

ORIGINAL RESEARCH ARTICLE

Low-impact development and sponge city adaptation for urban stormwater retention in Dhaka: Assessing the Hatirjheel–Gulshan–Banani lake system

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Abstract

Urban flooding in Dhaka, Bangladesh, is intensified by rapid urbanization, loss of permeable land, and constrained drainage. This study evaluates the Hatirjheel–Gulshan–Banani lake system using low-impact development (LID), water-sensitive urban design (WSUD), and sponge city principles. Multi-year satellite mapping was retained to describe urbanization between 2010 and 2024; however, the hydrological contribution of LID was assessed through a paired single-year analysis, holding urbanization constant. The runoff assessment used the 2024 land-use condition reported for the local drainage system: 56.43% built-up land, 32.11% open and cultivated land, and 11.46% water bodies and wetlands, producing an existing composite runoff coefficient of 0.534. The LID scenario kept the same land use, catchment areas, and rainfall intensities, but assumed that 30% of existing built-up surfaces received permeable or vegetated treatment with a planning-level treated-surface coefficient of 0.25. The resulting composite coefficient was 0.475. For the five-year design event, estimated peak discharge decreased from 87.89 to 78.14 m³/s in the 19.00 km² Hatirjheel sub-catchment and from 53.16 to 47.26 m³/s in the 8.27 km² Gulshan–Banani sub-catchment, corresponding to an 11.1% reduction in each case. A sensitivity range for treated-surface coefficients of 0.20–0.35 yielded peak-flow reductions of 7.9–12.7%. The result is therefore presented as a planning-level scenario estimate rather than measured field performance. The study identifies permeable paving, vegetated swales, bioretention, pocket wetlands, rainwater harvesting, and restoration of lake–canal connections as locally appropriate measures. LID should complement, rather than replace, conventional drainage and regular maintenance.

Keywords: Low-impact development; Sponge city; Water-sensitive urban design; Urban flooding; Stormwater retention; Land-use change; Green–blue infrastructure

1. Introduction

Cities around the world, especially in the tropics, deal with regular flooding and blocked drains. As more land is paved and rainfall becomes less predictable, surface runoff rises, and the natural water cycle breaks down.¹ Traditional pipe-and-channel drainage systems often cannot cope in dense cities, so there is a growing push for greener, more distributed approaches.

Low-impact development (LID) is one such approach. It is also called sustainable Urban drainage systems in the United Kingdom, water-sensitive urban design (WSUD) in Australia, and sponge city in China.² All these names describe the same basic idea: design cities so that rainwater soaks in, slows down, or is stored near where it falls, rather than being rushed away through concrete pipes. LID tools include green roofs, rain gardens, bioretention cells, permeable pavements, vegetated swales, and detention wetlands.^{3,4} It is worth noting that although China introduced the term “sponge city” in 2013 as part of its national urban policy,⁵ the underlying ideas behind LID were developed earlier and independently in many countries.

These ideas have been implemented globally. Germany has built distributed retention and infiltration systems into its planning laws to prevent sewer overflows.⁶ Australia has made WSUD part of planning rules in Melbourne and Brisbane to manage both the quantity and quality of stormwater.⁷ Singapore's Active, Beautiful, Clean Waters (ABC Waters) Programme blended WSUD with good urban design, showing clear drops in runoff and better water quality in a tropical climate like Dhaka's.⁸ A Dhaka-based study has also evaluated source-control infiltration measures under monsoon conditions, with promising runoff-control results.⁹ Despite all this, limited research has investigated LID in fast-growing South Asian delta cities like Dhaka, where the land is flat, groundwater is high, population density is extreme, and government capacity is limited. That gap is significant.

Dhaka, the capital of Bangladesh, floods regularly during the monsoon. The city gets roughly 1,500 to 2,000 mm of rain a year, and 70%–80% of that falls between June and September. With 25–30 million people and unplanned growth, Dhaka experiences annual waterlogging because drains are undersized, natural canals have been filled or narrowed, and more land is being paved.¹⁰ To make things worse, annual rainfall at the Dhaka weather station has risen from about 1,600 mm in 1980 to about 2,250 mm by 2023, a 40% increase. That rising rainfall adds to the flooding risk on top of what land-use change alone causes.

