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Urban Drainage Efficiency and Waterlogging Vulnerability Assessment through Field Surveys and Topographic Analysis: A Case Study of Balaghat City, Madhya Pradesh, India

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Abstract

Urban waterlogging has become an increasingly significant challenge in rapidly urbanizing Indian cities due to inadequate drainage infrastructure, unplanned urban expansion, and changing rainfall patterns. The present study assesses urban drainage efficiency and waterlogging vulnerability in Balaghat City, Madhya Pradesh, India, through systematic field surveys, topographic analysis, and Geographic Information System (GIS)-based mapping. Field investigations were conducted across representative urban locations to collect data on elevation, drainage condition, water stagnation, and drainage obstructions using GPS-based surveys and direct observations. A Waterlogging Vulnerability Index (WVI) was developed by integrating four weighted parameters: elevation (0.35), drainage condition (0.30), water stagnation (0.20), and waste accumulation/flow obstruction (0.15). The WVI classified surveyed locations into low, moderate, and high vulnerability categories. Elevation analysis revealed a topographic range of 317.73–336.92 m above mean sea level, with low-lying areas exhibiting significantly greater susceptibility to waterlogging. Statistical analysis demonstrated a strong inverse relationship between elevation and WVI ($r = -0.93$, $R^2 = 0.87$, $p < 0.001$), indicating that topography is a major determinant of waterlogging occurrence. Highly vulnerable locations identified included Bhatera Railway Crossing, Moti Nagar, Chitragupta Nagar, Railway Station surroundings, and Hanuman Chowk, where poor drainage conditions, sediment accumulation, waste blockage, and persistent water stagnation were frequently observed. The GIS-based vulnerability mapping effectively delineated priority intervention zones requiring drainage improvement and regular maintenance. The findings demonstrate that integrating field observations with topographic analysis provides a practical and reliable framework for evaluating urban drainage performance and identifying flood-prone areas. The developed methodology offers valuable scientific support for stormwater management, drainage infrastructure planning, and climate-resilient urban development in Balaghat and other rapidly growing cities facing similar hydrological challenges.

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Introduction

The rapid development of cities in the tropics and subtropics has caused severe disruption to traditional hydrologic cycles and resulted in urban developments that far exceed the capabilities of existing infrastructure which was originally built to meet the needs of projected rainfall prior to rapid urbanization (Gaurkhede and Adane, 2024). The increasing number of impervious surfaces leads to a decrease in water infiltration and an increase in the amount of surface runoff, creating a greater chance of localized flooding due to extreme rainfall events (Karunya and babu, 2026). Urban centres in India are facing greater stress being placed on stormwater drainage infrastructure as a result of rapid urban growth extending into previously undeveloped land, blocking natural drainage routes (Kamraju *et al.,* 2026). Increasingly severe hydro-geographical pressure resulting from climate change, as demonstrated by increased extreme weather events related to precipitation, has led to a "perfect storm" of over-stressing of conventional and improperly sized stormwater drainage systems (Ramachandran *et al*, 2019). Blockages of drainage systems as a result of debris accumulation have also slowed water flow in drainage systems leading to significant flooding even for small rainfall events (Kamraju *et al.,* 2026). Blockages within the urban drainage system demonstrate the inefficiency of municipal solid waste management systems within urban centres, highlighting the need for immediate infrastructure and policy changes (Singh and Lohani, 2025). In order to meet these challenges, stakeholders need to move from reactive to proactives in their asset management activities utilizing a data driven approach to enhancing drainage infrastructure, including the application of changes to hydraulic modelling and morphometric analysis in the identification of structural bottlenecks (Chandankhede, 2025; Luxmi *et al.,* 2026).

The urban expansion of Balaghat city, located in Madhya Pradesh, has been progressing over time as a result of various factors, including population growth, infrastructure development, and increased commercial activities. The hydrologic response of Balaghat's urban landscape has been altered due to the conversion of natural land surfaces to impervious built-up areas, reducing both infiltration and the amount of runoff that is generated during rainfall events (Oswald *et al.,* 2023). These land use changes have created additional stresses upon the urban drainage system and have increased the likelihood of localized flooding and the occurrence of waterlogging in those areas, especially during periods of significant precipitation.

Balaghat has a tropical monsoon climate and the majority of the annual precipitation falls during the southwest monsoon (June through September). River basins dominated by the southwest monsoon (monsoon sub-basins) exhibit a strong seasonal distribution of precipitation, such that cities within these basins are particularly exposed to drainage congestion and potential inundation during periods of intense precipitation (Soni *et al.,* 2013). Recent research has shown that the variability of hydro-climate conditions is increasing in central India, thus raising the concern about the challenges presented by extreme rainfall, flood risk, and urban stormwater management within the country (Singh *et al.,* 2025).

