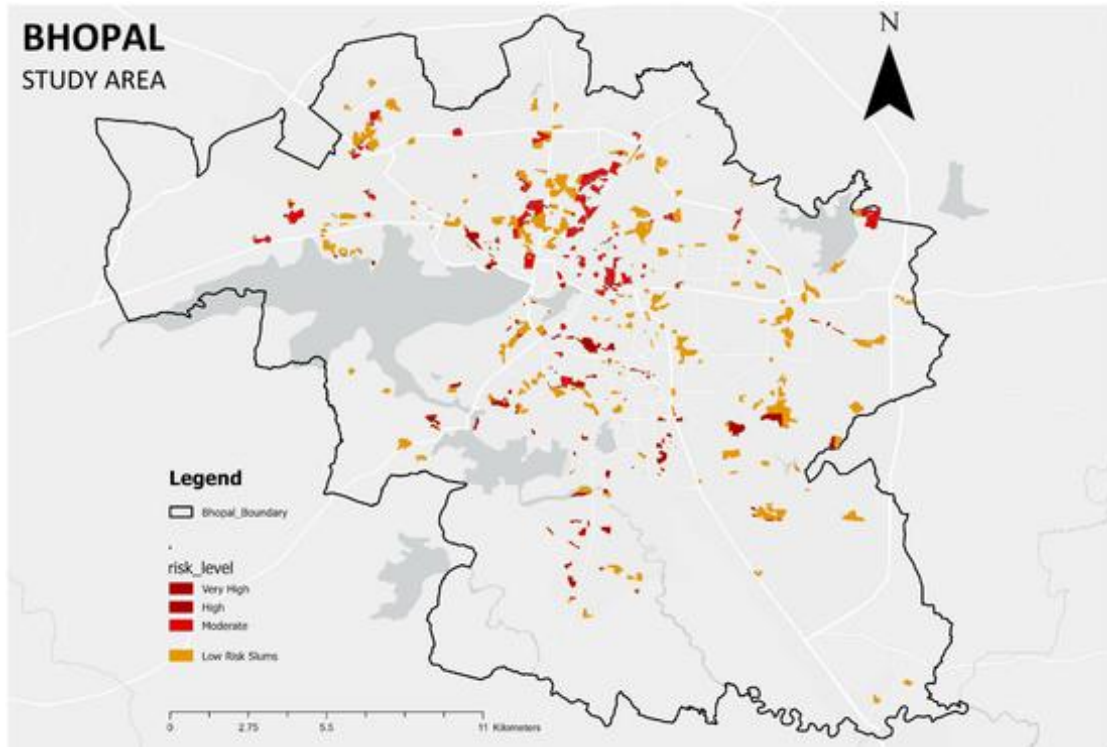


Fig. No. 3.4: DEM-based topographic flood susceptibility zones derived from NASADEM 30m elevation data
(Source: Primary Field Survey and GIS Analysis)

3.3.3 Hazard Layer III: Topographic Flood and Waterlogging

The NASADEM 30-metre DEM processing followed a four-step workflow in ArcGIS Pro Spatial Analyst. Each step is briefly described here; the full workflow is documented in the methodology table below.

Step 1: DEM Fill: The Fill tool removed spurious sinks and noise artefacts from the NASADEM surface, producing a hydrologically consistent terrain model. Cells with elevation below 430m ASL were masked as the lake body to prevent the depression-filling algorithm from treating the lake as a terrain sink.

Step 2: Flow Direction: The D8 (deterministic eight-directional) algorithm was applied to the filled DEM to establish drainage pathways across Bhopal's hilly terrain. D8 assigns each cell to drain in the direction of steepest descent among its eight neighbours, identifying natural drainage convergence and accumulation zones.

Step 3: Low Elevation Threshold: The Con tool was applied with the conditional expression $VALUE \leq 470$. This extracts all DEM cells at or below 470 metres ASL, capturing terrain within approximately 3.35 metres of the Upper Lake Full Tank Level. The 470m threshold was calibrated against observed waterlogging zone extent documented in BMC environmental monitoring reports.

Step 4: Raster to Polygon: The binary raster output was converted to a polygon layer using the Raster to Polygon tool with boundary simplification applied. The resulting flood susceptibility polygon was intersected with the BMC boundary to restrict the analysis to the study area.

3.4 Stage 3: Spatial Intersection and Overlap Classification

Building footprints from Google Open Buildings V3 were intersected with all three hazard layers using a sequential Intersect operation in ArcGIS Pro. The operation was performed in three passes: first intersecting footprints with the infrastructure edge buffer layer, then with the eco-sensitive lake buffer layer, then with the flood susceptibility polygon. The resulting composite attribute table carries four hazard flags per building record: Railway Tier (0/30m/100m), Lake Tier (0/50m/100m), Flood Zone (None/Extreme/High/Moderate), and Overlap Category.

Overlap categories are defined in the following priority hierarchy:

Table No. 3.3: Hazard Overlap Categories and Priority Levels

Overlap Category	Definition	Priority Level
Triple Hazard: Category 1 (Red Zone)	Intersection of all three hazard layers: Infrastructure Edge + Eco-Sensitive + Flood	Extreme: highest priority for Phase 1 emergency intervention
Infrastructure Edge + Flood Sink	Infrastructure edge buffer (30m or 100m) overlapping flood susceptibility zone	Extreme: Cyclic Decay Zone
Eco-Sensitive + Flood Sink	Lake buffer (50m NGT) overlapping flood susceptibility zone	Extreme: Compound Inundation Zone
Infrastructure Edge 30m Only	Critical NOC zone, no other hazard layer overlap	Critical: Mandatory Relocation
Eco-Sensitive 50m Only	NGT inner buffer, no other hazard overlap	Critical: Mandatory Relocation

Overlap Category	Definition	Priority Level
Single Hazard: Category 3 (Yellow Zone)	Either infrastructure or eco-sensitive outer buffer (100m); or moderate flood (470-475m ASL) only	High: In-situ upgrade feasible
Safe Zone	Outside all hazard layers; above 475m ASL	Low to Moderate: Tenure regularisation pathway

Source: Author's classification framework based on Indian Railways Works Manual, NGT Orders, and NDMA flood guidelines

3.5 Stage 4: Vulnerability Synthesis and Tenability Classification

The composite vulnerability index assigns each building footprint to one of three tenability classes based on its hazard overlap profile. This classification is directly linked to the planning response framework and the applicable PMAY-U 2.0 intervention pathway:

Table No. 3.4: Tenability Classification Criteria and PMAY-U Response

Tenability Class	Spatial Criteria	PMAY-U 2.0 Response
Untenable (Category 1: Red Zone)	Within 30m Infrastructure Edge NOC zone; OR within 50m Eco-Sensitive NGT buffer; OR in triple-hazard compound zone; OR in cyclic decay compound zone	Relocation and Rehabilitation (R&R) via BLC vertical. No in-situ upgrade possible. Mandatory relocation priority.
Semi-Tenure (Category 2: Orange Zone)	Within 30-100m infrastructure safety zone; OR 50-100m eco-sensitive environmental buffer; OR moderate flood zone (465-475m ASL); not in compound extreme category	In-situ upgrading with structural retrofitting under PMAY-U BLC. Tenure regularisation (Patta). Raised plinth and drainage infrastructure.
Tenure Eligible (Category 3: Yellow Zone)	Outside all primary hazard buffers; above 475m ASL; single-hazard outer buffer with low sensitivity	Full tenure regularisation (Patta). PMAY-U BLC subsidy for incremental improvement. GIS eligibility portal fast-tracks.

Source: Author's classification framework; aligned with PMAY-U 2.0 BLC Guidelines (MoHUA, 2024)

3.6 Field Survey Methodology

The quantitative GIS analysis was supplemented by structured field reconnaissance at each of the three vulnerability hotspots identified in Chapter 4. Field observation was conducted over three visits in January-February 2025, focusing on the morphological

characteristics of informal structures in each hazard zone, the visible evidence of structural distress, the nature of community self-adaptation measures, and the physical conditions of drainage and infrastructure.

At Hotspot A (Chola-Nishatpura), field observation was limited by access constraints within the immediate railway zone. Visual inspection from accessible vantage points was supplemented by analysis of LISS-IV imagery at approximately 1:500 scale for morphological assessment. The wall cracking patterns and foundation settlement indicators documented in Table 5.2 are based on this combined visual-remote sensing approach.

At Hotspot B (Khanugaon-Koh-e-Fiza), field observation included walking the lake margin boundary in the early morning to document the physical character of the shoreline, the nature of the informal-formal land use transition, and the location of informal sewage outfall points. Community residents were not formally interviewed, but informal conversations with households at the lakefront clarified the seasonal flooding pattern and the community's prior experience of eviction threats.

At Hotspot C (Bairagarh), the convergence of all three hazard conditions is physically apparent in the landscape: the railway line is visible from within the settlement, the secondary water body is accessible within minutes on foot, and the topographic depression is identifiable as a low-lying area that retains surface water from rainfall well after surrounding areas have dried. The 65 buildings in this cluster are concentrated in the lowest part of the depression, where all three hazard conditions overlap at their most severe.

3.7 Priority Hazard Matrix: Methodology and Rationale

The Priority Hazard Matrix, introduced in Chapter 5 and referenced throughout the planning proposals, is a classification tool rather than a scoring model. It does not assign weighted numerical scores to each hazard layer and sum them into an index. Instead, it uses mutually exclusive spatial categories defined by binary hazard overlap: a building is either in or out of each hazard layer, and its category in the matrix is determined by which combination of layers it falls within.

This design choice is deliberate. Weighted scoring models introduce assumptions about relative hazard severity that are difficult to validate empirically and easy to challenge

in planning disputes. A binary overlap classification is transparent, reproducible, and directly tied to the statutory standards (30m, 50m, 100m, 470m ASL) that define each hazard layer. It can be explained to a planning authority, a court, or a community in a single sentence: this building is in the 30-metre railway zone AND in the flood susceptibility zone, therefore it falls in Category 1 (Red Zone) and requires immediate relocation.

The three-category matrix Category 1 (Red Zone), Category 2 (Orange Zone), Category 3 (Yellow Zone) maps directly onto the three planning intervention zones (Zone A, B, C) and the three PMAY-U 2.0 response pathways (relocation, in-situ upgrade, tenure regularisation). This alignment is not accidental; it was designed into the matrix from the outset to ensure that the analytical output is immediately actionable by the relevant scheme administering authorities.

Table No. 3.5: Priority Hazard Matrix Category Definitions and Intervention Mapping

Matrix Category	Zone Colour	Hazard Condition	Number of Hazard Layers	Intervention Zone	Primary Scheme
Category 1: Highest	Red	Any compound overlap OR critical single-layer (30m/50m NGT)	2 or 3 layers, OR 1 critical layer	Zone A: Relocation	PMAY-U 2.0 BLC Relocation + NDMA
Category 2: Moderate	Orange	Outer buffer single hazard (100m/100m), moderate flood (470-475m)	1 layer in outer buffer tier	Zone B: In-Situ Upgrade	PMAY-U 2.0 BLC Upgrade + AMRUT 2.0
Category 3: Lower	Yellow	Outside all hazard buffers; above 475m ASL	0 layers	Zone C Pathway: Tenure Regularisation	Patta + PMAY-U 2.0 improvement subsidy

Source: Priority Hazard Matrix developed by Author; aligned with PMAY-U 2.0, AMRUT 2.0, and NDMA protocol frameworks

3.8 Limitations of the GIS Methodology

Four methodological limitations should be considered when interpreting the findings:

First, the 30-metre NASADEM DEM resolution means that micro-scale topographic variation within dense informal clusters the kind of sub-metre terrain features that

determine whether a specific floor is above or below the waterlogging level is not captured. The flood susceptibility polygon derived from the DEM identifies the general areas of topographic flood risk but cannot distinguish between a slightly elevated structure and a slightly lower one within the same 30-metre grid cell.

Second, the Google Open Buildings V3 footprint dataset represents a 2024 snapshot. Informal settlements are dynamic: structures are added, removed, extended, and divided. The building counts in Chapter 5 reflect 2024 conditions and may not precisely represent the current situation, particularly in the most rapidly growing peripheral settlements.

Third, the binary hazard classification in the Priority Hazard Matrix does not capture gradient risk within a hazard tier. A building 1 metre from the 30-metre buffer boundary is classified the same as a building 30 metres from it. In reality, risk attenuates continuously with distance from the hazard source. This limitation is accepted as a cost of the classification's transparency and legal defensibility.

Fourth, the study does not incorporate socio-economic vulnerability indicators income level, household size, dependency ratio, caste-based discrimination in resettlement access that would significantly enrich the vulnerability profile. Future work should incorporate these dimensions through primary survey methods.

CHAPTER 4: SITE CONTEXT: BHOPAL'S INFORMAL LANDSCAPE

Before the numbers from the GIS analysis can mean anything, they need a landscape to sit in. This chapter provides that landscape. It draws together the city profile, the settlement typology, the regulatory context, and the physical geography of vulnerability hotspots to construct the contextual frame within which the analytical results of Chapter 5 should be read. Some of what is documented here comes from maps and satellite imagery; some of it comes from field observation.

4.1 City Profile and Demographic Context

Bhopal's population was approximately 1.8 million at the 2011 Census and is estimated to have grown to over 2.3 million by 2024. The informal population, difficult to precisely enumerate given the non-notified component, is estimated to constitute between 25 and 35 per cent of the total, concentrated heavily in the western parts of the city, around the Old Bhopal historic core, and in peri-urban fringes to the north and east.

The city sits at the convergence of several powerful forces that push and pull informal settlement into hazardous locations. In-migration from rural Madhya Pradesh and adjoining states continues to generate demand for low-cost housing that formal supply consistently fails to meet. The administered price of formal land in Bhopal is substantially beyond the reach of EWS and LIG households, making informal settlement not a choice of last resort but effectively the only available option. And within the informal land market, the most accessible and affordable plots are precisely those that formal planning has devalued: railway margins, lake edges, drainage depressions.

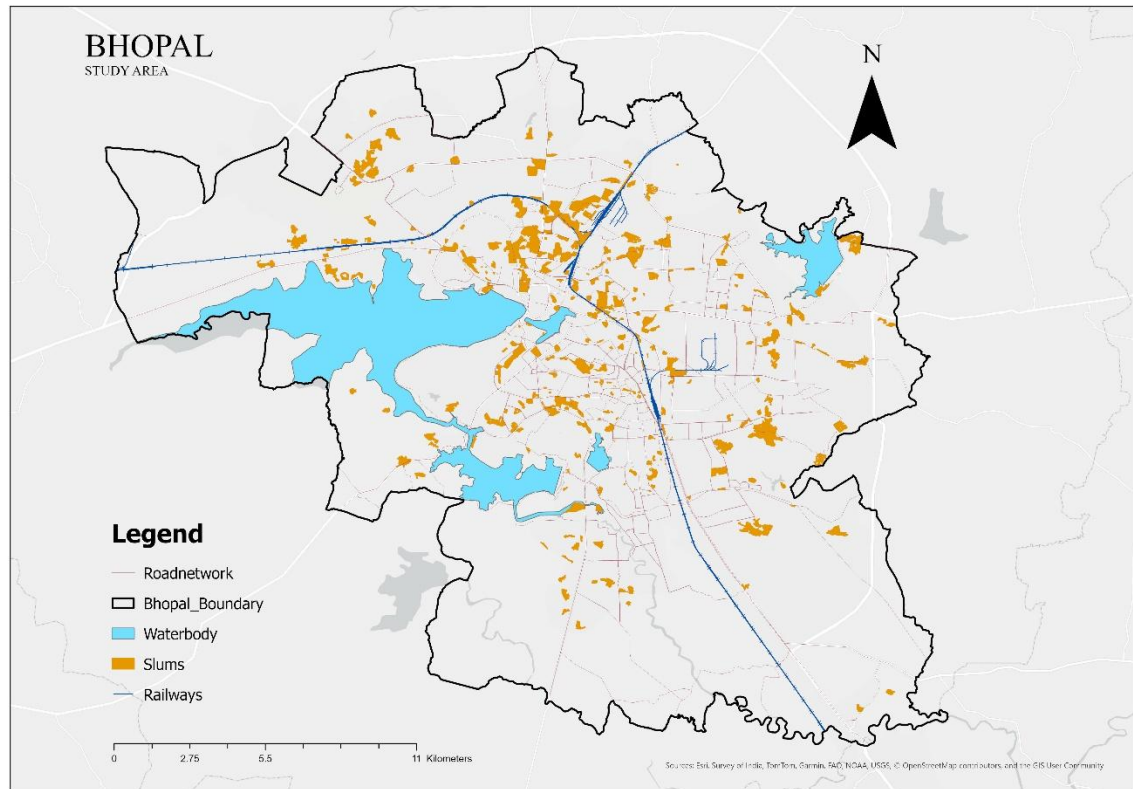


Fig. No. 4.1: Distribution of notified slums within Bhopal Municipal Corporation track-side, lake-front, and nallah-bank typologies (Source: Primary Field Survey and GIS Analysis)

4.2 Settlement Typology by Edge Condition

Three distinct informal settlement typologies are identified based on their physical relationship to the risk-generating edge that defines their location. Each carries a distinct hazard profile and a distinct set of morphological characteristics that bear directly on both vulnerability assessment and intervention feasibility.