Dhaka was historically built on a raised area surrounded

by rivers, with many natural canals that drained away excess rain. Three lake systems, Hatirjheel, Gulshan, and Banani, played an important role in holding water during storms. However, rapid urban growth has replaced open land and wetlands with hard surfaces, sending more water into the lakes faster than they can handle.¹¹ In response, the Hatirjheel–Gulshan–Banani lake system was developed as a major stormwater storage and drainage structure. Hatirjheel was completed in 2013 and designed to collect runoff from the surrounding area and slowly release it into the downstream rivers.¹² More than 10 years on, questions remain about how well it is working. Field surveys show that silt build-up, illegal encroachment on the banks, and poor maintenance have reduced its storage and drainage capacity.¹³

Despite being one of Dhaka's most important stormwater assets, the Hatirjheel–Gulshan–Banani system has never been studied as a whole using both spatial mapping and flood modeling under LID principles over the period 2010 to 2024. That is the gap this study fills. The work combines land-cover change analysis, drainage mapping, and rainfall–runoff modeling in a geographic information system (GIS)-based framework to assess how rising hard surfaces affect flooding and identify LID tools that could help.

The study investigates three ideas: first, that surface runoff has risen significantly between 2010 and 2025 because of more hard surfaces in the catchment; second, that the lakes' ability to store water has dropped because of silt and encroachment; and third, that LID tools, such as permeable paving, detention wetlands, and green roofs, can reduce peak runoff by 10–15% during monsoon storms. The findings provide city planners and engineers at the Dhaka North City Corporation (DNCC) and Rajdhani Unnayan Katripakha (RAJUK) a clear, number-based case for investing in green drainage. The method can also be applied to other cities facing the same pressures.

2. Materials and methods

This section describes the study area, data sources, and the analytical framework used to assess land-cover change, flood risk, and the potential of LID in the Hatirjheel–Gulshan–Banani catchment. The methodology combined five components: (i) GIS-based land-cover mapping from multi-year satellite imagery; (ii) flood-risk zone mapping using elevation and drainage data; (iii) runoff modeling under three land-use scenarios using the rational method; (iv) lake retention capacity assessment; and (v) hydrological connectivity mapping.

Figures 1 and 2 show the ground-level photograph of Hatirjheel Lake and the master plan of Hatirjheel across

Dhaka City.

2.1. Study area: The three-lake system

The study area is situated in the low-lying deltaic country of Bangladesh, located at the confluence of the Ganges, Brahmaputra, and Meghna rivers in South Asia. Bangladesh is located in the heart of the globe, between 20° 34' and 26° 38' north latitude and 88° 01' and 92° 41' east longitude, with an area of about 147,570 km². Dhaka is the national capital of Bangladesh and is situated in the central part of Bangladesh in the Dhaka Division. The city is situated on the low-lying floodplain bordered to the west by the Buriganga River, to the north and north-west by the Turag River, to the east by the Balu River, and to the south-east by the Shitalakhya River (national inset in Figure 3). The city of Dhaka is one of the most densely populated cities in the world, with a population of about 25–30 million in the metropolitan region. Due to its low elevation (most of the city lies below 10 m above mean sea level), the monsoon climate, and rapid urbanization, the city is extremely vulnerable to flooding. The lake system Hatirjheel–Gulshan–Banani is among the most valuable

stormwater management resources in the northern part of the city.

The study focused on the interconnected lake system of Hatirjheel–Gulshan–Banani in Dhaka City, Bangladesh. The lakes sit between roughly 23° 46' and 23° 48' north and 90° 24' and 90° 26' east (Figure 3). They are located in the middle and northern parts of the city of Dhaka, just adjacent to the Tejgaon industrial area to the west, Airport Road housing belt to the north, and Badda–Baridhara residential area to the east. The entire catchment area of the study is approximately 23.2 km².

Aerial and ground views of the lowland of the Hatirjheel during the rainy season (July 2004) and dry season (February 2005) show a substantial shift in water level between the two seasons (Figure 4).

Figure 3 shows a georeferenced map of all three lakes with their catchment boundaries marked, plus a national inset map in the corner showing where Dhaka sits relative to the Buriganga, Turag, Balu, and Shitalakhya rivers. All maps include coordinate grid lines, a north arrow, and a graphic scale bar.