In addition to the earlier identified increasing variability of rainfall and hydrological response throughout the Wainganga River basin, studies conducted in this basin have identified significant spatial and temporal variability in rainfall patterns and hydrological responses (Taxak *et al.,* 2014; Thakur *et al.,* 2020). Furthermore, flood assessments performed at the Balaghat gauging station show that intense monsoonal precipitation influences flooding and water accumulation in the Wainganga River basin (Patle *et al.,* 2023). Furthermore, geomorphological research has found that basin morphologies, localized trait characteristics, and relatively mild slopes will help concentrate runoff and create stagnant water in low land areas (Bhagat and Bisen 2016; Bisen 2021). As a result, the collective effect of these factors is to enhance the vulnerability of Balaghat and its surrounding areas to waterlogging caused by rain.

Currently, the city of Balaghat's existing drainage system is made up of mostly the open and closed roadside drains which were explicitly built to lead rainy runoff into the natural drainage systems with the Wainganga Basin. However, as a result of rapid urban growth, sediment deposition, and accumulation of solid waste, encroachment and a lack of maintenance; the ability of a number of sections of the drainage system to function has decreased in terms of capacity. These same types of problems with drainage systems in both Indian urban areas have been documented to greatly affect the ability of urban areas to perform drainage as it relates to urban flooding and creating waterlogging through poor drainage connectivity, capacity to drain water, and mismanagement of solid waste (Singh *et al.,* 2023). As a result, Balaghat City has many locations that regularly have stagnant water in drains, in many cases overflowing and flooding during moderate to heavy rainfall events; and these events impact the transportation systems, public infrastructure and urban environmental quality.

Topology is an important physical factor that influences urban drainage performance and flood vulnerability. Elevation, slope, drainage connectivity and local depressions determine how water surfaces run off as well as where waters run-off will accumulate within an urban boundary. Therefore, using both field-based drainage assessment and topology makes it possible to systematically identify drainage bottlenecks, evaluate the performance and capacity of the drainage system, and delineate areas that are susceptible to waterlogging. Despite the growing concern over urban flooding and poor drainage performance there has not been comprehensive studies conducted that evaluate urban drainage efficiency and flooding vulnerability in the City of Balaghat.

Therefore, the present study aims to assess urban drainage efficiency and waterlogging vulnerability in Balaghat city through systematic field surveys and topographic analysis. The study seeks to identify critical drainage bottlenecks, evaluate the condition and functionality of the existing drainage network, and delineate areas susceptible to waterlogging. The findings are expected to provide scientific support for urban stormwater management, drainage infrastructure planning, and flood-risk reduction strategies in Balaghat city.

Materials and Methods

Study Area

The study was conducted in Balaghat City, located in the southeastern part of Madhya Pradesh, India, within the Wainganga River Basin. Geographically, the city lies between 21°48′–21°50′ N latitude and 80°09′–80°13′ E longitude. The Wainganga Basin plays an important role in influencing the hydrological and drainage characteristics of the region (Agase *et al.,* 2025).

Fig. 1. Location map of the study area showing the geographical position of Balaghat City within Madhya Pradesh, India, and the spatial extent of the urban area considered for the present study

Balaghat City has a tropical monsoon climate; the vast majority of its total precipitation is derived from the southwest monsoonal rains (June to September). Monsoonal precipitation leads to large volumes of surface runoff that cause significant impacts on urban drainage conditions and urban area surface accumulation of water (Patle *et al.,* 2023). Elevation field observations indicate that the study area elevation was measured from approximately 317.73 m to 336.92 m above (mean) sea level (MSL). The study area's topographic characteristics impact stormwater flow and drainage (moving from higher to lower elevations) and have a significant effect on the efficiency of the drainage systems in the study area and susceptibility to flooding of the urban areas in Balaghat City (Bisen, 2021). Urban development and increased impervious surface cover within Balaghat have reduced the area's natural hydrological response leading to decreased infiltration and increased runoff (decreased stormwater infiltration and increased stormwater runoff). Decreases in infiltration and increases in runoff are leading to increased loads on existing drainage systems and correspondingly increasing localized drainage inefficiencies following precipitation events in Balaghat (Humnekar *et al.,* 2025). Because of the issues previously described, Balaghat City is a suitable study area for assessing urban drainage efficiencies and vulnerabilities to flooding through the use of field surveys and topographical analyses.

Field Survey and Data Collection

To evaluate the drainage and the areas that could be prone to waterlogging, field surveys were performed in Balaghat City at selected locations. Survey locations were chosen to represent the different land-use zones, i.e., residential, commercial, transportation and low-lying areas within the urban boundary. At each survey location, geographic coordinates and elevation values were collected with the assistance of a smartphone-based GPS Altimeter application. The collected data on elevation, was then used to investigate the variation in topography and how it affects the way in which stormwater flows through the city.

The field investigation involved making observations relating to the condition of drainage channels, solid- and construction-waste accumulation, sediment in drainage systems, drainage blockages, water accumulation, and flooding in localized areas and photographic records were taken during the field survey to provide documentation of the drainage-related problems encountered in the surveys.

The spatial data generated during the field survey were compiled and organized for GIS analysis. These data formed the basis for assessing the drainage efficiency within Balaghat City and for identifying areas at risk of surface water accumulation (waterlogging).