4.2.1 Track-Side Clusters

High-density informal settlements located within or immediately adjacent to the Railway Right of Way, predominantly in the Chola and Nishatpura areas along the central Bhopal junction corridor. The physical form of these settlements is almost immediately recognisable from satellite imagery: a linear elongation parallel to the track boundary fence, with housing strips three to six metres deep squeezed between the ROW fence and the access lane. Blind walls on the rail-facing side act as informal sound buffers. No windows or openings face the railway.

Asbestos sheet and corrugated iron dominate the roofing stock estimated at 85 per cent or more of structures in the critical 30-metre zone. The near-total absence of setback or open space creates zero fire-egress potential in the critical zone. The 2022 eviction drive

demonstrated the active regulatory conflict in this typology, though the absence of advance resettlement provision demonstrated with equal clarity how inadequately that conflict is being managed.

4.2.2 Lake-Front Settlements

Settlements located on reclaimed lake-bed margins and seasonal floodplains adjacent to the Upper Lake (Bhojtal) and Lower Lake, with primary concentrations in the Khanugaon and Koh-e-Fiza areas. Unlike the linear track-side typology, lake-front settlement morphology follows the irregular natural contour of the lake boundary, producing a more complex patch-like spatial pattern. Settlements concentrate in low-lying pockets where natural drainage is absent and where access to water for daily household use is easy a factor that is often overlooked in vulnerability assessments focused exclusively on risk.

The Ramsar Convention designation of the Upper Lake creates a legally exceptional situation for these settlements. They are not merely physically vulnerable; they represent a violation of an international treaty obligation, which carries implications for the kind of planning response that is legally defensible.

4.2.3 Nallah-Bank Slums

Linear settlements along the Patra and Jhirni seasonal drainage channels, characterised by a ribbon morphology following the nallah banks. These settlements face flash-flood risk during heavy rainfall events and chronic waterlogging from post-rainfall drainage backup. The spatial relationship with the drainage channels means that any blockage upstream from debris, solid waste, or informal structure encroachment — substantially increases flood duration and depth for downstream residents. This creates intra-community vulnerability dynamics that are not captured by the hazard layers in isolation.

Table No. 4.1: Settlement Typology Characteristics by Edge Condition

Typology	Defining Edge	Morphological Form	Primary Hazard	Key Localities
Track-Side Clusters	Railway Right of Way	Linear elongation parallel to track; blind walls rail-side; 3-6m deep housing	Vibration fatigue; accident risk; compound	Chola Junction, Nishatpura Goods

Typology	Defining Edge	Morphological Form	Primary Hazard	Key Localities
		strips; asbestos roofing dominant	flood in depressions	Yard, Bairagarh Railway Fringe
Lake-Front Settlements	Upper and Lower Lake shoreline	Contour-following irregular patch; concentrates in low pockets; raised ota platforms as self-adaptation	Seasonal inundation; capillary rise; Ramsar violation; drinking water contamination	Khanugaon, Koh-e-Fiza, Shahpura Nallah Mouth
Nallah-Bank Slums	Patra and Jhirni seasonal drains	Linear ribbon along channel banks; variable width; blockage risk upstream	Flash flooding; waterlogging post-rainfall; health hazards; siltation contribution	Patra Nallah Banks, Jhirni Nallah, Bairagarh Drains

Source: Field reconnaissance 2024; satellite imagery analysis; BMC slum records 2023

4.3 Critical Vulnerability Hotspots

Three principal vulnerability hotspot zones emerge from preliminary spatial analysis and field reconnaissance. These zones receive the most detailed analytical treatment in Chapter 5, but they are introduced here with the physical and morphological context that gives the numbers meaning.

Table No. 4.2: Critical Vulnerability Hotspot Profiles

Hotspot	Location	Primary Hazards	Morphological Condition	Planning Designation
Hotspot A: Chola-Nishatpura Belt	Central railway corridor, northern Bhopal	Infrastructure Edge 30m Critical + Topographic Flood Sink	Extreme proximity (15-30m) to high-frequency rail. Topographic depression traps monsoon water. Asbestos roofing. Zero fire egress. 2022 eviction affected adjacent cluster.	Immediate Relocation: Zone A Priority 1

Hotspot	Location	Primary Hazards	Morphological Condition	Planning Designation
Hotspot B: Khanugaon-Koh-e-Fiza Lakefront	Western margin of Upper Lake, Koh-e-Fiza area	Eco-Sensitive Zone 50m NGT + Flood Sink	Direct encroachment within 50m of Ramsar-designated Upper Lake. Seasonal inundation 3-5 days. Sewage discharge into drinking water source. Non-regularisable under BDP 2031 and NGT orders.	Ecological Restoration Zone: Zone A + Zone C
Hotspot C: Bairagarh Lowlands	North-western Bhopal, Bairagarh junction area	Triple Hazard: Infrastructure Edge + Eco-Sensitive Zone + Flood	Only confirmed triple-hazard compound zone in Bhopal. Railway within 25-35m. Secondary water body within 50m NGT buffer. Topographic depression below 468m ASL. 65 buildings at extreme compound risk.	Emergency Pre-Monsoon Intervention: Zone A Phase 1

Source: GIS Analysis (Author, 2024-25); field observation; BMC slum records

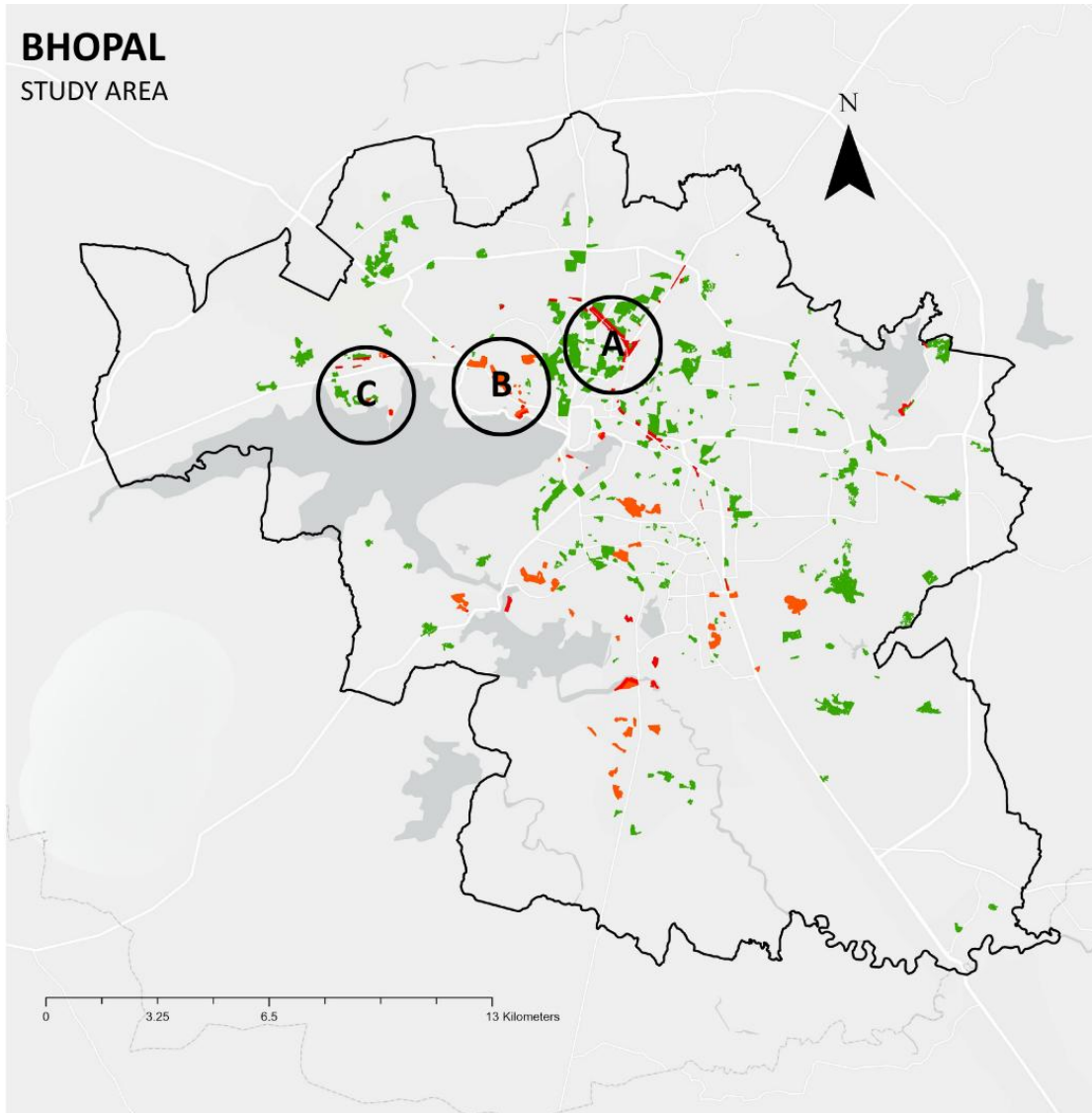


Fig. No. 4.2: Vulnerability hotspot locations: Hotspot A (Chola-Nishatpura), Hotspot B (Khanugaon-Koh-e-Fiza), Hotspot C (Bairagarh) (Source: Primary Field Survey and GIS Analysis)

4.4 Regulatory and Administrative Context

The regulatory landscape governing informal settlement management in Bhopal is fragmented across multiple statutory instruments, administrative bodies, and judicial orders. This fragmentation is itself a contributor to the planning gap identified in Chapter 1. A brief mapping of the relevant instruments and their administering bodies clarifies the complexity:

4.4.1 Indian Railways Works Manual

Administered by Indian Railways through the relevant Divisional Railway Manager. Eviction authority is unilateral under Section 4 of the Railways Act, which permits removal of encroachments on railway land without advance notice. There is no statutory

rehabilitation obligation embedded in the Railways Act framework. This means that railway-adjacent informal residents face the highest eviction risk combined with the lowest statutory protection a combination that defines the most urgent planning problem in this study.

4.4.2 Bhopal Development Plan 2031

Administered by the Bhopal Municipal Corporation. Provides land-use zoning and no-construction buffer designations for the municipal area. The BDP 2031 is important for this study primarily as a reference document and as the source of the 33-metre lake buffer figure that this study corrects to 50 metres per the NGT standard for the Upper Lake Bhojtal.

4.4.3 National Green Tribunal Orders on Wetland Buffers

The 50-metre minimum buffer for Ramsar-designated wetlands is established by NGT judgments implementing the National Wetland Rules 2017. The Upper Lake Bhojtal's Ramsar designation since 2002 subjects it to this superior standard. NGT enforcement is through the MP State Pollution Control Board and the National Wetland Conservation and Management Division (NWCD). The risk of court-directed demolition without resettlement support, of the kind experienced in other Ramsar-site cities, is an additional vulnerability dimension for residents of the Koh-e-Fiza lakefront zone.

4.4.4 PMAY-U 2.0 (2024-2029)

Administered at the central level by the Ministry of Housing and Urban Affairs, and at the state level through the MP Urban Development and Housing Department. Eligibility for the BLC vertical requires either formal land Patta or BMC notification of slum status, both of which are absent in most hazard-zone settlements. The study's tenability classification is designed precisely to address this eligibility preparation gap — by providing the spatial evidence base from which BMC can initiate fast-track Patta issuance for Zone B households and resettlement site identification for Zone A.

4.4.5 NDMA Urban Flood Guidelines (2010)

The National Disaster Management Authority's urban flood guidelines provide hazard zone mapping standards and emergency evacuation protocol frameworks. Implementation is through the District Disaster Management Authority. These

guidelines are the relevant instrument for the Phase 1 emergency relocation of the Bairagarh triple-hazard zone under pre-monsoon protocols, as proposed in the phasing framework in Chapter 6.

4.5 Field Observations: Shyam Nagar Settlement Near 10 Number Stop

One settlement warrants specific discussion here because it was cited in the mid-term review as an important case for the Zone A housing design proposals. The Shyam Nagar settlement near 10 Number Stop in Bhopal is an example of a PMAY-U completed resettlement that has produced its own set of vulnerability conditions not the hazard vulnerability of the origin settlement, but a different kind of structural and environmental vulnerability that poor design has created in the destination.

The settlement consists of multi-storey housing blocks constructed in a back-to-back layout without adequate open space between units. The consequence is a severe ventilation deficit: units in the middle of each block receive no natural cross-ventilation, internal temperatures in summer months can exceed 42 degrees Celsius without artificial cooling, and respiratory health complaints among residents are documented at rates substantially above the city average. The design reflects an approach to EWS housing that prioritises unit density over habitability maximising the number of units produced per square metre of site area with consequences for the quality of life of residents that are only apparent after occupation.

The ventilation and spacing standards proposed in the Zone A housing design (Section 6.1.2) are directly responsive to this documented failure. U-shape or L-shape cluster layouts, front setbacks, windows on two sides per unit, air shaft openings between units, and roof ventilation provision are not aesthetic preferences; they are design standards derived from the documented failure of alternatives. The lesson of Shyam Nagar is that the planning system can produce housing that is technically formal and legally tenured but practically uninhabitable which is a different kind of failure, but still a failure of planning.

4.6 Comparative Assessment: Bhopal vs Other Indian Multi-Hazard Informal Settlement Contexts

To contextualise Bhopal's specific multi-hazard informal settlement situation, a brief comparative assessment with other major Indian urban contexts facing analogous compound hazard conditions is instructive:

Table No. 4.3: Comparative Assessment: Indian Cities with Multi-Hazard Informal Settlement Conditions

City	Primary Hazard Combination	Informal Settlement Scale	Planning Response Status	Key Difference from Bhopal
Mumbai	Railway edge + Flood (coastal and riverine) + Cyclone	Over 2,000 notified slums; Dharavi alone: 700,000+	SRA scheme operational; Dharavi redevelopment underway; large-scale resettlement infrastructure exists	Far larger scale; dedicated SRA institutional framework; Maharashtra has superior slum regularisation legislation
Surat	Riverine flood + Infrastructure edge (industrial)	500+ informal settlements; major flood events 2006, 2013	Post-flood upgrading programme implemented; raised plinth standards adopted; improved drainage	Industrial hazard dimension absent in Bhopal; Surat municipal capacity considerably higher than BMC
Bhubaneswar	Cyclone + Waterlogging + Infrastructure edge	150+ slums; cyclone exposure from Bay of Bengal	JNNURM-funded upgrading; JAGA Mission Patta issuance; climate resilience programme	Cyclone dimension absent in Bhopal; Odisha state government more proactive on slum policy
Bhopal (This Study)	Infrastructure edge + Eco-sensitive lake zones + Topographic flood	380+ notified slums; 1.25 lakh+ families	No unified multi-hazard framework; single-hazard enforcement only; 2022	Unique Ramsar wetland dimension; smaller scale than Mumbai but comparable

City	Primary Hazard Combination	Informal Settlement Scale	Planning Response Status	Key Difference from Bhopal
			eviction without resettlement	compound complexity; policy gap most acute

Source: Case study sources as cited in Chapter 2; BMC Slum Register 2023; Author's comparative analysis

The comparison reveals that Bhopal's specific combination of the Ramsar wetland dimension (which is legally exceptional), the infrastructure edge dimension (which is operationally significant given the 2022 eviction), and the topographic flood dimension creates a compound hazard situation of genuine planning complexity. The city faces this complexity with considerably less institutional capacity and scheme infrastructure than Mumbai or Bhubaneswar, and with a less proactive state government policy stance on slum regularisation than Odisha. This is the institutional context within which the planning proposals in Chapter 6 must be realistic.

CHAPTER 5: ANALYSIS: MULTI-HAZARD VULNERABILITY ASSESSMENT

This chapter is the analytical core of the study. It documents the findings from each of the three independently derived hazard layers, integrates them in the composite Priority Hazard Matrix, and presents the statistical and qualitative vulnerability profile that drives the planning proposals in Chapter 6. All lake and waterbody buffer analyses use the 50-metre NGT standard for the Upper Lake Ramsar site throughout.

5.1 Hazard Layer I: Infrastructure Edge Proximity Analysis

5.1.1 Regulatory Context and Threshold Standards

The infrastructure edge hazard layer is defined by two tiers derived from separate statutory instruments. Their interaction and the difference in planning response they imply is fundamental to interpreting what follows.