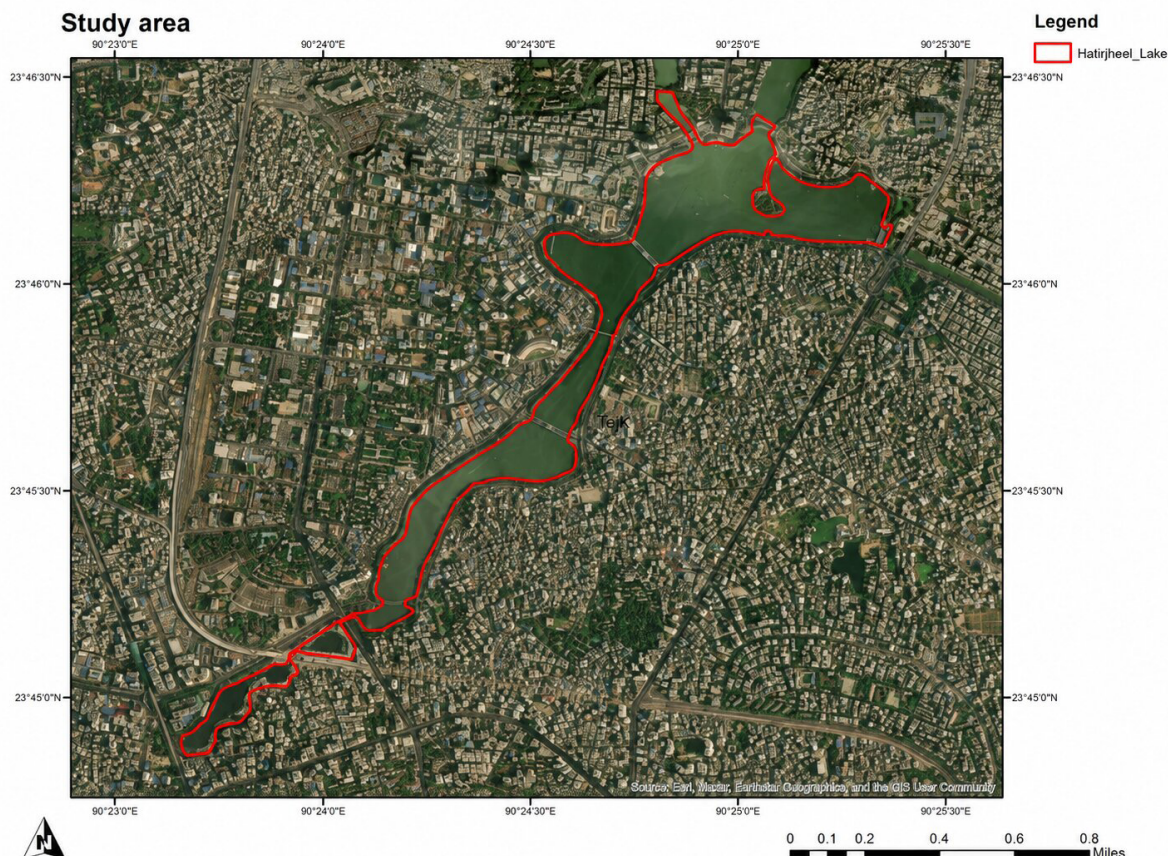


Figure 1. Ground-level image of Hatirjheel Lake

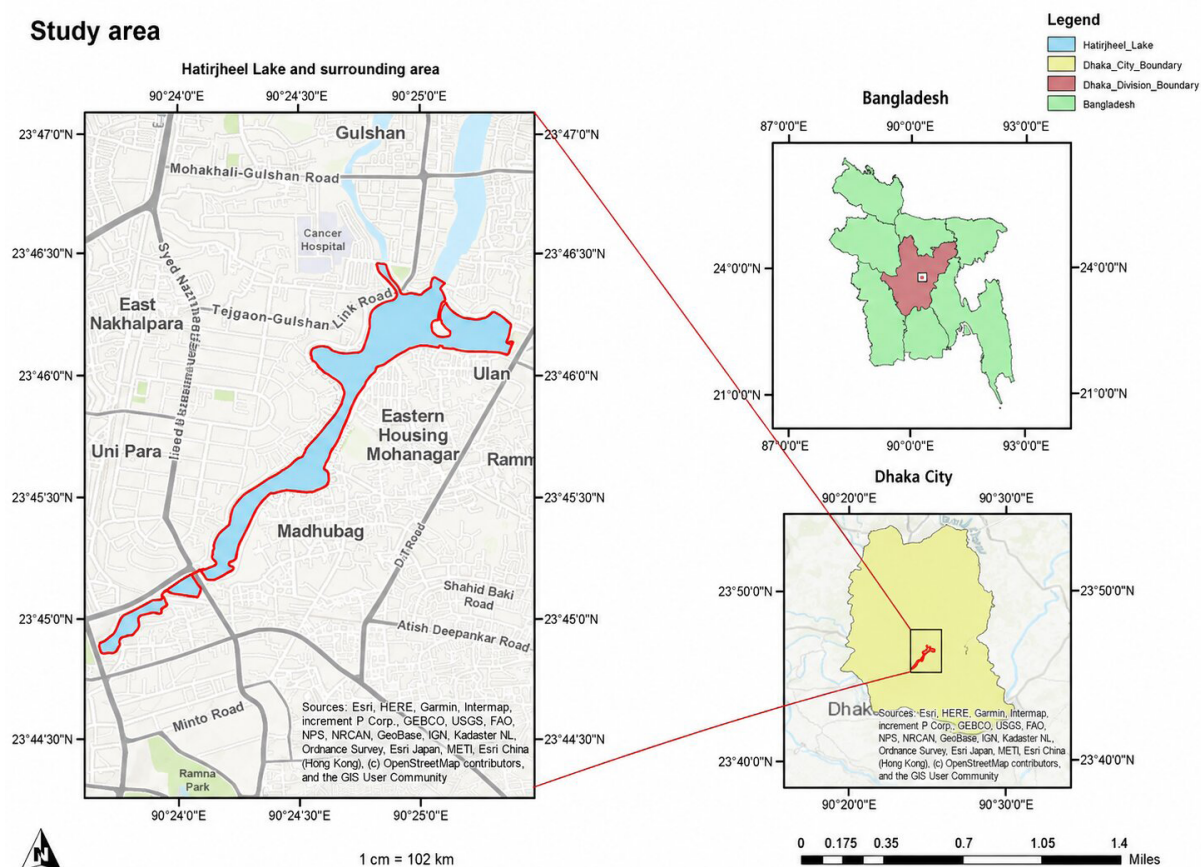


Figure 2. Master plan of Hatirjheel across Dhaka City. This schematic was remade at 300 dpi with all map labels set to a minimum of 8 pt. A north arrow and a graphic scale bar (km) were added. A two-panel regional locator inset was also inserted, showing Bangladesh within South Asia (left panel) and Dhaka Division with the study catchment boundary (right panel).

- Hatirjheel Lake (Figure 1; about 3.0 km² at normal water level, +5.5 m Public Works Datum [PWD]) gets most of its water from the Tejgaon–Rampura–Banasree area through a built drainage network. In the past, extra inflow came from Begunbari Khal, which connects to the Balu River during high-water periods. The lake acts mainly as an urban retention pond with controlled inlet and outlet structures. In the dry season, the storm drains feeding the lake carry mostly sewage and industrial wastewater. In the monsoon, the same pipes carry a mix of stormwater and wastewater that often floods low-lying areas nearby (Figure 4A and 4B). The Rampura flood gate is kept closed for two to three months each monsoon to stop river water from pushing back into the city, making Hatirjheel's storage role even more critical.
- Banani Lake (Figure 3C; about 0.7 km²) is fed mainly by stormwater runoff from the Banani–Kakoli–Airport Road area through built drainage pipes. It exchanges water seasonally with Gulshan Lake

through a network of canals. The lake has little direct river inflow and behaves mostly as a closed urban water body.

- Gulshan Lake (Figure 3B; about 1.2 km²) receives water mainly from the Badda–Baridhara sub-catchment in northeast Dhaka, which is bounded roughly by Progoti Sarani to the north and Gulshan Avenue to the south. Water reaches the lake through natural and modified canals (khals) and urban storm drains. Gulshan Lake is connected to Banani Lake through internal canal links. Because the catchment is heavily paved, almost all the water entering the lake comes from runoff, with very little groundwater flow.

2.2. Data collection

The study used both field data and secondary datasets to keep the analysis well-grounded.

- Primary data: Field visits to Hatirjheel and the nearby lakes were conducted in 2024. The team checked drainage connections, areas of encroachment, and



Figure 3. The three major lakes in Dhaka City: (A) Hatirjheel, (B) Gulshan, and (C) Banani lakes