Drainage Network Assessment

The evaluation of Balaghat City's drainage infrastructure was conducted using field-based observations of stormwater runoff by surveys at different locations.Parameters assessed as part of this drainage survey included continuity of drains, accumulation of debris in drains, accumulation of silt in drains, blockage of drains, ponding of water at or near drain outlets, and general condition of the maintenance and operation of the drainage system. Areas with blocked drains, low-capacity pipes, or signs of spill over were noted as locations with potential deficiencies in drainage.

Most of the information to assess the drainage system was based on visual inspection or observations made during the site visit. Information gathered during the survey will be used to evaluate whether or not the existing drainage system is functioning well and what might be causing localized waterlogging and low efficiency of drainage. Topographic data and observations from the drainage survey were combined to review terrain characteristics and relationship of the drainage system performance with the pattern of water accumulation within the study area.

GIS and Topographic Analysis

The spatial data, collected during the field study, will be analyzed using various techniques offered by Geographic Information Systems (GIS) to render and create both a spatial database for the geospatial data obtained from the survey and to generate output files with use of QGIS software, including additional files that correspond with the necessary survey points. The points resulting from the geocoding process for both elevation data gained from the field study will be used to determine the spatial distribution of the aforementioned elevation levels and the locations of relevant drainage from the city of Balaghat. The field study-derived elevation data has provided the means to ascertain the variance in topography of the areas of focus, establishing areas where topography is either elevated or depressed. The resulting analyses (of topography) assisted in the evaluation of how topography served to direct both the movement of stormwater and how much stormwater accumulated at specific points.

The analytical work conducted on the terrain's physical characteristics in relation to drainage will facilitate understanding of how the gradients of terrain define the location of accumulated stormwater. The lowest points on the ground generally may be considered more likely to accumulate stormwater than higher elevation points due to the fact that rain falling on the higher elevations generally will move to lower elevations via surface runoff.

The analyses performed with the aid of GIS have provided a spatial representation of the drainage patterns across the study area and an overall spatial framework for assessing the vulnerability of the urban landscape to waterlogging.

Waterlogging Vulnerability Assessment

The integration of topographic characteristics and on-site observations was used to assess the vulnerability to waterlogging. The characteristics that affect stormwater accumulation were considered including elevation change, drainage condition, evidence of standing water, obstruction to flow, and overall efficiency of the existing drainage network.

Areas exhibiting poor drainage performance, frequent water accumulation and lower relative elevations were deemed to be more vulnerable to waterlogging than other areas with better drainage conditions and higher relative elevations. It was assumed that both topography and drainage efficiency influence the occurrence and persistence of urban waterlogging.

Field data and spatial data collected were evaluated in a GIS environment to determine areas that exhibit differing degrees of vulnerability to waterlogging. The assessment was ultimately used in the identification of vulnerable areas and evaluation of the relationship between topography, drainage performance and water accumulation patterns throughout Balaghat City.

Results

Existing Drainage Conditions

According to findings from field study, the urban drainage system within Balaghat City is mainly composed of uncovered roadside drainage, but there are instances of some drainage lines being covered at different strategic locations. The current stormwater drainage systems convey rain flow from storm events across the entire urbanised areas of Balaghat City. Drainage channels throughout Balaghat City were observed to have varied conditions and functional capabilities. Some of these channels are performing well under average flow conditions. However, on many other occasions, sediment build-up, vegetation growth and solid waste deposition were occurring within these channels. In addition to the previous observations, many of the drainage channels were also found to have partial blockage and localized standing water. The locations throughout the city differed in drainage connectivity and flow continuity. There were some specific locations that had difficulty draining because they are low-lying, resulting in the accumulation of rainwater on the ground during rainfall events.

Topographic Characteristics

Elevation analysis indicated noticeable topographic variation across Balaghat City, with elevations ranging from 317.73 m to 336.92 m above mean sea level. The highest elevation was recorded at Devi Talab (336.92 m), followed by Bus Stand Balaghat (335.76 m), Jay Stambh Chowk (333.97 m), Kali Putli Chowk (333.66 m), and Kali Path Mandir (332.10 m). Relatively lower elevations were recorded at Shankar Ghat (317.73 m), Moti Nagar (320.84 m), Narmada Nagar Shiv Mandir (322.93 m), Railway Station (323.60 m), and Sarekha (323.78 m). The generated elevation map revealed a distinct elevation gradient across the study area.

Waterlogging-Prone Areas

Field surveys identified several locations susceptible to temporary water accumulation during moderate to heavy rainfall events. Major waterlogging-prone locations included Bhatera Railway Crossing, Chitragupta Nagar, Budhi Area, Moti Nagar, Railway Station surroundings, Hanuman Chowk, and Narmada Nagar. Among these locations, Moti Nagar, Narmada Nagar Shiv Mandir, and the Railway Station surroundings were situated within relatively lower elevation zones. Water accumulation was frequently observed in these areas following rainfall eventsThe scatter plot analysis revealed a strong negative relationship between elevation and Waterlogging Vulnerability Index (WVI) across the surveyed locations of Balaghat City. Lower-elevation locations generally exhibited higher WVI values, whereas higher-elevation locations showed lower vulnerability. The regression analysis indicated a strong inverse correlation ($r = -0.93$), with elevation explaining approximately 87% of the variation in WVI values ($R^2 = 0.87$). These findings suggest that topography is a major controlling factor influencing waterlogging susceptibility within the study area, as low-lying areas serve as natural zones for runoff convergence and temporary water accumulation during rainfall events.