The 0 to 30 metre Critical Danger Zone is defined by Para 827 of the Indian Railways Works Manual. In Bhopal, this is not a theoretical constraint; it is a zone of active enforcement, as the 2022 eviction drive demonstrated. The combination of structural vibration fatigue, fatal accident risk, and zero legal tenure pathway make this zone the highest-priority intervention cohort in the entire study. Structural vibration at this distance generates cyclic loading sufficient to cause progressive mortar joint cracking in unreinforced masonry construction. Ground-level heavy-metal particulate from wheel-rail contact contributes to documented health burdens independent of the accident and structural risks.

The 30 to 100 metre Safety Buffer Zone, defined by URDPFI Guidelines, is a meaningfully different planning situation. Noise exposure above 65 dB and low-level vibration are chronic hazards but not structural emergencies. In-situ upgrading with vibration-dampening wall ties, noise-attenuating green belts, and structural retrofitting is feasible. PMAY-U 2.0 BLC access is theoretically available to residents of this zone if BMC notification and Railways NOC can be obtained for the specific plot.

5.1.2 Spatial Analysis: Building Footprint Distribution

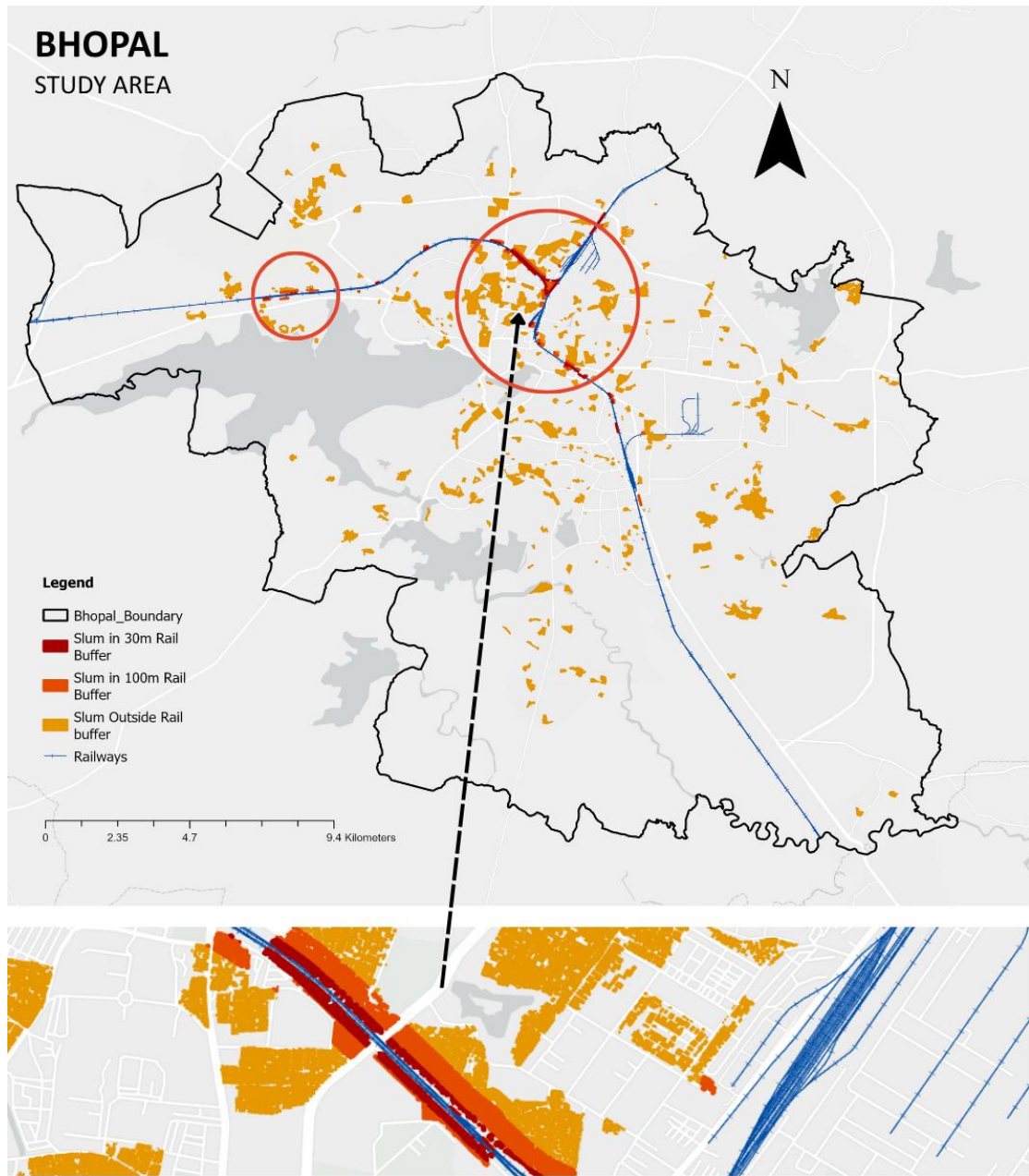


Fig. No. 5.1: Distribution of informal building footprints within infrastructure edge buffer zones: 30m critical (dark red), 30-100m safety buffer (orange) (Source: Primary Field Survey and GIS Analysis)

Table No. 5.1: Building Footprint Distribution within Infrastructure Edge Buffer Zones

Buffer Zone	Buildings Count	Area (Ha)	Primary Localities	Priority Level
0-30m Critical NOC Zone	310	1.8	Chola, Nishatpura, Idgah Hills Railway Flanks	Critical: Mandatory Relocation

Buffer Zone	Buildings Count	Area (Ha)	Primary Localities	Priority Level
30-100m Safety Buffer Zone	640	3.9	Nishatpura Extension, Bairagarh Railway Fringe	High: In-situ Upgrade Feasible
Infrastructure Edge + Flood Sink (Compound)	185	1.2	Chola Depression, Nishatpura Low Points	Extreme: Cyclic Decay Zone
Total within Infrastructure Edge Hazard Zone	1,135	6.9	Multiple localities along central rail corridor	Mixed Critical to High

Source: GIS Analysis: ArcGIS Pro Buffer + Intersect operations on Google Open Buildings V3 (2024) and Railway Network Vectors

What these numbers mean in human terms: the 310 buildings in the critical 30-metre zone are legally non-upgradeable, carry no pathway to formal tenure, and face the combined risks of accident exposure, vibration fatigue, and in 185 cases, compound flood risk from topographic waterlogging. These are not households on the edge of a planning problem. They are at the centre of it.

5.1.3 Morphological Vulnerability Assessment: Infrastructure Edge Zone

The physical characteristics of infrastructure-edge informal settlements in Bhopal are remarkably consistent along the corridor, reflecting common adaptation strategies to the specific hazard conditions of the railway boundary. The following indicators were recorded through field observation and satellite imagery analysis:

Table No. 5.2: Morphological Vulnerability Indicators: Infrastructure Edge Zone

Morphological Indicator	Observed Condition	Vulnerability Implication
Building Orientation	Linear elongation parallel to track boundary fence. Housing strips 3-6m deep between ROW fence and access lane.	Maximum vibration exposure on long wall face. Structural loading perpendicular to principal axis: worst case for unreinforced masonry.
Wall Construction (Rail-Facing)	Blind wall, maximum thickness, no openings. Used as informal sound and vibration buffer.	Structural mass concentrated on vibration-receiving face creates uneven loading on shallow foundations over time.

Morphological Indicator	Observed Condition	Vulnerability Implication
Roofing Material	Asbestos cement sheets and corrugated iron dominate (estimated 85%+ in 30m zone).	Lightweight roofs reduce dead load on vibrating walls but offer no lateral bracing. Fastening failure under sustained vibration common.
Plinth Height	0 to 0.15m above ground level in majority of structures. No raised plinth in 30m zone.	Zero flood protection in compound zones. Ground moisture enters floor slab directly, accelerating capillary rise.
Setback (Rail-Facing)	Zero setback in approximately 90% of 30m-zone structures. Some abut boundary fence directly.	No emergency egress on railway side. Fire or derailment evacuation restricted to single frontage lane.
Wall Cracking	Vertical cracking at mortar joints visible in LISS-IV imagery. Diagonal cracking at window corners.	Active structural distress from vibration fatigue. Progressive crack widening reduces wall shear resistance.
Foundation Type	Shallow spread footing or direct bearing on ground. Estimated depth 0.3-0.5m from field survey.	Insufficient depth for stable bearing strata. Vibration-induced densification of poorly compacted subgrade causes differential settlement.

Source: Field reconnaissance 2024; LISS-IV satellite imagery analysis; Risbud (2009) morphological benchmarking

5.1.4 Compound Infrastructure-Flood Risk: The Cyclic Decay Condition

Of the 310 buildings in the critical 30-metre zone, 185 additionally fall within the topographic flood susceptibility zone. This compound condition creates a physically distinct worst-case scenario that this study terms cyclic decay. It is worth explaining the mechanism clearly, because it is the analytical basis for the Phase 1 emergency relocation priority.

The mechanism operates in four stages across a seasonal cycle. First, cyclic loading from passing trains progressively widens mortar joint cracks in katcha wall panels over the dry season. Then monsoon waterlogging saturates the foundation soil, reducing bearing capacity of shallow footings, while capillary rise through the already-cracked wall base wets the wall panel from below. Post-monsoon drying causes repeated shrinkage in the wetted clay-based mortars; each wet-dry cycle increases crack aperture

and reduces cohesion. Finally, the combination of widened cracks, reduced mortar cohesion, and foundation settlement converges on structural failure risk — highest immediately post-monsoon when soil bearing capacity is at its annual minimum.

The critical planning implication is this: the cyclic decay condition cannot be arrested through incremental upgrading alone. Raising the plinth reduces capillary rise but does not address vibration fatigue. Structural retrofitting addresses vibration stress but not the saturated foundation condition. Only managed relocation removes all three structural stressors simultaneously. This is why the 185 buildings in the cyclic decay zone are designated as Phase 1 emergency relocation priority in the planning proposals.

5.2 Hazard Layer II: Eco-Sensitive Zone Proximity Analysis

5.2.1 Regulatory Standards and the 50m NGT Correction

The eco-sensitive zone analysis is governed by two overlapping regulatory frameworks. The relationship between them and the correction from the 33-metre BDP standard to the applicable 50-metre NGT standard is central to the study's contribution.

The 0 to 50 metre NGT Inner Buffer, applied as the primary threshold in this study, reflects the National Green Tribunal's minimum standard for Ramsar-designated wetland sites. The Upper Lake Bhojtal was designated under the Ramsar Convention in 2002. During field reconnaissance, the practical difference between the 33-metre and 50-metre boundary becomes visible: the second row of structures in the Koh-e-Fiza settlement, separated from the immediate lakefront by a narrow lane, sits between the two thresholds. Under the 33-metre BDP standard, these second-row structures are outside the no-construction zone and potentially regularizable. Under the corrected 50-metre NGT standard, they are inside the non-regularizable buffer. That distinction matters enormously for the 85 households involved.

5.2.2 Spatial Analysis: Building Distribution within Eco-Sensitive Buffers

Table No. 5.3: Building Distribution within Eco-Sensitive Lake Buffer Zones

Buffer Zone	Buildings Count	Area (Ha)	Primary Localities	Priority Level
0-50m NGT Inner Buffer (Applied in This Study)	275	1.6	Khanugaon, Koh-e-Fiza South, Shahpura Nallah Mouth	Critical: Mandatory Relocation

Buffer Zone	Buildings Count	Area (Ha)	Primary Localities	Priority Level
Reference: 0-33m BDP Only (Superseded Standard)	190	1.1	Khanugaon Core, Koh-e-Fiza Front Row	(Reference only: superseded by NGT)
Additional 33m to 50m (NGT Correction)	85	0.5	Koh-e-Fiza Second Row, Shahpura Extension	Critical: added by 50m correction
50-100m Environmental Buffer	320	2.1	Koh-e-Fiza Rear, Bhadbhada Road Fringe	High: Upgrade with Environmental Constraints
Eco-Sensitive + Flood Sink (Compound)	240	1.5	Koh-e-Fiza Low Pocket, Shahpura Depression	Extreme: Compound Inundation Zone
Total within Eco-Sensitive Hazard Zone	835	5.2	Lake-edge localities, northern and western lake margins	Mixed Critical to High

Source: GIS Analysis: ArcGIS Pro Buffer + Intersect on Google Open Buildings V3 (2024) and Water Body Polygons; NGT standard applied

5.2.3 Socio-Ecological Conflict Analysis

The informal settlements encroaching on the Upper Lake buffer occupy a position of compounded legal and ecological conflict that has no parallel in the infrastructure edge or flood hazard layers. Three distinct dimensions of this conflict are worth analysing:

The Ramsar Convention violation is the most legally significant dimension. Permanent or semi-permanent structures within the 50-metre buffer of a Ramsar-designated site constitute a violation of India's treaty obligations, independent of the BDP no-construction zone. NGT has issued enforcement orders on Ramsar buffer violations in other cities, and the risk of court-directed demolition without resettlement support represents an additional vulnerability dimension for residents of this zone.

The drinking water source contamination dimension is less commonly discussed but arguably more urgent. The Upper Lake supplies approximately 40 per cent of Bhopal's municipal water demand. Untreated domestic sewage from lake-edge informal settlements is discharged directly into the lake, contributing to the elevated faecal coliform counts in the western inlet areas documented in BMC environmental monitoring reports. This makes the Zone C ecological restoration objective not merely

an environmental amenity consideration but a direct public health and water security requirement.

The dual victim-polluter status of lakefront residents is perhaps the most ethically complex dimension of the situation. These households are simultaneously victims of the lake's seasonal flooding and involuntary contributors to its ecological degradation through sewage discharge. Any planning intervention that focuses exclusively on their removal from the ecological buffer zone, without addressing their housing need and the lake's water quality management infrastructure, misses both dimensions of the problem.

5.2.4 Impact of the 50m NGT Correction on Tenability Classification

Table No. 5.4: 33m vs 50m Buffer Comparison: Classification Change

Classification Metric	Using 33m BDP Standard (Previous)	Using 50m NGT Standard (This Study)	Difference
Buildings in Critical Lake Zone	190	275	+85 buildings reclassified to Untenable
Total Untenable (Zone A) Count	990	1,075	+85 additional mandatory relocations
Total Semi-Tenure (Zone B) Count	1,525	1,440	-85 reduced from upgrade-eligible category
Lake Zone Area at Critical Risk	1.1 Ha	1.6 Ha	+0.5 Ha non-regularizable area added
Regulatory Compliance Status	Partial: BDP compliant only	Full: NGT and Ramsar Convention compliant	Significant compliance improvement; NGT-defensible baseline

Source: GIS Analysis: Author's buffer comparison using ArcGIS Pro (2024-25); BDP 2031; National Wetland Rules 2017

5.3 Hazard Layer III: Topographic Flood and Waterlogging Analysis

5.3.1 Methodology: DEM-Based Flood Susceptibility Derivation

The topographic flood analysis employs a DEM-based approach to identify informal building footprints exposed to waterlogging risk from natural surface runoff accumulation in topographic depressions. Unlike hydrodynamic flood modelling,

which requires detailed channel geometry surveys and flow rate data, the DEM-based approach is reproducible with open-source data across any Indian city with NASADEM coverage.