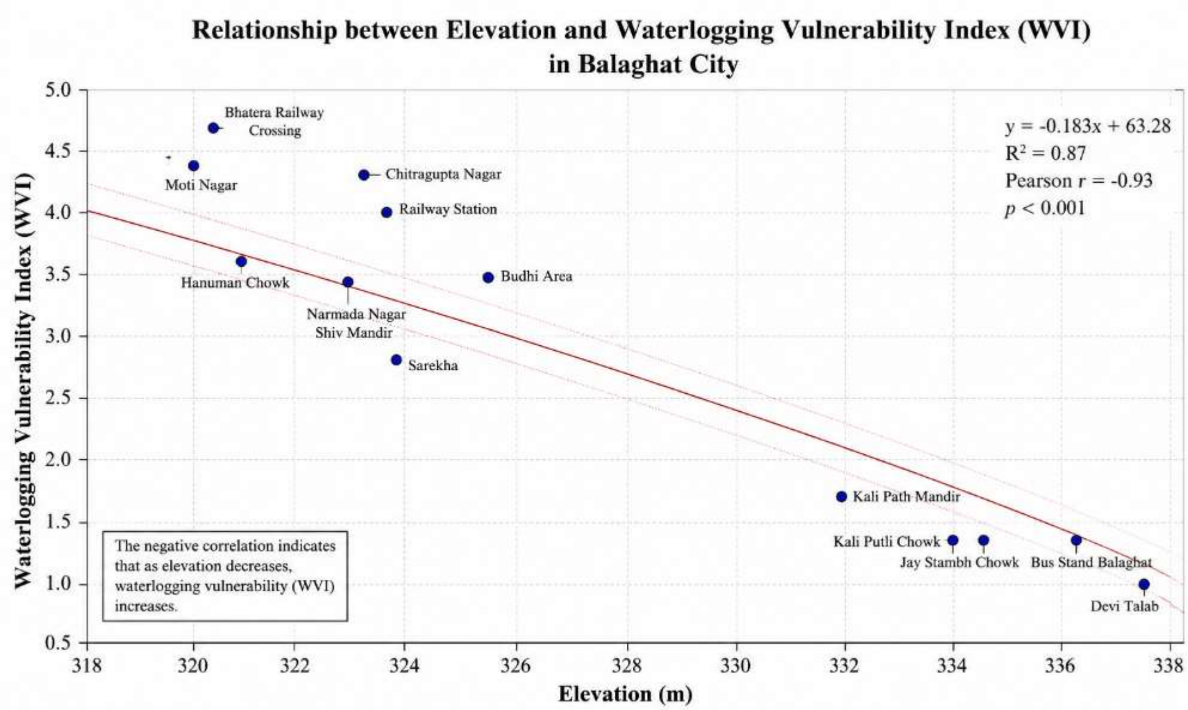

Fig. 2. Relationship between Elevation (m) and Waterlogging Vulnerability Index (WVI) in Balaghat City showing a strong negative correlation ($R^2 = 0.87$, Pearson $r = -0.93$, $p < 0.001$), indicating higher vulnerability at lower elevations

Waterlogging Vulnerability Index (WVI)

Based on field observations and topographic analysis, waterlogging vulnerability within Balaghat City was classified into three categories: high, moderate, and low vulnerability. Highly vulnerable locations included Bhatera Railway Crossing, Moti Nagar, Railway Station surroundings, and Chitragupta Nagar. Moderately vulnerable locations included Hanuman Chowk, Narmada Nagar, and Budhi Area. Areas situated at relatively higher elevations with better drainage connectivity were categorized as low-vulnerability zones. The resulting vulnerability map highlighted the concentration of highly vulnerable zones within lower-lying portions of the city.

To improve the quantitative assessment of waterlogging susceptibility, a Waterlogging Vulnerability Index (WVI) was developed using field-based observations and topographic characteristics. The index integrates multiple factors influencing stormwater accumulation and drainage performance within the urban environment.

Based on field observations conducted across Balaghat City, four parameters were selected for vulnerability assessment: elevation, drainage condition, observed water stagnation, and waste accumulation/flow obstruction. These parameters were chosen because they directly influence runoff concentration, drainage efficiency, and the persistence of waterlogging. Each parameter was assigned a relative weight according to its importance in influencing waterlogging occurrence (Table 1).

Table 1. Parameters and weights used in Waterlogging Vulnerability Index calculation

Parameter	Weight
Elevation	0.35
Drainage Condition	0.30
Water Stagnation	0.20
Waste Accumulation / Flow Obstruction	0.15
Total	1.00

Each parameter was assigned a rating ranging from 1 to 5, where higher ratings indicated greater susceptibility to waterlogging.

Table 2. Rating criteria used for Waterlogging Vulnerability Index

Parameter	Rating 1	Rating 2	Rating 3	Rating 4		Rating 5
Elevation (m)	>333	330–333	326–330	322–326		<322
Drainage Condition	Excellent	Good	Moderate	Poor		Very Poor
Water Stagnation	None	Rare	Occasional	Frequent		Persistent
Waste Accumulation / Obstruction	None	Minor	Moderate	High		Severe

Lower elevations received higher ratings because stormwater naturally accumulates in low-lying terrain. Similarly, locations exhibiting poor drainage conditions, frequent water stagnation, and significant waste accumulation were assigned higher scores due to their greater vulnerability to waterlogging.

The Waterlogging Vulnerability Index (WVI) for each survey location was calculated using the weighted linear combination method:

$$WVI = (0.35 \times ES) + (0.30 \times DS) + (0.20 \times WS) + (0.15 \times OS)$$

where:

- WVI = Waterlogging Vulnerability Index
- ES = Elevation Score
- DS = Drainage Condition Score
- WS = Water Stagnation Score
- OS = Obstruction/Waste Accumulation Score

The resulting WVI values were classified into three vulnerability categories:

WVI Range	Vulnerability Class
< 2.0	Low
2.0 – 3.5	Moderate
> 3.5	High

Table 3. Waterlogging Vulnerability Index (WVI) Assessment of Surveyed Locations in Balaghat City

Location	Elevation (m)	Elevation Score	Drainage Condition Score	Water Stagnation Score	Obstruction Score	WVI Value	Vulnerability Class
Bhatera Railway Crossing	321.50	5	5	4	4	4.65	High
Moti Nagar	320.84	5	4	4	4	4.35	High
Chitragupta Nagar	323.00	4	5	4	4	4.30	High
Railway Station	323.60	4	4	4	4	4.00	High
Hanuman Chowk	321.80	5	3	3	2	3.55	High
Narmada Nagar Shiv Mandir	322.93	4	3	3	3	3.45	Moderate
Budhi Area	325.00	4	3	3	3	3.45	Moderate
Sarekha	323.78	4	2	2	2	2.80	Moderate
Kali Path Mandir	332.10	2	2	1	1	1.70	Low
Kali Putli Chowk	333.66	1	2	1	1	1.35	Low
Jay Stambh Chowk	333.97	1	2	1	1	1.35	Low
Bus Stand Balaghat	335.76	1	2	1	1	1.35	Low
Devi Talab	336.92	1	1	1	1	1.00	Low

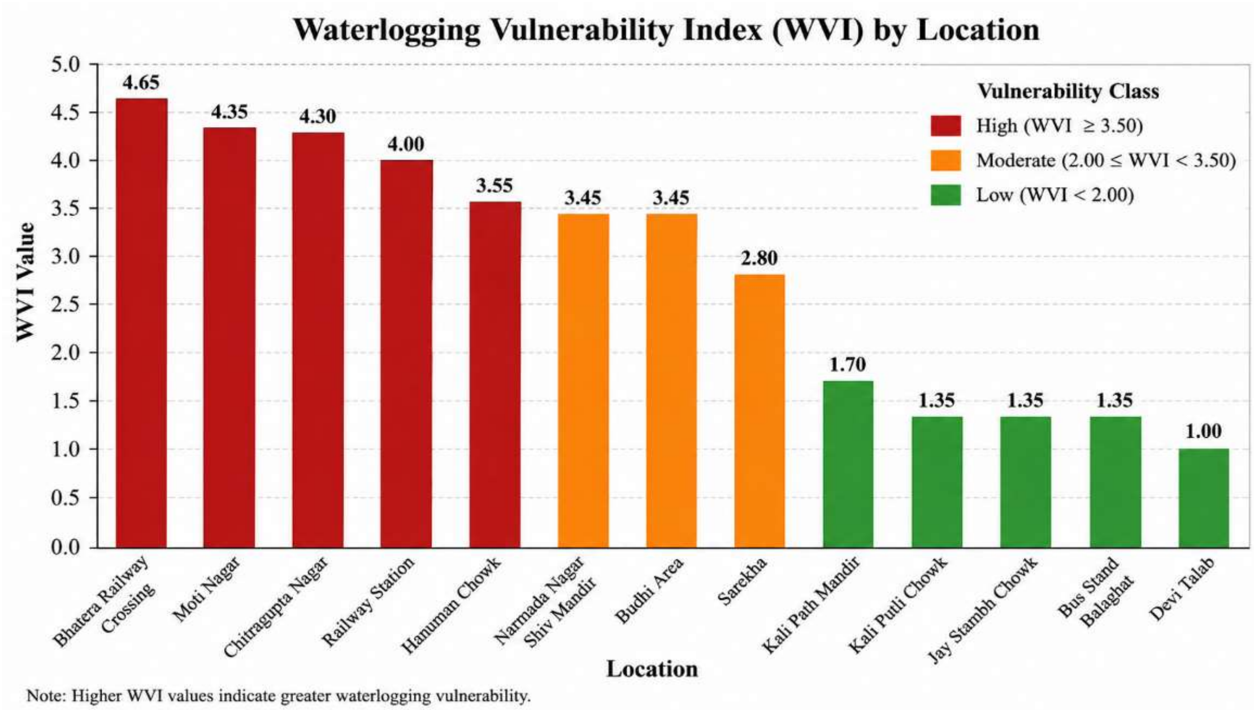

Fig. 3. Spatial Distribution of Waterlogging Vulnerability Index (WVI) Across Surveyed Locations in Balaghat City