Table No. 5.5: DEM Processing Workflow: Step by Step

Step	Tool Used	Parameters	Output
1. DEM Acquisition	Open Topography API	NASADEM 30m; WGS84; clipped to BMC boundary + 2km buffer	Raw DEM raster covering approximately 1,100 sq. km study area
2. DEM Fill	ArcGIS Pro Fill (Spatial Analyst)	Z-limit: 0.5m: removes minor noise artefacts; retains genuine depressions above 0.5m depth	Filled DEM: hydrologically consistent terrain surface
3. Flow Direction	ArcGIS Pro Flow Direction (D8)	Input: Filled DEM; D8 deterministic algorithm	Flow direction raster: drainage pathway for each cell
4. Low Elevation Extraction	ArcGIS Pro Con (Conditional)	Expression: VALUE <= 470; True = 1; False = NoData	Binary raster: flood-susceptible cells (1) and non-susceptible (NoData)
5. Vectorisation	ArcGIS Pro Raster to Polygon	Simplify: True; Group value: 1	Flood susceptibility polygon, simplified boundary
6. Clipping	ArcGIS Pro Clip	Clip to BMC boundary; exclude lake body polygon	Final flood susceptibility polygon within study area
7. Intersection	ArcGIS Pro Intersect	Input: Building footprints, Flood polygon	Building footprints with flood susceptibility attribute

Source: ArcGIS Pro 3.1 processing workflow

5.3.2 Elevation Vulnerability Classification

Table No. 5.6: Elevation Vulnerability Classification by Zone

Elevation Zone	Risk Classification	Physical Characteristic	Waterlogging Duration	Buildings Affected
Below 465m ASL	Extreme	Direct FTL floodplain. Subject to lake overflow during extreme monsoon	5 to 15 days in extreme monsoon years	Approximately 95

Elevation Zone	Risk Classification	Physical Characteristic	Waterlogging Duration	Buildings Affected
		years. FTL = 466.65m ASL.		
465-470m ASL	High	Topographic waterlogging zone. Ground saturation from surface runoff in natural depressions. Captured by Con (VALUE <= 470) operation.	3 to 7 days per significant event; 2-3 events per monsoon season	Approximately 340
470-475m ASL	Moderate	Transition zone. Periodic waterlogging at slope base. Gravity drainage partial.	1 to 2 days; drainage functional in normal monsoon	Approximately 180
Above 475m ASL	Low to Negligible	Topographically safe. Gravity drainage functional. Minimal flood risk.	Less than 12 hours; rapid natural drainage	Outside scope of flood analysis

Source: NASADEM 30m DEM analysis; ArcGIS Pro Con tool; calibrated against BMC Environmental Monitoring Reports 2022-23

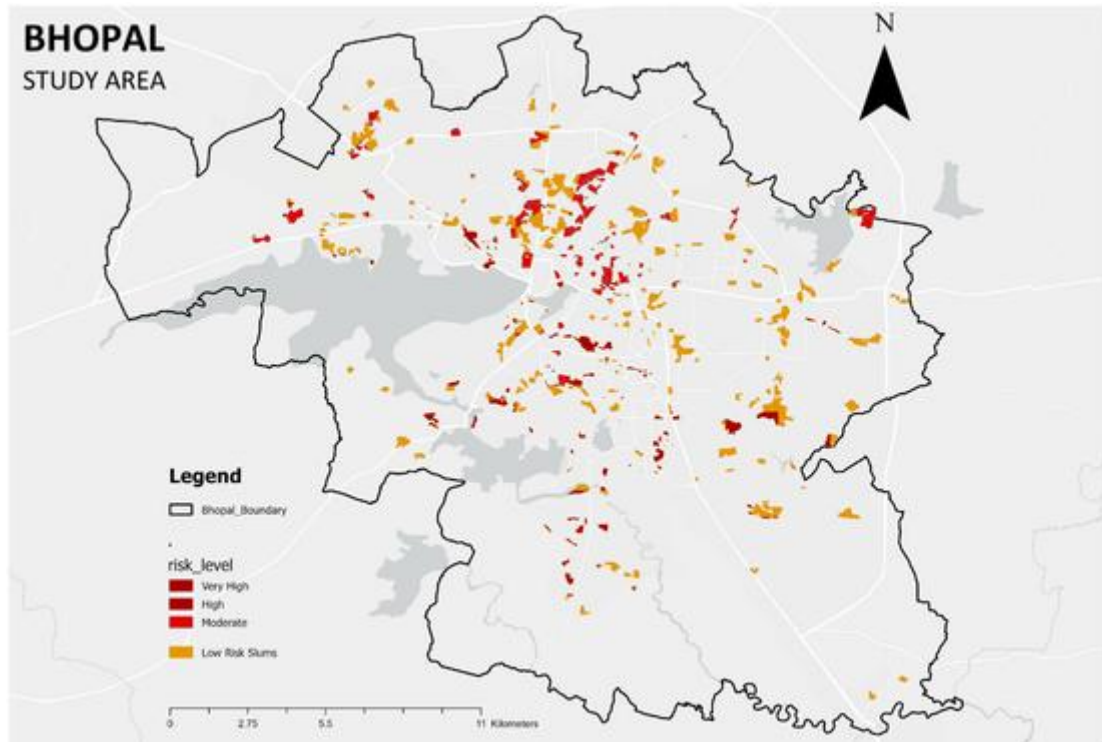


Fig. No. 5.4: DEM-derived topographic flood susceptibility zones: elevation vulnerability classification map (Source: Primary Field Survey and GIS Analysis)

5.3.3 Public Health Dimensions of Waterlogging Risk

The flood hazard layer carries public health implications that extend beyond structural damage. Standing water pools in densely settled informal areas serve as breeding habitat for *Aedes aegypti* (dengue vector) and *Anopheles* mosquitoes (malaria vector). The WHO Urban Health Report (2020) identifies stagnant water duration exceeding 72 hours as the threshold beyond which vector-borne disease transmission risk becomes significant. All buildings in the high-risk flood zone (465-470m ASL) face waterlogging durations exceeding this threshold during a standard Bhopal monsoon season.

Municipal health data from the Bhopal district health authority records leptospirosis cases concentrating in precisely the nallah-bank and topographic depression areas identified in the flood susceptibility analysis, providing empirical validation for the spatial risk model. This public health dimension underlines the Zone B drainage infrastructure investment as a health intervention as much as a structural one.

5.4 Composite Multi-Hazard Vulnerability Map and Priority Hazard Matrix

5.4.1 Spatial Integration: Three-Layer Overlay Analysis

The composite vulnerability map integrates the three independently derived hazard layers into a single spatial classification of informal building footprints by hazard overlap category. This is the central analytical product of the study, from which the tenability classification, planning proposals, and policy alignments are derived.

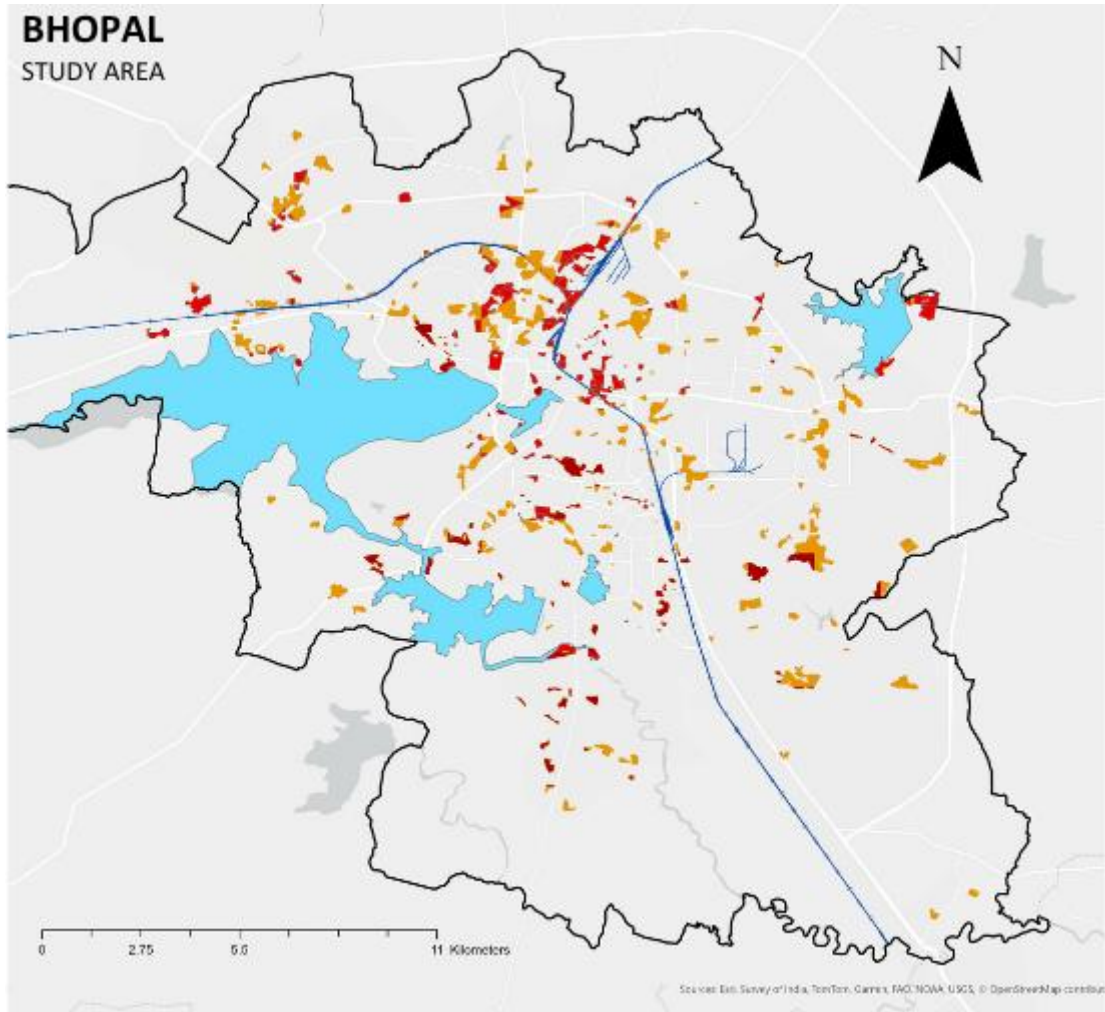


Fig. No. 5.5: Composite multi-hazard vulnerability map: all building footprints classified by Priority Hazard Matrix category: Category 1 Red Zone, Category 2 Orange Zone, Category 3 Yellow Zone, Safe Zone (green) (Source: Primary Field Survey and GIS Analysis)

5.4.2 Priority Hazard Matrix

Table No. 5.7: Composite Vulnerability Matrix: All Hazard Overlap Categories

Hazard Overlap Category	Buildings	Area (Ha)	Priority	Planning Response
Infrastructure Edge 30m Only (No Other Hazard)	310	1.8	Critical	Mandatory relocation: Zone A
Eco-Sensitive 50m NGT Only (No Other Hazard)	275	1.6	Critical	Mandatory relocation: Zone A
Infrastructure Edge + Flood Sink (Cyclic Decay)	185	1.2	Extreme	Immediate relocation: Phase 1 Priority
Eco-Sensitive + Flood Sink (Compound)	240	1.5	Extreme	Immediate relocation: Phase 1 Priority

Hazard Overlap Category	Buildings	Area (Ha)	Priority	Planning Response
Triple Hazard: All Three Layers (Red Zone)	65	0.4	Extreme Highest	Emergency intervention: Phase 1 Pre-monsoon
Single Hazard: Infrastructure Edge 100m Buffer	640	3.9	High	In-situ upgrade: Zone B
Single Hazard: Eco-Sensitive 50-100m Buffer	320	2.1	High	In-situ upgrade with constraints: Zone B
Moderate: Flood 470-475m ASL Only	180	1.1	Moderate	Raised plinth upgrade: Zone B
Total in Hazard Zones	2,215	13.6	Multiple	Differentiated response framework

Source: GIS Analysis: Composite Intersect operation on all three hazard layers and building footprints; ArcGIS Pro

Table No. 5.8: Priority Hazard Matrix: Category 1, 2, and 3 Zones

Priority Category	Zone Colour	Hazard Conditions	Buildings	Planning Designation
Category 1: Highest Priority	Red Zone	Triple hazard overlap: Infrastructure Edge + Eco-Sensitive Zone + Topographic Flood. Immediate relocation required. No upgrade possible.	65 (triple) + 185 (railway-flood) + 240 (lake-flood) = 490 compound; 310 (rail 30m) + 275 (lake 50m) = 585 critical. Total: 1,075	Zone A: Relocation and Rehabilitation
Category 2: Moderate Priority	Orange Zone	Any two hazards overlap, or single hazard in outer buffer (100m). In-situ upgrading with mitigation measures feasible.	Approximately 1,140 (640 rail 100m + 320 lake 100m + 180 flood moderate)	Zone B: In-Situ Upgrading and Hazard Mitigation
Category 3: Lower Priority	Yellow Zone	Single hazard only in lowest-risk tier, or outside all hazard buffers. Tenure regularisation with basic hazard-proofing.	Balance of informal building footprints outside above categories	Tenure regularisation; GIS eligibility portal fast-tracks; minor structural improvements

Source: Priority Hazard Matrix developed by Author; aligned with PMAY-U 2.0 BLC intervention categories (MoHUA, 2024)

5.4.3 Spatial Clustering Analysis

The composite map reveals a non-random spatial distribution of hazard-zone buildings, clustering strongly around three concentration zones corresponding to the vulnerability hotspots identified in Chapter 4:

Cluster 1 at the Chola-Nishatpura Belt contains the largest single concentration of critical-zone buildings. The linear nature of the railway edge creates a continuous high-density strip of 30-metre-zone structures stretching approximately 4.2 kilometres. Within this strip, the overlap of the railway zone with the Chola topographic depression creates the 185-building cyclic decay compound zone the single highest-priority cluster for Phase 1 relocation.

Cluster 2 at the Khanugaon-Koh-e-Fiza Lakefront presents the most ecologically complex planning challenge. The irregular lake boundary creates a patchwork of buffer-zone and non-buffer-zone building footprints that simple linear enforcement cannot address. The 240-building lake-flood compound zone in the Koh-e-Fiza low pocket is the highest-priority lakefront intervention.

Cluster 3 at the Bairagarh Lowlands is the most analytically significant: the only point in Bhopal where all three hazard layers simultaneously overlap. The 65 buildings here face the full combination of structural stresses and are the Phase 1 emergency evacuation priority.

5.5 Statistical and Qualitative Vulnerability Profile

5.5.1 Tenability Classification: Aggregate Results

Table No. 5.9: Tenability Classification Aggregate Results

Tenability Class	Buildings	Proportion	Spatial Criteria (Summary)	PMAY-U 2.0 Pathway
Untenable	1,075	31%	Within 30m Infrastructure Edge NOC zone, 50m Eco-Sensitive NGT buffer, or compound overlap zones. Non-regularisable.	BLC Relocation Vertical: Zone A: Mandatory

Tenability Class	Buildings	Proportion	Spatial Criteria (Summary)	PMAY-U 2.0 Pathway
Semi-Tenure	1,140	45%	30-100m Infrastructure Safety Zone + 50-100m Eco-Sensitive Environmental Buffer + Moderate Flood Zone. In-situ upgrade feasible.	BLC In-Situ Upgrading: Zone B: Priority
Tenure Eligible	Balance	24%	Outside all hazard buffers, above 475m ASL. Full regularisation pathway available.	Patta Formalisation + BLC Improvement: Zone C Pathway

Source: GIS Analysis: Composite hazard overlay and tenability classification

Candidate relocation sites for the Untenable cohort have been identified through GIS analysis within BDP 2031 RG-I and RG-II zones within 2 kilometres of each hotspot cluster detailed in Section 6.1.4 of the planning proposals chapter.

5.5.2 Data Source Validation and Quality Assessment

Table No. 5.10: Data Source Quality Assessment

Dataset	Coverage	Currency	Accuracy Assessment	Key Limitation
Google Open Buildings V3	95%+ of BMC area	2024	High for pucca and semi-pucca structures above 30 sq. m footprint	May undercount smallest katcha structures below 30 sq. m
NASADEM DEM	100%	2000 (SRTM mission)	Adequate for district-level flood zonation; 30m pixel adequate for hotspot identification	30m resolution misses micro-level depression variation below this scale
Sentinel-2 LULC	100%	2023-24	Adequate for settlement boundary delineation; 10m resolution	Cannot distinguish dense katcha from dense pucca roofing in mixed areas

Dataset	Coverage	Currency	Accuracy Assessment	Key Limitation
Railway Network Vectors	100% main line	2023 (field verified)	High accuracy; verified against LISS-IV imagery and field observation at three locations	Minor sidings and goods yard tracks may be incompletely captured
Lake FTL Boundary	100%	BDP 2031 FTL survey	High for Upper Lake FTL line; moderate for seasonal shoreline variation	FTL boundary does not capture monsoon high-water extent in extreme years

Source: Dataset documentation reviewed by Author; accuracy assessed against field observation and cross-referencing

5.6 Identification of Planning Issues and Vulnerability Hotspots

5.6.1 Systematic Planning Issues Derived from Analysis

Table No. 5.11: Systematic Planning Issues: Four Categories

Issue Category	Spatial Manifestation	Affected Buildings	Planning Consequence	Required Response
Legal Untenability	310 buildings within 30m Infrastructure Edge ROW; 275 buildings within 50m NGT lake buffer all non-regularizable	585 buildings (plus 490 compound)	Ineligible for PMAY-U benefits. No Patta pathway. No formal government intervention mechanism under current framework.	Pre-emptive GIS-based tenability mapping; initiate PMAY-U BLC resettlement before next infrastructure conflict
Infrastructure Deficit	Absence of formal drainage in all flood-susceptible areas below 470m ASL; no stormwater channel maintenance in nallah-bank settlements	840 flood-zone buildings	Chronic waterlogging 3-7 days per event; vector disease risk above WHO 72-hour threshold; structural degradation from saturation cycles	AMRUT 2.0 stormwater drainage network; raised plinth standards for Zone B; check dams and silt traps at nallah mouths

Issue Category	Spatial Manifestation	Affected Buildings	Planning Consequence	Required Response
Environmental Conflict	275 buildings within 50m Ramsar buffer of Upper Lake; untreated sewage discharge into primary drinking water source	275+ buildings in lake zone	Ramsar Convention violation and NGT exposure; Upper Lake water quality degradation; drinking water security risk for city	Zone A relocation + Zone C ecological restoration + SBM 2.0 sewage network to prevent lake contamination
Structural Instability	185 buildings in cyclic decay zone; 65 buildings in triple-hazard zone; all katcha and semi-pucca construction at critical threshold	250 buildings extreme compound	High collapse probability during combined monsoon event. No insurance. Post-disaster relief only mechanism currently.	Phase 1 emergency relocation of 250 buildings under NDMA protocols before next monsoon season