The Waterlogging Vulnerability Index (WVI) assessment revealed significant spatial variability in waterlogging susceptibility across Balaghat City. The calculated WVI values ranged from 1.00 to 4.65, indicating substantial differences in drainage performance and water accumulation potential among surveyed locations. Bhatera Railway Crossing recorded the highest WVI value (4.65), followed by Moti Nagar (4.35), Chitragupta Nagar (4.30), Railway Station surroundings (4.00), and Hanuman Chowk (3.55), all of which were classified as highly vulnerable locations. These areas are characterized by relatively low elevations, poor drainage conditions, frequent water stagnation, and considerable flow obstruction caused by waste accumulation and sediment deposition.

Moderately vulnerable locations included Narmada Nagar Shiv Mandir (3.45), Budhi Area (3.45), and Sarekha (2.80). These locations exhibited moderate drainage deficiencies and occasional water accumulation during rainfall events but showed comparatively better drainage performance than highly vulnerable areas.

Low vulnerability was observed in Kali Path Mandir (1.70), Kali Putli Chowk (1.35), Jay Stambh Chowk (1.35), Bus Stand Balaghat (1.35), and Devi Talab (1.00). These locations are situated at relatively higher elevations and exhibited efficient runoff drainage, better drainage connectivity, and minimal evidence of water stagnation during field observations.

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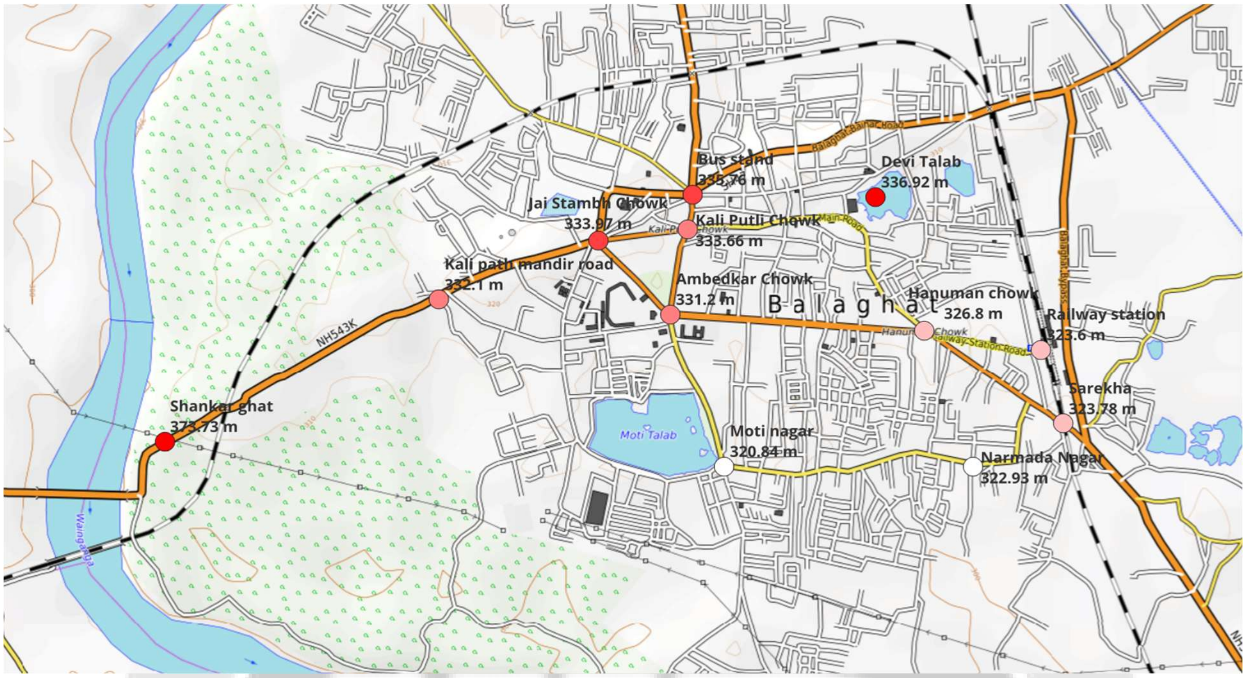

Fig. 4. GIS-based map illustrating the spatial distribution of surveyed locations and corresponding elevation values used for waterlogging vulnerability assessment in Balaghat City, Madhya Pradesh, India.

The WVI results demonstrate a clear relationship between topographic position and waterlogging susceptibility. Lower-elevation locations generally exhibited higher vulnerability scores, whereas elevated locations showed lower vulnerability. The spatial distribution of WVI values indicates that waterlogging risk within Balaghat City is concentrated primarily in low-lying urban sectors where stormwater runoff naturally converges and drainage limitations reduce the efficiency of stormwater conveyance. The generated Waterlogging Vulnerability Map further highlights these priority zones and provides a scientific basis for targeted drainage improvement and urban flood mitigation planning.

Discussion

The present investigation provides a comprehensive assessment of urban drainage efficiency and waterlogging vulnerability in Balaghat City by integrating field observations, topographic analysis, GIS-based mapping, and a Waterlogging Vulnerability Index (WVI). The results revealed substantial spatial variability in drainage performance and waterlogging susceptibility across the city. Elevation emerged as the most influential factor controlling water accumulation patterns, as evidenced by the strong negative correlation between elevation and WVI values ($r = -0.93$, $R^2 = 0.87$, $p < 0.001$). This finding indicates that approximately 87% of the observed variation in waterlogging vulnerability can be explained by topographic differences among surveyed locations, emphasizing the dominant role of terrain in urban hydrological processes.

The elevation analysis demonstrated that Balaghat City exhibits a distinct topographic gradient, ranging from 317.73 m at Shankar Ghat to 336.92 m at Devi Talab. Locations characterized by lower elevations, including Bhatera Railway Crossing (321.50 m), Moti Nagar (320.84 m), Chitragupta Nagar (323.00 m), Railway Station (323.60 m), and Narmada Nagar (322.93 m), consistently recorded higher WVI values and greater susceptibility to waterlogging. These observations support the concept that low-lying urban sectors function as natural runoff convergence zones where stormwater accumulates during rainfall events. Similar relationships between topography and flood susceptibility have been reported in studies conducted within the Wainganga Basin, where physiographic characteristics significantly influence runoff concentration, drainage behavior, and flood occurrence (Bhagat and Bisen, 2016; Bisen, 2021). Monsoon-dominated river systems commonly exhibit increased inundation risk in low-gradient terrains and local depressions due to prolonged water retention and slower drainage processes (Soni *et al.,* 2013).

The WVI assessment further highlighted the spatial distribution of vulnerability across Balaghat City. Bhatera Railway Crossing recorded the highest WVI value (4.65), followed by Moti Nagar (4.35), Chitragupta Nagar (4.30), Railway Station (4.00), and Hanuman Chowk (3.55). These locations were classified as highly vulnerable because they combined unfavorable topographic conditions with poor drainage performance, frequent water stagnation, and significant obstruction caused by sediment and waste accumulation. In contrast, elevated locations such as Devi Talab (1.00), Bus Stand Balaghat (1.35), Jay Stambh Chowk (1.35), Kali Putli Chowk (1.35), and Kali Path Mandir (1.70) exhibited low vulnerability, reflecting efficient runoff removal and comparatively better drainage conditions. The observed pattern confirms that vulnerability is not solely dependent on drainage infrastructure but is strongly influenced by the interaction between terrain characteristics and drainage efficiency.

The observations made during the study showed that the drainage system in Balaghat City generally facilitates the movement of stormwater. However, some sections of the drainage system are deficient due to localized failures. These failures are exhibited as sediment accumulation, growth of vegetation, debris build-up and partial blockage of drainage channels, especially in areas deemed highly susceptible to flooding. These deficiencies limit hydraulic performance by restricting the available capacity for flow and delaying the discharge of stormwater. Similar cases have been documented in Indian cities with rapidly growing urbanization, where the presence of blockage in the drainage systems is an important cause of urban waterlogging and pluvial flooding (Singh *et al.,* 2023). Kamraju *et al*. (2026) documented in an earlier study that blockage of drainage systems and lack of proper maintenance would result in a significant increase in the occurrence of waterlogging in Hyderabad, India. Singh and Singh and Lohani (2025) also verified that solid waste accumulation in drainage channels negatively impacts the performance of drainage systems and contributes to former flooding. This study indicates that similar processes are occurring in Balaghat City such that the inadequate maintenance of drainage systems is a contributing factor to localized accumulation of stormwater.

Urbanisation could also play a role in waterlogging vulnerability within the study area. Urban expansion, roads, commercial and residential construction convert natural permeable land into impervious areas of development. The conversion of permeable surfaces reduces infiltration and increases surface runoff from rainfall. Oswald *et al*. (2023) stated that the development of impervious surfaces dramatically alters urban water fluxes through increased runoff generation and decreased groundwater recharge. Further, Karunya and Babu (2026) have suggested that urbanisation increases the pressure on drainage systems by producing greater volumes of runoff than the current infrastructure can accommodate efficiently. Thus, the continued urbanisation of Balaghat City may exacerbate drainage issues unless stormwater infrastructure is upgraded to accommodate the additional volumes of runoff.