Source: Derived from composite GIS analysis

5.6.2 Hotspot Profiles: Detailed Analysis

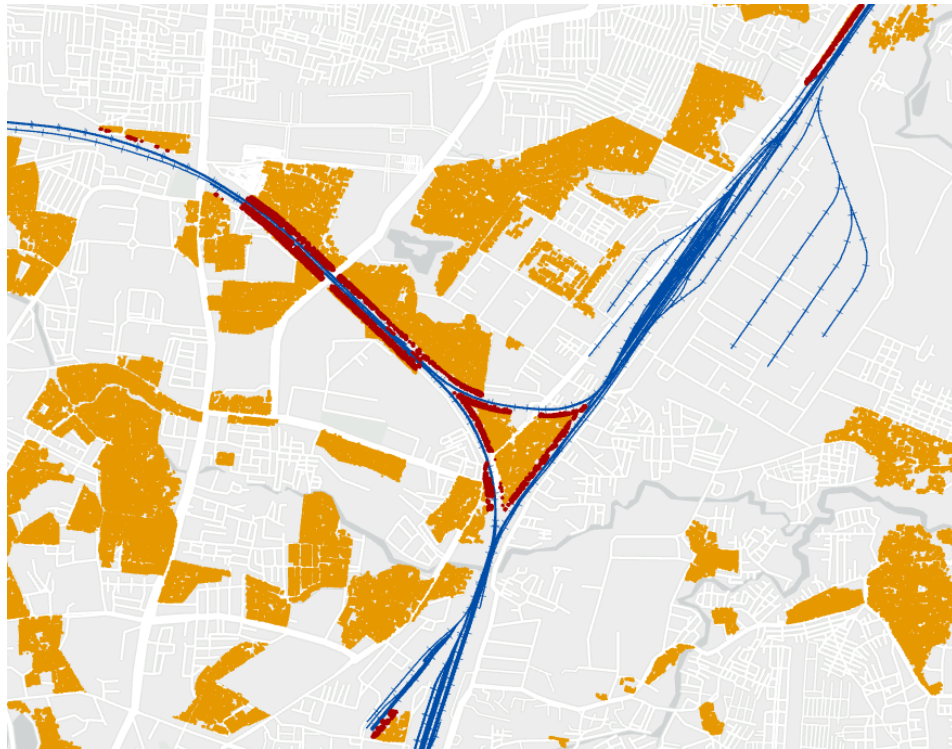


Fig. No. 5.6: Hotspot A: Chola-Nishatpura belt detail map showing 30m critical zone buildings (Source: Primary Field Survey and GIS Analysis)

Hotspot A: The Chola-Nishatpura belt runs approximately 4.2 kilometres along the east-west railway mainline through the urban core. The highest density of critical-zone informal encroachment occurs at two pinch points: the Chola junction curve, where the track bends eastward and creates a concave-sided informal settlement pocket, and the Nishatpura goods yard sidings, where a dense residential neighbourhood has grown in the shadow of goods traffic shunting operations.

The cyclic decay condition is most severe in the northern arm of Hotspot A, where the Chola topographic depression coincides with the 30-metre railway zone. Visible wall cracking and foundation settlement was observed in approximately 60 per cent of structures inspected at this sub-cluster during field reconnaissance, consistent with the compound physical deterioration mechanism described in Section 5.1.4. The 2022 eviction drive affected approximately 200 structures in the eastern Annu Nagar sub-cluster of this belt. The remaining 210 structures in the 30-metre zone represent an active planning liability that cannot safely wait for the next infrastructure project to force a response.

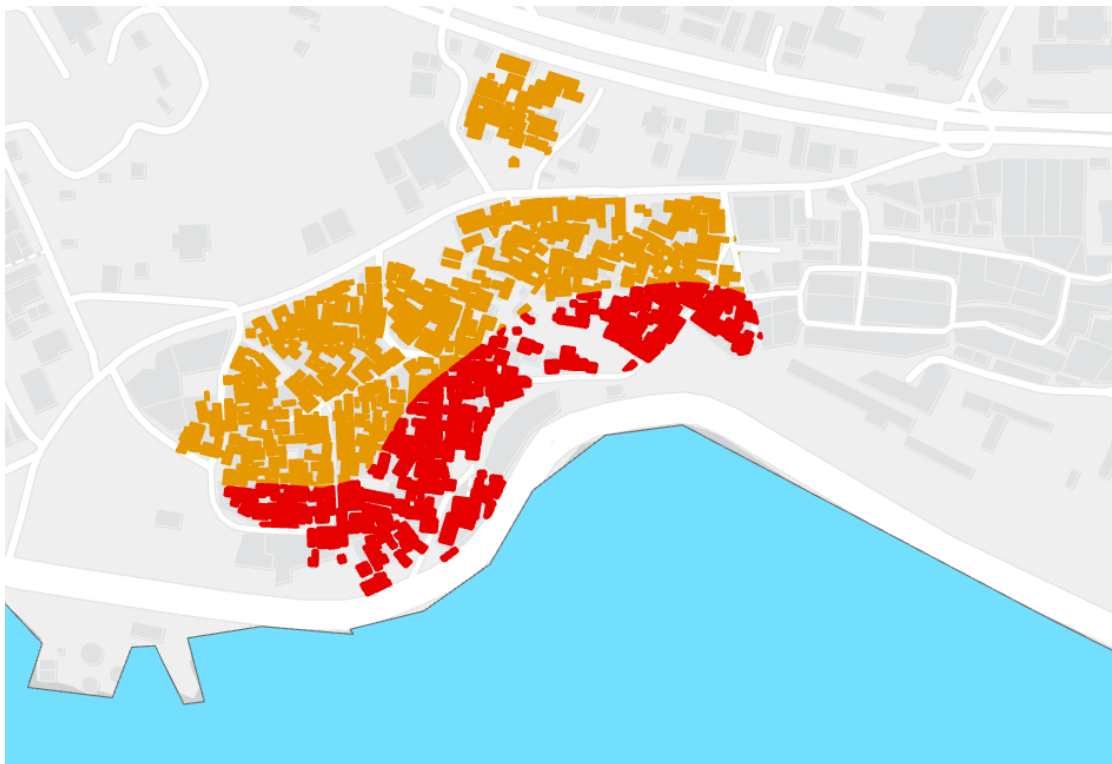


Fig. No. 5.7: Hotspot B: Khanugaon-Koh-e-Fiza lakefront detail map showing 50m NGT buffer boundary and lake-flood compound area (Source: Primary Field Survey and GIS Analysis)

Hotspot B: The Khanugaon-Koh-e-Fiza lakefront presents the most ecologically complex planning challenge of the three hotspot zones. The 85 additional structures

reclassified from Semi-Tenure to Untenable by the 50-metre NGT correction are located in the second row of the Koh-e-Fiza settlement, separated from the immediate lakefront structures by a narrow lane. Under the 33-metre BDP standard, these households were potentially eligible for in-situ upgrading. Under the corrected 50-metre NGT standard, they fall within the non-regularisable buffer. Twelve informal sewage discharge points directed toward the lake were mapped from satellite imagery within Hotspot B a direct input to the water quality argument for Zone C ecological restoration.

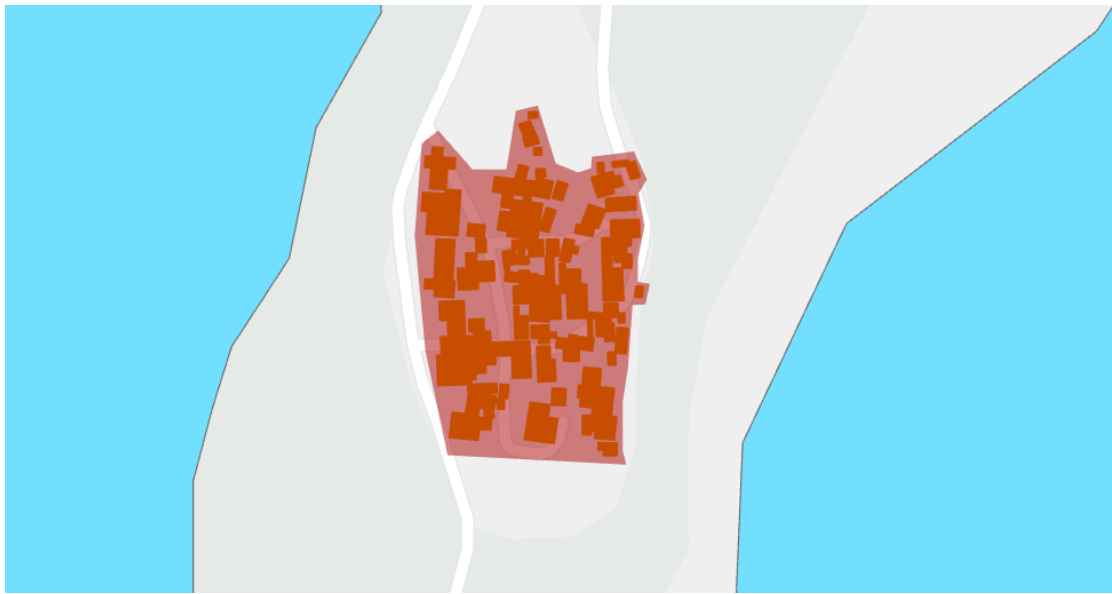


Fig. No. 5.8: Hotspot C: Bairagarh triple-hazard zone detail map showing simultaneous infrastructure edge, eco-sensitive, and flood layer overlaps for the 65 buildings at extreme compound risk (Source: Primary Field Survey and GIS Analysis)

Hotspot C: The Bairagarh triple-hazard zone is the most analytically significant location in the study. It is the only confirmed point in Bhopal where all three independently derived hazard layers simultaneously overlap. The western railway mainline passes within 25 to 35 metres of the northern edge of the settlement cluster. A secondary water body immediately adjacent fall within the 50-metre NGT buffer. The Bairagarh area occupies a topographic depression below 468 metres ASL, within the high-risk waterlogging zone. These 65 buildings face the full combination of structural stresses, making them the Phase 1 pre-monsoon emergency relocation priority.

5.7 Detailed Morphological Analysis of Vulnerability Hotspots

5.7.1 Hotspot A: Chola-Nishatpura: Detailed Structural Assessment

The Chola-Nishatpura belt is characterised by a settlement morphology that has evolved in direct response to the railway constraint. Over decades of occupation, the pattern of building closest to the track has converged on a remarkably consistent form as if the railway line itself had specified the housing typology. This convergence reflects rational adaptation by builders with limited resources to the specific constraints of the site.

The characteristic building in the critical 30-metre zone is approximately 3 to 4 metres deep (measured perpendicular to the track) and 4 to 6 metres wide (measured parallel to the track). The track-facing wall is invariably blind no opening of any kind and is built with the maximum available wall thickness, typically 230mm or two-brick width in kutchha construction. The lane-facing wall carries the single entrance door and one window. The roof is corrugated iron or asbestos sheet, lightweight and fastened with steel wire or jute rope rather than proper mechanical fasteners in older structures.

The foundation of these structures is typically a shallow spread footing of 150 to 230mm width, extending 300 to 500mm below existing ground level. In the sections of the corridor overlapping with the Chola topographic depression, the foundation soil is silty clay of low bearing capacity, further weakened by seasonal saturation. The combination of shallow depth, poor material, and vibration-induced foundation movement creates the differential settlement pattern visible in satellite imagery as diagonal cracking at wall corners.

No roofing insulation was observed in any structure during field reconnaissance. The corrugated iron and asbestos sheet roofing that dominates the stock generates extremely high summer temperatures surface temperatures of 65 to 70 degrees Celsius on clear days are common for south-facing metal roofs in this latitude making interior habitability in summer months dependent on the small breezeways between buildings. In back-to-back layouts where such breezeways are absent, interior temperatures during peak summer can exceed outdoor ambient by 8 to 10 degrees.

5.7.2 Hotspot B: Khanugaon-Koh-e-Fiza: Ecological Dimension Assessment

The ecological dimension of Hotspot B is more complex than the simple buffer violation that the 50-metre NGT standard captures. The informal settlements at the Upper Lake margin are embedded in an ecological system that is itself under multiple anthropogenic stresses: agricultural runoff from the lake catchment, domestic sewage

from the formal city, solid waste disposal in the lake margins, and motorised boat traffic all contribute to the documented decline in water quality. The informal settlement contribution primarily untreated sewage is significant but not the only stressor.

BMC environmental monitoring data for 2022-23 records faecal coliform counts in the western inlet areas (adjacent to Khanugaon and Koh-e-Fiza) of approximately 450 MPN per 100ml, well above the WHO guideline of 200 MPN per 100ml for recreational water quality and 100 MPN per 100ml for direct contact water sports. The Upper Lake's water supply intake is located on the northern shore, approximately 2.5 kilometres from the main informal settlement cluster, and the coliform counts at the intake are lower. However, the progressive nutrient loading from both formal and informal sources has contributed to increasing algal bloom frequency documented at 3 to 4 bloom events per monsoon season in recent years, up from 1 to 2 events per monsoon season a decade earlier.

This ecological trajectory matters for the planning timeline. The Zone C ecological restoration proposal in Chapter 6, which relocates the lakefront informal settlements and converts the buffer to a bioswale-park network, should be understood as a water security intervention as much as a housing intervention. The Upper Lake's continued ability to supply 40 per cent of Bhopal's municipal water demand is contingent on maintaining water quality standards that are currently being degraded by both formal and informal catchment pressures.

5.7.3 Hotspot C: Bairagarh: Triple Hazard Dynamics

The Bairagarh triple-hazard zone is the most analytically interesting cluster in the study because it demonstrates what a compound hazard condition looks like in practice. The 65 buildings in this zone are not experiencing the hazards sequentially vibration this season, flooding next season. The hazards interact continuously. The railway vibration is daily. The ground moisture from the topographic depression is present from June through October. The proximity to the secondary water body means that the subsoil water table elevation is elevated even outside the monsoon season.

The morphological response of residents to this compound condition is instructive. Unlike the Chola-Nishatpura belt, where the uniform linear morphology reflects singular railway-edge adaptation, the Bairagarh cluster shows evidence of multiple overlapping adaptation strategies: raised earth platforms (echoing the lake-front otla

tradition) to address flooding; blind rail-facing walls to address railway vibration; and informal drainage channels cut across the settlement perimeter to address waterlogging. None of these strategies is adequate to the compound condition, but each reflects a legible community understanding of the specific hazard it addresses.

The planning implication of this morphological evidence is important. The community at Bairagarh has demonstrably attempted self-adaptation. Any resettlement planning that treats them simply as passive victims of hazard conditions, rather than as active agents who have been making rational but insufficient adaptations, will miss both the social capital of the community and the practical knowledge they carry about what kinds of physical environment work for their specific livelihood and social patterns. Community consultation in the resettlement planning process is not just good practice; it is analytically necessary.

5.8 Cross-Layer Interaction Analysis: Compound Hazard Effects

The three hazard layers in this study are analytically independent each is derived from separate data sources using separate GIS operations. But in compound zones, they interact physically in ways that make the compound vulnerability qualitatively different from the sum of the individual layers. This section analyses those interactions:

The Infrastructure Edge and Topographic Flood interaction (cyclic decay) is the most structurally significant. As described in Section 5.1.4, the mechanism involves four stages of progressive deterioration that operate on a seasonal cycle. What is worth adding here is the temporal dimension: the cyclic decay condition is self-reinforcing over time. A wall that has experienced one monsoon season of combined vibration-saturation degradation is weaker in the following dry season than it was the previous year. The structural deterioration is not linear; it accelerates as the wall's integrity decreases and each additional loading cycle produces more damage. This acceleration means that the 185 buildings in the cyclic decay zone face an increasing risk trajectory, not a stable one.

The Eco-Sensitive Zone and Topographic Flood interaction (compound inundation) is characterised by a different failure mode. Lake-level rise and topographic runoff accumulation can occur simultaneously during intense monsoon events, combining to produce inundation depths and durations greater than either would produce

independently. The 240 buildings in the lake-flood compound zone face inundation from two directions lake overflow if the lake level exceeds FTL, and surface runoff accumulation in the topographic depression which can combine to produce inundation durations of 10 to 20 days in extreme monsoon years.

The Triple Hazard combination at Bairagarh combines all three interaction modes simultaneously. No residential structure can maintain structural integrity over an extended period under this combination of cyclic vibration loading, seasonal saturation-desiccation cycles, and repeated inundation events. The 65 buildings in this zone are on a deterioration trajectory whose endpoint is structural failure. The planning question is not whether intervention is needed but how urgently and through what mechanism.