The hydrology associated with Balaghat enhances its vulnerability. Balaghat City exists in the Wainganga River Basin and experiences tropical monsoon weather patterns characterised by concentrated seasonal rainfall. Previous studies have also documented significant temporal and spatial variances in rainfall across the Wainganga Basin (Taxak *et al.,* 2014; Thakur *et al.,* 2020). Flood assessments conducted at Balaghat station indicate that intense rainfall from the monsoon contributes greatly to flooding and water accumulation. Recent evidence indicates that extreme climatic variability across central Indian river basins may be leading to an increase in the frequency and intensity of extreme rainfall events due to climate change (Singh *et al.,* 2025). Changes like this will likely create additional stressors on urban drainage systems and exacerbate the risk of waterlogging in vulnerable parts of the urban area.

The combination of both GIS field surveys as well as topographic analyses were very beneficial at identifying drainage bottlenecks and delineating vulnerable zones. The vulnerability map that was developed successfully identified areas that require priority intervention while also showcasing geospatial techniques for assessing the urban flood risk. Previous studies has also highlighted how important utilizing GIS for assessing drainage performance as well as providing evidence based stormwater management planning (Andimuthu *et al*. 2019; Gaurkhede and Adane 2024). This study builds on this previously mentioned research by showing how simple field derived datasets can produce meaningful assessments when used in conjunction with a GIS framework.

Overall, the vulnerability of waterlogging that exists within Balaghat City is resultant from a complex interaction between topography, urban runoff production, the condition of the drainage network, and climate. The strong relationship derived from statistical analysis between elevation and vulnerability supports the role of terrain being instrumental in the determine the patterns of where water accumulates. Further, the observations made in the field support deficiency of drainage along with human caused disruptions as components of waterlogging vulnerability. Therefore, waterlogging mitigation within Balaghat will involve both structural improvements to the drainage infrastructure as well as improved maintenance systems to maintain hydraulic efficiency.

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Future Scope

The present study is a starting point for determining the drainage performance and vulnerability due to waterlogging in Balaghat City, but there are many possibilities for further research and enhancement. To get more precise runoff modeling and flood forecasting, other research efforts should integrate higher-resolution digital elevation model (DEM) hyperspectral data, LiDAR, and detailed hydrodynamic models. Additionally, including intensity-duration-frequency (IDF) precipitation data and climate change forecasts into the evaluation of future flood exposure would assist in determining the flood hazards with predicted hydro-climatic changes over time. By implementing more advanced storm drains like SWMM, HEC-HMS, and HEC-RAS, the researchers could better understand the system's ability to drain water and move it through the storm drain system during heavy rain events. The investigations need to focus on how land use and land cover have changed runoff production and how remote-sensing technology can be used to evaluate those changes. By using a combination of sensor-based systems, IoT devices, and real-time flooding warning systems, the infrastructure would be continuously monitored to help prepare and respond better to flooding in urban environments. Moreover, social-economic vulnerability assessments should be used with physical vulnerability mapping to help to identify populations and dwellings at greater risk of flooding due to waterlogging. The methodology that will be developed in this study can be expanded and used for several rapidly developing communities within the Wainganga basin and other similar monsoonal-based areas, supporting sustainable urban stormwater management practices and creating climate-resilient planning for cities.5.

Conclusion

This study assessed the level of effectiveness of urban drainage in the city of Balaghat, Madhya Pradesh, regarding its ability to handle waterlogging impacts using the combination of field surveys, geographic information systems (GIS)-based topographic analysis, and a Waterlogging Vulnerability Index (WVI). Results of this work show while the city's present drainage system allows stormwater (or rainfall) to be transported from some locations throughout the city, the presence of local site constraints on drainage such as sediment accumulation, waste accumulation, vegetative growth, and physical impediments to flow significantly decreases the drainage system's ability to function at various locations throughout Balaghat. A topographic analysis indicated a pronounced change in elevation from the low point at 317.73 m above mean sea level to 336.92 m above mean sea level, which greatly impacts the movement of runoff and the patterns of stormwater accumulation.

A statistically significant correlation between elevation and waterlogging vulnerability based upon analysis of the WVI data ($R^2 = 0.87$; $r = -0.93$) was confirmed, indicating that low land areas are more likely to have a higher incidence of water accumulation. Based upon this correlation, four specific areas were identified with high vulnerability to water accumulation: Bhatera Railway Crossing, Moti Nagar, Chitragupta Nagar, and the area adjacent to the Railway Station – along with a general area surrounding Hanuman Chowk – all of which are located in low-lying areas, and all of which have constraints to drainage. The combination of GIS analysis and field observations allowed researchers to clearly identify drainage deficiencies, and develop maps of vulnerable areas, and showed the relationship between topography and drainage performance.

This study serves as a scientific basis for determining the priority of drainage management interventions; routine system maintenance; improvement of continuous flow; and for developing urban plans that are informed by topographic conditions. The overall methodology developed in this research may provide a framework for analysing urban drainage conditions and vulnerabilities related to water-logging that will be applicable as cities develop and face similar stormwater management challenges.

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