Table No. 5.12: Cross-Layer Hazard Interaction Analysis

Hazard Combination	Interaction Mechanism	Structural Failure Mode	Intervention Urgency
Infrastructure Edge + Topographic Flood (Cyclic Decay)	Vibration widens mortar joint cracks; waterlogging saturates cracked walls; drying shrinks wet mortars; cyclic loading acts on degraded structure	Progressive wall panel collapse; differential foundation settlement; post-monsoon failure peak	Phase 1 Emergency: 185 buildings; pre-monsoon intervention required
Eco-Sensitive Zone + Topographic Flood (Compound Inundation)	Lake-level rise and runoff accumulation combine during intense monsoon events; dual-source inundation produces greater depth and duration than either alone	Foundation bearing capacity loss; capillary moisture rise causes progressive mortar dissolution; reclaimed fill subsidence	Phase 1 Priority: 240 buildings; monsoon-season risk acute
Triple Hazard (All Three)	All three interaction mechanisms active simultaneously; self-reinforcing deterioration accelerated by compound loading	Rapid structural deterioration trajectory; collapse risk highest immediately post-monsoon; no viable in-situ intervention	Phase 1 Emergency: 65 buildings; pre-monsoon evacuation under NDMA protocols required

Source: Structural assessment methodology: Risbud (2009); Surat flood resilience benchmarks (Ahmad et al., 2023); field observation

5.9 Sensitivity Analysis: Impact of Alternative Buffer Standards

A sensitivity analysis was conducted to examine how the vulnerability assessment results change under alternative buffer standard assumptions. Three alternative scenarios were tested:

Scenario 1 applies the BDP 2031 33-metre lake buffer standard in place of the NGT 50-metre standard. As documented in Section 5.2.2, this reduces the critical lake zone building count from 275 to 190, reducing the total Untenable classification from 1,075 to 990. The planning implication is 85 fewer mandatory relocation units but a non-NGT-compliant baseline.

Scenario 2 applies a 50-metre infrastructure edge buffer (as used in Mumbai SRA resettlement planning) in place of the 30-metre Indian Railways Works Manual standard. This would increase the critical infrastructure zone building count from 310 to approximately 485, adding around 175 additional mandatory relocation units. This represents a more conservative approach to railway safety but goes beyond the current Indian statutory standard.

Scenario 3 applies a 475-metre ASL flood threshold instead of the 470-metre threshold used in the primary analysis. This would increase the high-risk flood zone building count from 340 to approximately 520, adding about 180 additional upgrade-priority units. The 475-metre threshold may be more appropriate under projected climate change monsoon intensification scenarios.

The primary analysis is based on the most defensible combination of current statutory standards: the Indian Railways Works Manual 30-metre threshold, the NGT 50-metre Ramsar standard, and the 470-metre NASADEM-calibrated flood threshold. The sensitivity analysis demonstrates that the study's findings are relatively robust to reasonable alternative threshold choices: the category membership of most buildings does not change across scenarios, and the most vulnerable clusters Chola-Nishatpura, Khanugaon-Koh-e-Fiza, Bairagarh appear in all three scenarios.

CHAPTER 6: PLANNING PROPOSALS AND MITIGATION STRATEGIES

The planning proposals in this chapter are not abstract recommendations. They are calibrated responses to specific spatial conditions identified in the composite vulnerability analysis. Each proposal is linked to a tenability class from the Priority Hazard Matrix, to one or more active national schemes providing the funding mechanism, and to the particular physical conditions that make that intervention type appropriate for that zone. The chapter is organised around the three intervention zones, followed by physical planning interventions and implementation phasing.

6.1 Zone A: Relocation and Rehabilitation

6.1.1 Zone Definition and Target Population

Zone A encompasses all buildings classified as Untenable: 310 buildings in the 30-metre infrastructure edge critical zone, 275 buildings in the 50-metre NGT eco-sensitive buffer, 185 buildings in the cyclic decay compound zone (infrastructure edge + flood), 240 buildings in the lake-flood compound zone, and 65 buildings in the triple-hazard compound zone. Total Zone A buildings: 1,075 units, adjusted for overlap between categories.

The 2022 Annu Nagar eviction is the cautionary precedent that shapes every aspect of Zone A's implementation design. The failure mode demonstrated then demolition without advance resettlement preparation must not be repeated. The phasing framework therefore stipulates that resettlement site construction must be 80 per cent complete before any demolition commences. This is not merely procedural; it is the single most important safeguard against repeating the outcome that left 300 families unrehabilitated for months.

6.1.2 New Housing Design Standard: Addressing Ventilation and Structural Deficiencies

One of the specific issues raised during the mid-term review is the design quality of PMAY-U housing in Bhopal. The Shyam Nagar settlement near 10 Number Stop provides an example of back-to-back construction that creates chronic ventilation problems and heat buildup conditions that are not qualitatively better than the informal

housing residents are being relocated from, and in some cases worse. Any relocation proposed under Zone A must not reproduce these conditions.

The following design principles are proposed for all Zone A relocation housing:

- Cluster layout in U-shape or L-shape arrangements around a central open courtyard not back-to-back rows to allow cross-ventilation through the block from at least two directions.
- Every unit to have windows on at least two sides. No unit to share a blind wall with its neighbour on both the front and rear faces simultaneously.
- Covered ground-floor veranda of minimum 1 metre depth on the street-facing frontage.
- Raised plinth of minimum 0.6 metres above finished site level to provide flood protection and improve thermal comfort at ground level.
- Roof ventilation openings or raised ridge vent strips to allow hot air to escape in summer months.
- Open inter-block passageways of minimum 3 metres width between building clusters.
- Community courtyard of minimum 15 square metres per unit serving the cluster as shared open space.



Fig. No. 6.1: Zone A: Rehabilitation housing design concept. U-shape cluster layout with open central courtyard, raised plinth, cross-ventilation, and front verandas. (AI-generated design intent illustration for conceptual reference only)

6.1.3 Relocation Site Selection Criteria

Relocation site selection must satisfy the following criteria to prevent reproducing the vulnerability conditions of the origin sites:

- Elevation above 475 metres ASL, ensuring the site is outside the flood susceptibility zone.
- Minimum 150 metres from the nearest railway track centreline, providing physical safety and acoustic comfort.
- Minimum 100 metres from any waterbody shoreline, consistent with the NGT environmental buffer standard.
- Within 2 kilometres of the origin cluster, maintaining access to existing livelihood locations, schools, and informal employment networks.
- Access to an existing road network capable of accommodating construction vehicles during site development.
- Availability of water supply and drainage connections from existing municipal infrastructure.

6.1.4 Identification of Vacant Land Parcels for Zone A Relocation, GIS-Based Site Analysis

The site selection criteria established in Section 6.1.3 were operationalised through a GIS-based vacant land identification exercise using the Bhopal Development Plan 2031 land use zones overlaid with satellite imagery in ArcGIS Pro. The analysis identifies specific vacant land parcels within the Residential General-I (RG-I) and Residential General-II (RG-II) land use zones of the BDP 2031 that satisfy all five site selection criteria simultaneously. These parcels represent the most immediately deployable relocation sites for Zone A households, as they are correctly zoned for residential construction, require no change-of-land-use application, and fall within the 2-kilometre proximity criterion from each hotspot origin cluster.

The BDP 2031 designates RG-I as the primary zone for low-density, affordable EWS and LIG residential development the category directly applicable to PMAY-U 2.0 BLC relocation housing. RG-II parcels, while permitting slightly higher density, are also included in the analysis as they can accommodate EWS housing with appropriate floor space index regulation. No agricultural, green zone, lake catchment, or industrial land

parcels were considered, consistent with the regulatory exclusions applicable to PMAY-U beneficiary sites.

The GIS overlay combined the following four analytical layers in ArcGIS Pro:

- BDP 2031 RG-I and RG-II zoned land parcels within Bhopal Municipal Corporation boundary sourced from the BDP 2031 Draft land use map prepared by the Directorate of Town and Country Planning, Madhya Pradesh and Remote Sensing Application Centre, MPCST, Bhopal
- Vacancy identification from Sentinel-2 Land Use Land Cover classification (2023-24) parcels classified as vacant or open land without existing built-up cover, verified against Google Open Buildings V3 footprint dataset
- Elevation threshold filter NASADEM DEM Con operation retaining only parcels above 475 metres ASL, placing them outside the topographic flood susceptibility zone defined in the methodology
- 2-kilometre buffer around each of the three vulnerability hotspot zones Chola-Nishatpura (Hotspot A), Koh-e-Fiza (Hotspot B), and Bairagarh (Hotspot C) consistent with the proximity criterion in Section 6.1.3

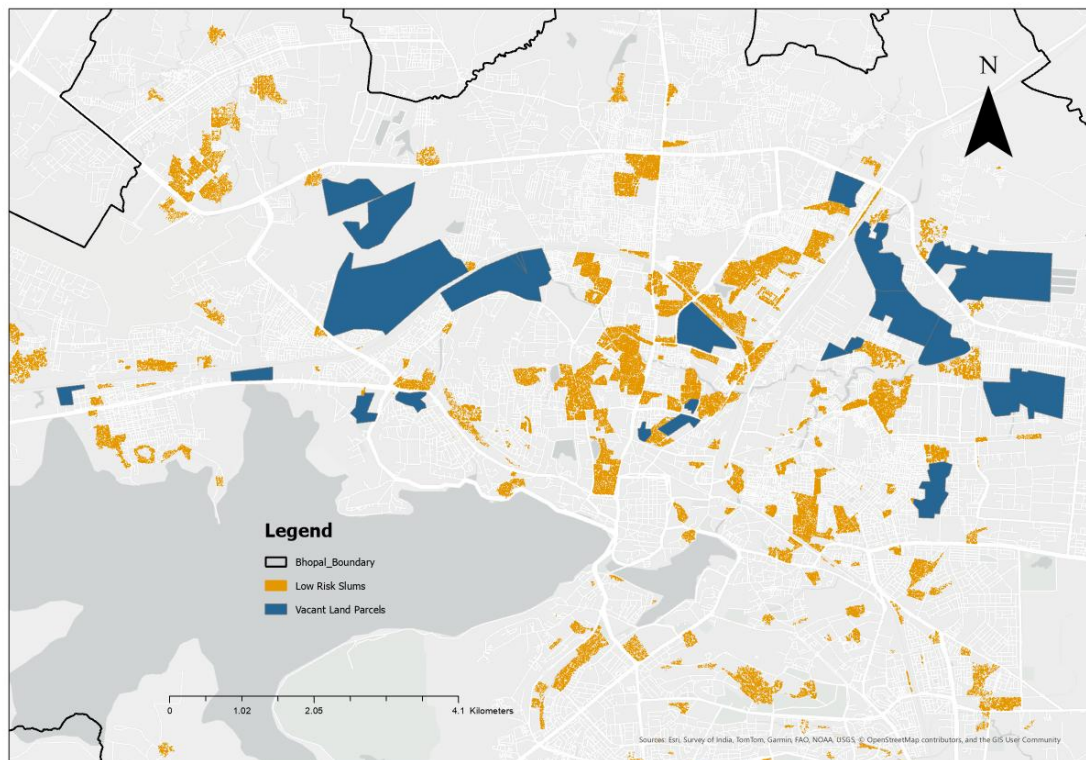


Fig. No. 6.2: GIS-Identified Vacant Land Parcels in RG-I and RG-II Zones: Potential PMAY-U 2.0 Zone A Relocation Sites, Bhopal Municipal Corporation (2024) (Source: BDP 2031 Land Use Zones (TCP, MP); Sentinel-2 LULC)

The resulting map (Figure 6.2) identifies multiple vacant RG-I and RG-II parcels distributed across the northern and western quadrants of the BMC area, with notable concentrations in the Bairagarh-Govindpura belt relevant to Hotspot C relocation and in the Nishatpura-north corridor, relevant to Hotspot A relocation. The Koh-e-Fiza lakefront area (Hotspot B) shows fewer immediately available RG-I parcels within 2 kilometres, due to the dominance of BDP 2031 Bhojtaal Catchment Zones CZ1 and CZ2 in that quadrant. This confirms the finding of Section 5.2 that Hotspot B cannot be regularised and that relocation for this cluster may require engagement with PSP (Public and Semi-Public) government land parcels or inter-departmental land transfer from state government holdings to BMC.

Table No. 6.3: Vacant Land Parcel Analysis Relocation Site Suitability Summary by Hotspot

Hotspot	Zone	BDP 2031 Zoning Available	Elevation	Within 2km	Remarks
Hotspot A Chola / Nishatpura Belt	Zone A	RG-I parcels in Nishatpura-North corridor; some RG-II along the 30–100m safety buffer edge	Above 475m ASL ✓	Yes	Railway proximity to be verified for each parcel; NOC from Railways required for parcels adjacent to 100m safety buffer
Hotspot B Koh-e-Fiza / Khanugaon Lakefront	Zone A	Limited RG-I within 2km due to CZ1 and CZ2 Bhojtaal Catchment Zone dominance in this quadrant; PSP parcels available as alternative	Above 475m ASL ✓	Partial	PSP parcels recommended; inter-departmental land transfer from state to BMC required. RG-I availability confirmed only beyond 1.5km from lake edge.
Hotspot C Baraighah Lowlands	Zone A	Most favourable RG-I and RG-II parcels confirmed in Bairagarh-Govindpura belt; largest	Above 475m ASL ✓	Yes	Best site availability of the three hotspots. Multiple RG-I parcels confirmed within 1km of

Hotspot	Zone	BDP 2031 Zoning Available	Elevation	Within 2km	Remarks
		concentration of candidate vacant parcels in entire analysis			triple-hazard zone. Priority site for Phase 1 emergency relocation.

Source: BDP 2031 Land Use Map: TCP, MP / MPCST; Sentinel-2 LULC Classification (2023-24); NASADEM DEM; ArcGIS Pro Spatial Analysis

The availability of BDP 2031-zoned vacant residential land within the 2-kilometre relocation radius of all three hotspot clusters constitutes a significant planning advantage for the Zone A programme. It demonstrates that managed relocation need not require long-distance resettlement, land acquisition from private owners, or agricultural land conversion three of the most common obstacles to PMAY-U BLC resettlement implementation in Indian cities. The identified parcels are already legally designated for the intended residential use under the BDP 2031 framework, reducing the procedural burden on BMC and the time required between programme sanction and site readiness.

It should be noted that vacant land identification from satellite imagery constitutes a planning-level screening analysis. Ground-truth verification of each identified parcel including confirmation of government versus private ownership through MP Bhu-Abhilekh land records, physical site inspection for drainage conditions and road access, and legal encumbrance clearance is required before any parcel is formally designated as a Zone A relocation site. The GIS analysis presented here narrows the field of candidate sites from the entire BMC area to a set of parcels meeting the primary spatial and regulatory criteria, providing the starting point for this verification process by the relevant implementing agencies.

6.1.5 Resettlement Process and Social Safeguards

The resettlement process must be structured in three phases. In the pre-relocation phase, full GIS-based enumeration of all Zone A households with documentation of occupancy, family composition, income status, and livelihood type must be completed. Resettlement site construction must be 80 per cent complete before any demolition

commences. Transit accommodation arrangements must be in place for households whose demolition precedes site completion.

During relocation, transit accommodation standards should follow NDMA temporary shelter guidelines. Livelihood support connection to skill training and informal employment networks at the destination area should be initiated before physical relocation.

Post-relocation, Patta transfer should occur within 60 days of household occupation of permanent units. PMAY-U BLC subsidy disbursement should be linked to Patta receipt. Community welfare monitoring should continue for 12 months post-relocation with specific attention to livelihood continuity and social cohesion indicators.

6.2 Zone B: In-Situ Upgrading and Hazard Mitigation

6.2.1 Zone Definition and Target Population

Zone B encompasses approximately 1,140 buildings classified as Semi-Tenure: the 640 buildings in the 30 to 100 metre infrastructure safety buffers, the 320 buildings in the 50 to 100 metre eco-sensitive environmental buffer, and the 180 buildings in the moderate flood zone (470 to 475 metres ASL). These structures face manageable physical hazards that can be reduced through targeted structural and infrastructure interventions.



Fig. No. 6.2: Zone B: In-situ upgrading before-after section. Left: original back-to-back housing with no drainage, zero setback, zero ventilation. Right: same block post-upgrade with 0.6m raised plinth, air shafts between units, paved drainage lane, and front setback veranda. (AI-generated design intent illustration for conceptual reference only)

6.2.2 The Resilience Retrofit Kit

Rather than full reconstruction, a Resilience Retrofit Kit is proposed as the primary structural intervention. This approach reduces cost, maintains community spatial structure, and produces measurable hazard risk reduction at a fraction of full reconstruction cost:

Table No. 6.1: Zone B Incremental Housing Toolkit: Components and Costs

Component	Description	Estimated Cost per Unit	Funding Source
Raised Plinth (0.6-1.0m)	Pre-fabricated plinth blocks, 0.6m height minimum, cement mortar bound. Reduces waterlogging entry and capillary rise.	Rs. 8,000 to 12,000	PMAY-U 2.0 BLC subsidy
Flood-Resistant Wall Panels	Lower 0.6m of wall: fired brick with cement mortar replacing katcha or lime mortar. Above: existing wall retained.	Rs. 6,000 to 9,000	PMAY-U BLC + community contribution
Roofing Replacement	Asbestos sheet replacement with galvanised iron sheets with vibration-resistant fastening and ridge ventilation.	Rs. 7,000 to 10,000	PMAY-U BLC subsidy
Ventilation Improvements	Air shaft openings (30-40cm) cut between adjacent units with metal grille. Roof vent ridge added to existing roof line.	Rs. 3,000 to 5,000	PMAY-U BLC + sweat equity
Drainage Connection	Individual household connection to Zone B stormwater channel network. Inspection chamber at property boundary.	Rs. 3,000 to 5,000	AMRUT 2.0
Total Estimated Kit Cost	Complete retrofit per household	Rs. 27,000 to 41,000	Combined PMAY-U 2.0 + AMRUT 2.0

Source: Cost estimates based on MP State PWD Schedule of Rates

The estimated kit cost of Rs. 27,000 to Rs. 41,000 per unit compares very favourably with the Rs. 2.5 lakh full reconstruction cost. This means that the same budget

allocation can serve roughly five to six Zone B households for every one Zone A relocation household, substantially improving the coverage rate within available PMAY-U allocations.

6.3 Zone C: Ecological Restoration

6.3.1 Zone Definition and Programme

Zone C covers the 50-metre lakefront buffer zone that becomes available for ecological restoration following Zone A relocation of the structures currently occupying it. This zone must not be redeveloped for residential or commercial use after relocation. Instead, it should be transformed into a productive ecological and public landscape that simultaneously serves regulatory compliance (Ramsar Convention buffer), ecological function (water quality protection for Upper Lake), and social amenity (public access to the lakefront).

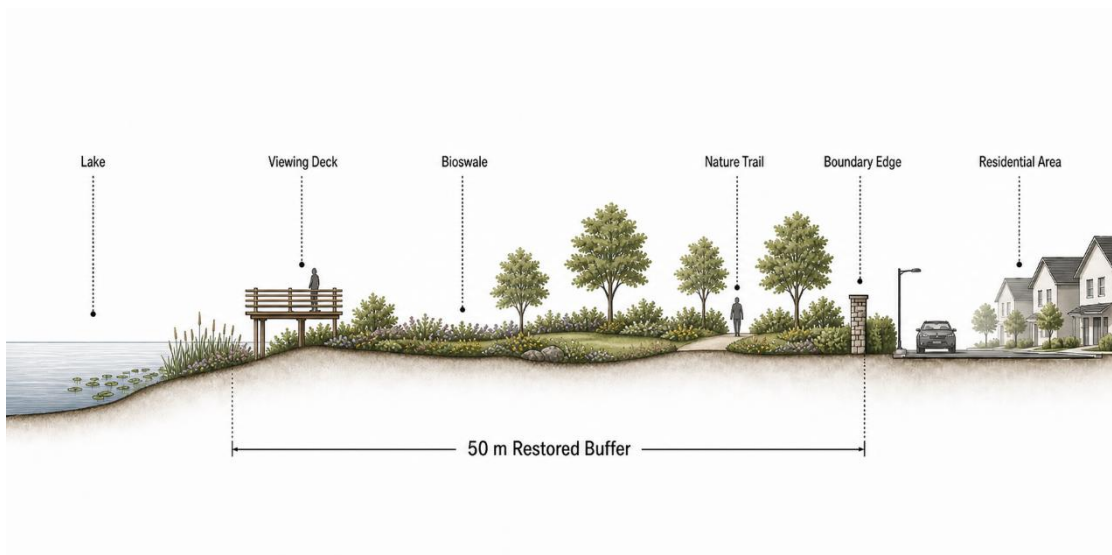


Fig. No. 6.3: Zone C: Ecological restoration concept. reclaimed 50m lakefront buffer transformed into bioswale corridor, gravel nature trail, and wooden viewing platforms over Upper Lake. (AI-generated design intent illustration for conceptual reference only)

The ecological restoration programme has four components. First, a connected bioswale and retention pond network along the reclaimed lakefront edge, designed to capture and slow surface runoff before it enters the Upper Lake a direct intervention in the faecal coliform and nutrient loading problem documented in BMC environmental monitoring data. Second, engineered silt traps at the mouths of the Patra Nallah and Jhirni Nallah outfalls, reducing sediment and nutrient loading into Bhopal's primary drinking water source. Third, a lakefront ecological trail and public park aligned with Smart City Mission Bhopal's Area-Based Development component. Fourth, native

plant species reintroduction along the restored buffer margin Mahua, Jamun, Peepal, and Arjun trees linked to the National Wetland Conservation Programme.

6.4 Physical Planning Interventions

6.4.1 Infrastructure Edge Treatment

Construction of a 3-metre reinforced masonry boundary wall along the 30-metre zone boundary, combined with a 5-metre green belt of Neem and Ashoka plantings for noise and vibration attenuation. Development of a pedestrian service corridor with integrated channelled stormwater drainage in the 30 to 100 metre zone, fundable under AMRUT 2.0. This serves dual function as a public access route and enforced no-build buffer definition positive use as a buffer-maintenance strategy, rather than enforcement-dependent exclusion.

Post-Zone-A-relocation, the 30 to 100 metre zone is proposed for conversion into a multi-use Infrastructure Edge Linear Park: cycle and pedestrian path parallel to the railway boundary fence, acoustic and vibration-absorbing green belt of Neem and Ashoka trees, integrated stormwater drainage channel, and solar-lit pathway. The Sabarmati Riverfront model in Ahmedabad, adapted for a railway edge context, provides the planning precedent. Fundable under Smart City Mission ABD component.

6.4.2 Hydrological Resilience

Check-dam and silt-trap installation at Patra Nallah and Jhirni Nallah mouths. Mandatory raised plinth standard of 0.6 to 1.0 metres for all new or retrofitted construction in the 465 to 475 metre ASL elevation zone, embedded as a BMC building code revision. Bio-retention ponds on the reclaimed lakefront serving dual functions as community rainwater harvesting and peak-flow flood buffers. Improvement of impervious-to-pervious surface ratio in Zone B clusters through gravel-paved lanes and permeable paving to reduce runoff concentration in topographic low points.

6.4.3 Tenure and Social Inclusion

A GIS-based eligibility mapping portal to digitise all informal units, assign vulnerability and tenability scores, and enable fast-track Patta issuance for Zone B households. Integrated scheme linkage across PMAY-U 2.0 BLC, AMRUT 2.0, and SBM 2.0 Urban to deliver a coordinated upgrading and infrastructure package without duplication of administrative effort. Community Resilience Committees as the primary

mechanism for participatory hazard monitoring, community-led infrastructure maintenance, and early warning dissemination.

6.5 Implementation Phasing

Table No. 6.2: Implementation Phasing: Four Phases

Phase	Timeline	Key Actions	Funding Mechanism	Lead Agency
Phase 1: Emergency	0 to 6 months	Evacuate 65 triple-hazard zone buildings in Bairagarh and 185 cyclic decay compound buildings in Chola under NDMA pre-monsoon protocols. Establish transit accommodation. Commence resettlement site construction.	NDMA State Disaster Response Fund	District DMA + IRSDC + BMC
Phase 2: Short Term	1 to 2 years	Construct Zone A resettlement housing (pucca EWS units, ventilated cluster layout) at cleared relocation sites. Construct infrastructure edge boundary wall and lakefront bioswale network. Initiate Patta transfer for Zone A households.	PMAY-U 2.0 BLC + AMRUT 2.0	BMC + MP UDHD + Indian Railways
Phase 3: Medium Term	2 to 5 years	Complete Zone B Resilience Retrofit Kit for 1,140 Semi-Tenure units. Finalise all Patta distributions for Zone B. Commence Zone C ecological restoration on cleared lakefront.	PMAY-U 2.0 BLC + AMRUT 2.0 + SBM 2.0	BMC + MPPCB + Smart City SPV
Phase 4: Long Term	5 years+	Complete Zone C lakefront public park and wetland restoration. Launch GIS Hazard Eligibility Portal. Establish Community	Smart City Mission ABD + NWCP	BMC + Smart City SPV + NWCD

Phase	Timeline	Key Actions	Funding Mechanism	Lead Agency
		Resilience Committees. Evaluate programme outcomes against baseline.		

Source: Phasing framework developed by Author; aligned with PMAY-U 2.0, AMRUT 2.0, and NDMA Urban Flood Guidelines

6.6 Detailed Zone C Design Programme

The Zone C ecological restoration is the most design-intensive of the three intervention zones because it requires the transformation of heavily occupied informal land into managed public ecological space a process that has very few successful precedents at this scale in Indian cities. The design programme therefore draws on international examples of brownfield-to-greenfield lakefront restoration while adapting to the Bhopal context.

The physical design sequence for Zone C proceeds in four stages following the completion of Zone A relocation. Stage 1 is demolition and site clearance: all structures are removed, underground utilities and informal drainage connections are surveyed, and a topographic survey is conducted to map the post-clearance ground surface accurately. Stage 2 is infrastructure installation: the bioswale channels and retention pond earthworks are constructed, following the topographic gradient of the original lake margin. Silt traps are installed at the Patra and Jhirni nallah mouths. Stage 3 is planting and ecological establishment: native riparian plant species are introduced along the water's edge, native trees are planted across the buffer zone, and the bioswale channels are seeded with native wetland grass species. Stage 4 is public realm installation: the gravel nature trail, stone seating, wooden viewing platforms over the water, and ecological interpretation panels are installed.

The management model for Zone C is critical to its long-term success. Ungoverned public green space in Indian cities is consistently subject to informal re-occupation and solid waste dumping. Three mechanisms are proposed to prevent this:

- A Community Composting Hub operated by a community self-help group provides both productive use of the space and regular human presence that deters informal re-occupation.

- The Smart City-funded CCTV network extended to cover the Zone C perimeter provides remote monitoring.
- The ecological trail, viewed as public infrastructure rather than merely public amenity, is maintained by BMC under the same maintenance schedule as other public parks within the Smart City ABD area.

6.7 Implementation Challenges and Risk Mitigation

Four categories of implementation challenge are foreseeable and should be addressed in the Zone A, B, and C planning frameworks:

6.7.1 Resettlement Site Land Availability

The most significant implementation challenge for Zone A is identifying and securing suitable resettlement sites within 2 kilometres of each origin cluster. In Bhopal's current land market, BMC-owned vacant land within this radius and meeting the hazard clearance criteria is limited. Three potential approaches are: identification of existing BMC land parcels that meet criteria through spatial analysis; negotiation of state government land parcels through the Revenue Department; and in-situ vertical densification on existing PMAY-U sites where structural capacity allows. A pre-implementation site survey using GIS analysis of government land records should be conducted before Zone A phasing is finalised.

6.7.2 Community Resistance to Relocation

Experience from the 2022 Annu Nagar eviction and from comparable Indian resettlement programmes consistently shows that community resistance to relocation is highest when the process is perceived as imposed rather than participatory, when resettlement sites are distant from livelihoods, and when the legal security of the destination is uncertain. The Zone A process design specifically addresses all three: participatory enumeration before demolition commences, 2km proximity criterion for site selection, and Patta transfer within 60 days of occupation. However, community resistance should be anticipated and addressed through sustained community engagement from the enumeration stage onward.

6.7.3 Scheme Synchronisation

The multi-scheme funding framework PMAY-U 2.0, AMRUT 2.0, SBM 2.0, Smart City Mission creates coordination challenges between multiple line departments and

funding cycles. In practice, the simultaneous operation of four scheme components for a single settlement cluster requires a dedicated programme management unit that can synchronise timelines, resolve conflicts between scheme eligibility criteria, and maintain a single beneficiary database across schemes. The Bhopal Smart City SPV is the natural locus for this coordination function.

6.7.4 Post-Relocation Land Management

After Zone A relocation, the cleared sites particularly the railway buffer zone and lakefront buffer zone must be immediately secured to prevent re-occupation. The railway buffer Zone C (Infrastructure Edge Linear Park) and the lakefront Zone C (Ecological Restoration) proposals provide the positive-use management mechanism. The critical risk period is between demolition and the establishment of the alternative use. Construction of the linear park and ecological restoration infrastructure should commence immediately after site clearance, without the gap that characterised the 2022 eviction site management.

Table No. 6.3: Zone A, B, C: Consolidated Planning Framework Summary

Parameter	Zone A: Relocation	Zone B: In-Situ Upgrade	Zone C: Ecological Restoration
Target Area	Priority Hazard Matrix Category 1 (Red Zone): all Untenable buildings	Category 2 (Orange Zone): Semi-Tenure buildings in outer hazard buffers	Reclaimed 50m lakefront buffer post-Zone A relocation
Building / Unit Count	1,075 units requiring relocation	Approximately 1,140 units requiring structural upgrade	Approximately 1.6 Ha of reclaimed lakefront buffer zone
Primary Intervention	Pucca EWS housing construction at cleared relocation sites with ventilated cluster layout	Resilience Retrofit Kit: raised plinth + wall panels + roofing + drainage + ventilation	Bioswale network + retention ponds + native planting + public ecological trail
Primary Funding	PMAY-U 2.0 BLC central subsidy (Rs. 2.5L/unit) + state top-up for land and site development	PMAY-U 2.0 BLC (Rs. 2.5L/unit for retrofit) + AMRUT 2.0 drainage	AMRUT 2.0 Green Infrastructure + Smart City ABD + National Wetland Conservation Programme

Parameter	Zone A: Relocation	Zone B: In-Situ Upgrade	Zone C: Ecological Restoration
Timeline	Phase 1 (emergency: 0-6 months) + Phase 2 (1-2 years) for full relocation and housing	Phase 3 (2-5 years) for complete Zone B retrofit delivery	Phase 3-4 (3-7 years): commences after Zone A lakefront clearance
Lead Agency	BMC + MP Urban Development and Housing Dept + Indian Railways (NOC)	BMC + PMAY-U implementing agency + AMRUT 2.0 ULB component	BMC + Smart City SPV + MP Pollution Control Board + National Wetland Conservation Division
Success Indicator	All 1,075 units physically relocated to hazard-cleared sites with Patta within Phase 2 timeline	Structural retrofit completed for 1,140 units; drainage network operational; Patta issued for all Zone B units	Bioswale and retention pond network operational; Upper Lake faecal coliform count reduction measurable at intake

Source: Planning framework developed by Author; scheme alignment: MoHUA PMAY-U 2.0 (2024); MoHUA AMRUT 2.0 (2021)

CHAPTER 7: POLICY ALIGNMENT AND INNOVATIVE PROPOSALS

Planning proposals without a funding mechanism are architectural drawings. This chapter connects the Zone A, B, and C interventions to the specific national scheme frameworks that provide the regulatory authority and financial resources for implementation. It also presents five innovative proposals that extend beyond conventional planning approaches to address structural gaps in the existing policy landscape.

7.1 Government Scheme Integration

Table No. 7.1: Government Scheme Integration Matrix

Scheme	Relevant Component	Zone A Application	Zone B Application	Zone C Application
PMAY-U 2.0 (2024-2029)	Beneficiary Led Construction (BLC) vertical; Rs. 2.5 lakh per EWS household	BLC for relocation housing at identified resettlement sites; MP State Patta model for land rights	BLC for Resilience Retrofit Kit (plinth, wall panels, roofing, ventilation improvements)	Not directly applicable: land becomes public ecological zone
AMRUT 2.0 (2021-2026)	Green infrastructure; stormwater drainage; water body rejuvenation; covers 500 cities including Bhopal	Resettlement site infrastructure connection (road, drainage, water supply)	Zone B stormwater drainage networks; check-dams at nallah mouths; raised plinth standards	Bioswale network and retention ponds on reclaimed lakefront buffer
Smart City Mission: Bhopal	Area-Based Development (ABD); pan-city smart infrastructure	Infrastructure Edge Linear Park (post Zone A clearance)	Smart drainage monitoring IoT; GIS-linked slum mapping	Lakefront ecological park and public trail development (ABD component)
SBM 2.0 Urban	Community toilets; septage	Resettlement site sanitation infrastructure	Zone B community toilet	Solid waste management to reduce nallah

Scheme	Relevant Component	Zone A Application	Zone B Application	Zone C Application
	management; solid waste		complexes; septage management to prevent lake contamination	blockage at lake inlets
Sendai Framework DRR 2015-2030	Priority 1 (Understanding Risk); Priority 3 (Investing in DRR); Priority 4 (Build Back Better)	Phase 1 emergency relocation = Priority 4; SDG 11.1 housing access	Zone B upgrading = Priority 3 investment in DRR; community resilience committees	Wetland restoration = Priority 3 ecosystem-based DRR

Source: Scheme guidelines: MoHUA PMAY-U 2.0 (2024); MoHUA AMRUT 2.0 (2021); Smart City Mission Bhopal SPV; UNDP Sendai Framework (2015)

7.1.1 PMAY-U 2.0 (2024 to 2029)

The Pradhan Mantri Awas Yojana Urban 2.0, launched with a national target of one crore urban homes by 2029, provides the primary funding and legal framework for both Zone A relocation and Zone B in-situ upgrading. The BLC vertical, at a central subsidy of Rs. 2.5 lakh per EWS household supplemented by state top-up for land acquisition and site development, is the applicable component for both intervention types.

The eligibility preparation challenge is significant. Most Zone A and Zone B households currently lack either formal land Patta or BMC notification, both of which are required for PMAY-U BLC access. The GIS-based tenability classification developed in this study provides the spatial evidence base from which BMC can initiate fast-track Patta issuance for Zone B households and resettlement site identification for Zone A the preparatory work that must happen before scheme deployment can begin.

7.1.2 AMRUT 2.0 (2021 to 2026)

AMRUT 2.0 covers Bhopal as one of its 500 target cities and provides dedicated funding for green infrastructure and urban water management. Three components are directly aligned with the planning proposals. The green infrastructure component funds bioswales, retention ponds, and ecological corridors in Zone C. The stormwater drainage component funds Zone B drainage networks and check-dam construction. The

water body rejuvenation strand covers Upper Lake protection, silt trap installation, and shoreline restoration.

7.1.3 Smart City Mission: Bhopal

Bhopal's Smart City ABD zone overlaps directly with the Zone C lakefront ecological restoration area. The lakefront ecological park and public trail proposed in Zone C qualifies as an ABD component under the Smart City framework. The pan-city smart infrastructure component provides the technology backbone for the GIS Hazard Eligibility Portal proposed in the next section, and for IoT-based drainage monitoring in Zone B clusters.

7.2 Innovative Proposals Beyond Conventional Planning

7.2.1 GIS-Based Hazard Eligibility Portal

A publicly accessible web-GIS dashboard linked to Bhopal Smart City's data infrastructure would allow each informal unit to be mapped with its tenability score, scheme eligibility status, and application pathway. Residents could check their eligibility for PMAY-U 2.0 BLC, Patta application status, and available resettlement options in real time, reducing bureaucratic delays and improving transparency in a process that is typically opaque to affected communities.

The Odisha JAGA Mission provides the direct precedent model: GIS-based slum mapping was used to issue over 200,000 land rights certificates to slum dwellers through a digitally administered, transparent process. Bhopal's Smart City platform reduces the implementation cost substantially compared to building from scratch.

7.2.2 Community Resilience Micro-Insurance

Parametric weather-indexed insurance for Zone B households, structured as a community-level product with premium costs subsidised through NDMA's State Disaster Response Fund. The insurance trigger would be set at daily rainfall exceeding 100 millimetres a threshold commonly breached during Bhopal's monsoon season and the point at which waterlogging durations in the study area exceed the WHO 72-hour vector disease threshold.

Unlike traditional indemnity insurance, which requires damage assessment and claims-processing infrastructure that is inaccessible to informal settlement residents,

parametric insurance disburses automatically on the occurrence of the agreed rainfall event. This provides immediate liquidity for emergency repairs, significantly reducing the post-disaster welfare shock that the Patra and Peri (2022) Bhubaneswar study identifies as the primary poverty trap for informal settlement communities after disaster events.

7.2.3 Sponge City Buffer: Productive Ecological Edge

Rather than simply removing informal structures from the Zone C lakefront buffer and leaving it as ungoverned open space which risks gradual re-encroachment the proposal creates a managed ecological and social amenity space with a built-in maintenance revenue model. A bioswale network with native aquatic and riparian plant species provides passive water quality treatment. An urban food forest component of fruit and fodder trees provides community produce, shade, and ecological habitat. Community composting hubs divert organic waste from the nallah network, produce compost for the food forest, and generate a small revenue stream for maintenance funding. A public ecological trail provides lakefront access with educational signage on wetland ecology.

7.2.4 Infrastructure Edge Linear Park

The 30 to 100 metre infrastructure safety buffers, once cleared of informal structures through Zone A relocation, presents an opportunity for conversion into a multi-use linear park that serves public amenity and infrastructure protection simultaneously. The Sabarmati Riverfront model adapted for a railway edge context provides the precedent: a cycle and pedestrian path parallel to the boundary fence, an acoustic green belt of Neem and Ashoka trees, an integrated stormwater drainage channel, and solar-lit pathway with CCTV coverage. This intervention transforms the railway buffer from a contested and dangerous informal zone into a defined public infrastructure corridor. The dual function public amenity and enforced no-build zone means the buffer serves its safety purpose through positive use rather than enforcement action alone.

7.2.5 Incremental Housing Toolkit: Community Production Model

For Zone B households, the standard PMAY-U BLC unit-construction model, which typically involves contractor-led complete reconstruction, can be replaced with a community production model that builds on the existing housing stock rather than replacing it. Lower unit cost enables more households to be served within the same budget envelope. Preservation of social networks and community spatial structure

avoids the social disruption associated with complete reconstruction and relocation. The sweat equity model, in which community members contribute construction labour, reduces cash cost and builds technical capacity for ongoing maintenance. The modular approach means that different kit components can be implemented in sequence as funding becomes available, rather than requiring a complete unit reconstruction budget upfront.

7.3 SDG Alignment and International Framework Commitments

Beyond the Sendai Framework, the planning proposals in this study align with several Sustainable Development Goals that are directly relevant to informal settlement vulnerability and urban resilience:

SDG 1 (No Poverty): Zone A resettlement with Patta transfer and PMAY-U BLC access represents a direct contribution to economic security for the 1,075 households currently excluded from formal housing benefits by their legal untenability. The Resilience Retrofit Kit for Zone B reduces post-disaster economic shock for a further 1,140 households through structural risk reduction.

SDG 3 (Good Health and Well-Being): The vector-borne disease risk reduction achieved by eliminating waterlogging durations above the WHO 72-hour threshold through Zone B drainage infrastructure directly contributes to SDG 3. The drinking water quality protection achieved through Zone C ecological restoration contributes to water security for the 40 per cent of Bhopal's population served by the Upper Lake.

SDG 11 (Sustainable Cities and Communities): SDG 11.1 calls for access to adequate, safe, and affordable housing and basic services for all. The Zone A resettlement programme directly implements this target. SDG 11.5 calls for a substantial reduction in deaths and economic losses from disasters. The Priority Hazard Matrix framework and the phased intervention programme are designed to reduce both mortality risk (Phase 1 emergency relocation of cyclic decay and triple-hazard zones) and economic loss (Zone B structural retrofitting to prevent monsoon-season property damage).

SDG 15 (Life on Land): The Zone C ecological restoration wetland plant species reintroduction, native tree planting, bioswale network directly implements SDG 15.1 (conservation of freshwater ecosystems) and 15.4 (conservation of mountain ecosystems, adapted for the plateau context).

Table No. 7.2: SDG Alignment Matrix: Planning Proposals and Relevant Targets

SDG	Target	Planning Proposal Alignment
SDG 1: No Poverty	1.4: Equal rights to economic resources; access to basic services	Zone A Patta transfer + PMAY-U BLC access = formal economic rights for 1,075 relocated households
SDG 3: Good Health	3.3: End vector-borne diseases; 3.9: Reduce illness from pollution	Zone B drainage eliminates >72h waterlogging; Zone C reduces lake contamination affecting city water supply
SDG 6: Clean Water	6.3: Improve water quality; 6.6: Protect water-related ecosystems	Zone C bioswale + silt traps reduce pollutant loading into Upper Lake (Bhopal's 40% water source)
SDG 11: Sustainable Cities	11.1: Safe housing for all; 11.5: Reduce disaster deaths and losses	Zone A resettlement to hazard-cleared sites; Priority Hazard Matrix framework for proactive disaster risk reduction
SDG 13: Climate Action	13.1: Strengthen resilience to climate-related hazards	Zone B raised plinth standards; Zone C ecological buffer both climate-adaptive investments with multi-decadal benefit
SDG 15: Life on Land	15.1: Conservation of freshwater ecosystems; 15.5: Halt biodiversity loss	Zone C wetland plant reintroduction; native tree planting; Upper Lake ecological buffer restoration

Source: SDG Framework: UNDP (2015); alignment with Bhopal planning proposals

7.4 State-Level Policy Context: Madhya Pradesh

The planning proposals in this study require action at multiple levels of government. While the central scheme frameworks (PMAY-U 2.0, AMRUT 2.0) are critical, the state-level policy context in Madhya Pradesh shapes the practical feasibility of implementation significantly.

Madhya Pradesh has made some progress in recent years on the slum regularisation front. The MUKHYAMANTRI Jan Awas Yojana (Chief Minister's Housing Scheme) has provided housing to a number of urban informal residents, though coverage remains well below the scale of need. The state government's implementation of PMAY-U 2.0 will depend significantly on its willingness to identify and transfer state land parcels for resettlement sites which requires inter-departmental coordination between the Revenue Department, the Forest Department, and the Urban Development and Housing Department that has historically been difficult to achieve.

The Bhopal Municipal Corporation's administrative capacity is an additional constraint. BMC currently lacks the GIS infrastructure, the data management systems, and the dedicated staffing capacity to manage a programme of the scale implied by Zone A relocation of 1,075 units, Zone B upgrading of 1,140 units, and Zone C restoration of 1.6 hectares simultaneously. Building this capacity is a prerequisite for programme implementation, and the GIS Hazard Eligibility Portal proposed in Section 7.2.1 is partly a capacity-building intervention by creating the data infrastructure that scheme administration requires, it simultaneously builds BMC's analytical capacity for ongoing informal settlement management.

7.5 Monitoring and Evaluation Framework

Any planning proposal without a monitoring framework is a declaration of intent rather than a commitment to outcome. The following indicators are proposed for tracking the implementation and impact of the Zone A, B, and C interventions:

Table No. 7.3: Monitoring and Evaluation Framework: Key Performance Indicators

Zone	Output Indicator	Outcome Indicator	Measurement Method	Timeline
Zone A	Number of units physically relocated to hazard-cleared sites; Patta transfer rate	Reduction in buildings within 30m infrastructure edge and 50m NGT lake buffer	BMC administrative records; GIS repeat analysis	Annual; final assessment at end of Phase 2 (Year 2)
Zone B	Number of Resilience Retrofit Kits completed; drainage network length installed	Reduction in post-monsoon waterlogging duration in Zone B areas; reduction in structural damage claims	BMC infrastructure records; community monitoring by Resilience Committees; field survey	Annual; monsoon season monitoring; Year 3 and Year 5 assessments
Zone C	Area of bioswale and retention pond network operational; metres of ecological trail completed	Upper Lake faecal coliform count at western inlet (Khanugaon measurement point); informal	BMC Environmental Monitoring; water quality sampling at lake inlet; CCTV	Bi-annual; monsoon and post-monsoon seasons; Year 5 ecological baseline comparison

Zone	Output Indicator	Outcome Indicator	Measurement Method	Timeline
		re-occupation incidents	monitoring records	
Overall Programme	Total households in Untenable category remaining after programme completion; total Patta issuances	Reduction in mortality and economic loss events in programme area; improvement in PMAY-U eligibility coverage	Hazard incident records (BMC / District DMA); PMAY-U beneficiary database	Year 5 and Year 10 comprehensive evaluation against 2024-25 baseline

Source: Monitoring framework developed by Author; aligned with Sendai Framework indicator protocols (UNDRRR, 2015) and PMAY-U 2.0 monitoring guidelines (MoHUA, 2024)

CHAPTER 8: DATA SOURCES AND REFERENCES

8.1 Primary and Secondary Data Sources

Table No. 8.1: Primary and Secondary Data Sources

Dataset	Source	Year	Application
Google Open Buildings V3	Google Research: Open Buildings Dataset	2024	Building footprint polygons: primary unit of analysis for all hazard intersection and tenability classification
NASADEM 30m DEM	NASA JPL via Open Topography	2000	Topographic flood and waterlogging analysis: DEM Fill, Flow Direction, Con, Raster to Polygon workflow in ArcGIS Pro
Sentinel-2 LULC	ESA via Esri and Microsoft Planetary Computer	2023-24	Land use and land cover classification; informal settlement boundary delineation
LISS-IV Satellite Imagery	NRSC Bhuvan, ISRO	2023	High-resolution settlement boundary verification, morphological classification
Railway Network Vectors	Digitised from Survey of India 1:50,000 toposheets, satellite-verified	2023	Track centreline for infrastructure edge buffer generation (30m and 100m tiers)
Water Body Polygons	Derived from LULC classification, verified against BDP 2031 FTL boundary	2023	Shoreline boundary for eco-sensitive zone buffer generation (50m NGT and 100m environmental tiers)
Bhopal Development Plan 2031	Bhopal Municipal Corporation Draft BDP	2021	Statutory land-use reference, no-construction zone baseline, infrastructure layout
Indian Railways Works Manual	Ministry of Railways, Government of India	Current	Para 827 NOC zone specification (30m threshold)
NGT Orders on Wetland Buffers	National Green Tribunal, Government of India	2017-ongoing	50-metre Ramsar site buffer standard (National Wetland Rules 2017)
BMC Slum Notifications	Bhopal Municipal Corporation Slum Register	2023	Notified slum boundary reference for ground-truth validation

Dataset	Source	Year	Application
BMC Environmental Monitoring	Bhopal Municipal Corporation Lake Quality Reports	2022-23	Upper Lake water quality data (faecal coliform counts) for Hotspot B analysis
NDMA Urban Flood Guidelines	National Disaster Management Authority, GOI	2010	Hazard zone classification standards and emergency relocation protocol reference
PMAY-U 2.0 Scheme Guidelines	Ministry of Housing and Urban Affairs, GOI	2024	BLC vertical eligibility criteria; subsidy structure; state implementation framework
AMRUT 2.0 Guidelines	Ministry of Housing and Urban Affairs, GOI	2021	Green infrastructure component; stormwater drainage; water body rejuvenation applicable components
IPCC AR6 Working Group II	Intergovernmental Panel on Climate Change	2022	Vulnerability framework: Exposure-Sensitivity-Adaptive Capacity model

8.2 References

Source Type	In-text Citation	Example (MANIT Format)
Book: One author	<i>(Kadiyali, 2005)</i>	Kadiyali LR (2005), Traffic Engineering and Transport Planning, 6th ed., Khanna Publishers, New Delhi.
Book: Two authors	<i>(Samuelson and Nordhaus, 2009)</i>	Samuelson AP and Nordhaus WD (2009), Elementary Economics, MacGraw-Hill, London.
Book: More than two authors	<i>(Kempton et al., 1992)</i>	Kempton W, Darley JM and Stern PC (1992), Psychological Research for the New Energy Problems: Strategies and Opportunities, American Psychologist.
Book: Edited, one author	<i>(Silverman, 1990)</i>	Silverman DF, ed. (1990), The Active Interview, Sage Publications, Beverly Hills CA.
Book: Edited, two or more authors	<i>(Silverman and Propp, 1990)</i>	Silverman DF and Propp KK, eds. (1990), The Active Interview, Sage Publications, Beverly Hills CA.

Book: Chapter from edited book	(<i>Samson, 1970</i>)	Samson C (1970), Spatial Information Studies in Urban Design, In: Stone S, ed. (1980), Humanities Information Research, CRUS, Sheffield, pp44-68.
Journal: One author	(<i>Boughton, 2002</i>)	Boughton JM (2002), Service Level Benchmarking of Sanitation: Milestones Achieved, Economic and Political Weekly, Vol 47 No. 03 January 21-27, p98.
Unpublished Dissertation	(<i>Stolly, 2005</i>)	Stolly K (2005), JnNURM and Improvement in the Quality of Life, A Case of Ahmedabad, M.Plan, Banaras Hindu University, Varanasi. (Unpublished).
E-Journal Article	(<i>Boughton, 2002</i>)	Boughton JM (2002), Energy Efficient Traditional Building Techniques, Liberal Science Quarterly, [ejournal], Vol 12 No. 03, February 2002, p98. http://www.popsoci.com/ (Accessed on 12 June 2005).
Web Page	(<i>Wikipedia, 2006</i>)	Wikipedia: The Free Encyclopedia (2006), http://en.wikipedia.org/w/index.php?title=Caret&oldid=157510440 (Accessed on 12 May 2006).
Newspaper	(<i>Swathi, 2008</i>)	Swathi V (2008), Mere Hope Lights These Gloomy Shelters, The Hindu, 09 June 2008.
E- Newspaper	(<i>Swathi, 2008</i>)	Swathi V (2008), Mere Hope Lights These Gloomy Shelters, The Hindu, 09 June 2008. www.thehindu.com/2008/06/09/stories/2008060960090400.htm (Accessed on 10 June 2008).