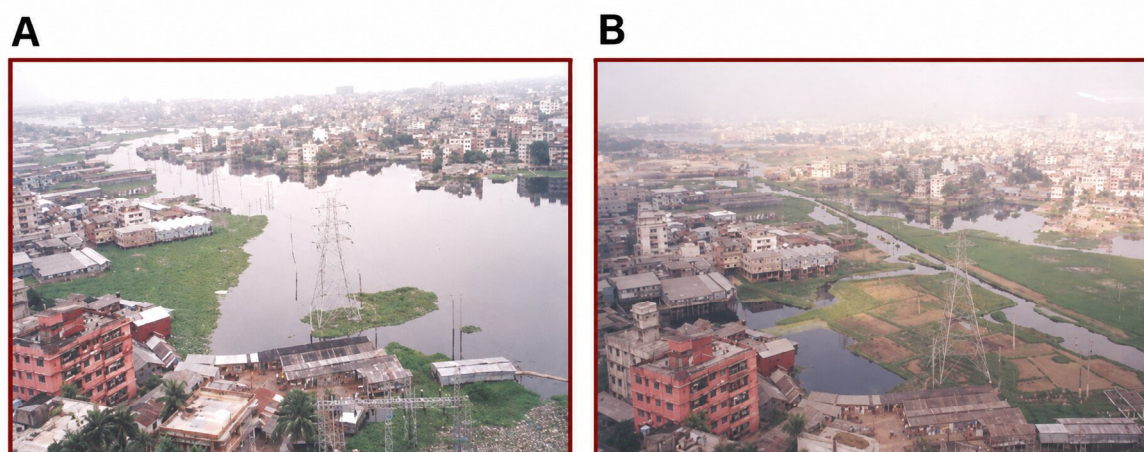


Figure 4. The view of Hatirjheel lowland during (A) rainy (July 17, 2004) and (B) dry (February 17, 2005) seasons

sediment levels. Photos and global positioning system readings were taken at key points to record conditions on the ground.

- Secondary data: The main datasets included: (i) satellite images from Landsat 5 Thematic Mapper, Landsat 8 Operational Land Imager/Thermal Infrared Sensor, and Sentinel-2 Multispectral Instrument for the years 2000, 2010, 2020, and 2024, downloaded from the United States Geological Survey Earth

Explorer (<https://earthexplorer.usgs.gov>) and the Copernicus Data Space Ecosystem (<https://dataspace.copernicus.eu/>). All images were taken during the dry season (January to March), when cloud cover is low, and were aligned to World Geodetic System 84, Universal Transverse Mercator Zone 46N (European Petroleum Survey Group: 32646). Landsat path and row: 136/043; Sentinel-2 tile: 45QXE. (ii) Drainage and topographic maps from RAJUK and DNCC

(2020, shapefile format). (iii) Rainfall records (1990 to 2024) and water level data (2005 to 2024) from the Bangladesh Meteorological Department and Bangladesh Water Development Board (BWDB). (iv) Urban planning documents from the Dhaka Water Supply and Sewage Authority (DWASA) and the published Hatirjheel detention study.¹⁴ Table 1 shows the full list of datasets.

2.3. Analytical tools and techniques

Data were processed using several analytical tools, and conclusions were drawn. A sequence of flows is presented as a step-by-step flowchart (Figure 5) from raw satellite images through land-cover classification and flood modeling to flood-risk mapping, and finally to LID scenario testing. Each component of the analytical framework is explained

in the six sub-sections.

2.3.1. Geographic information system-based land-cover mapping

Four land cover classes were classified from satellite images using the maximum likelihood method in ArcGIS (10.8, Esri, USA): built-up, vegetation, open or bare land, and water. The training samples for the classifier were chosen from each image year, assisted by field knowledge and visual interpretation of high-resolution base maps. The 50 ground-truth points for each image year were then selected randomly and independently of the training points, and post-classification accuracy was evaluated. These validation points did not form part of the training or adjustment of the classifier, but were used only to test predictive accuracy as recommended by Congalton and

Table 1. Datasets used in the study

Data type	Source	Acquisition period	Format	Purpose
Landsat 5 TM imagery	USGS Earth Explorer ¹⁵	January–March 2000; January–March 2010 (Path 136, Row 043)	GeoTIFF (WGS84 UTM 46N)	Land-cover mapping and change detection
Landsat 8 OLI/TIRS imagery	USGS Earth Explorer ¹⁵	January–March 2020; January–March 2024 (Path 136, Row 043)	GeoTIFF (WGS84 UTM 46N)	Land-cover mapping and change detection
Sentinel-2 MSI imagery	Copernicus Data Space Ecosystem ¹⁶	January–March 2015; January–March 2024 (Tile 45QXE)	GeoTIFF (WGS84 UTM 46N)	Fine-scale spatial analysis
Drainage and topographic maps	RAJUK; DNCC (2020)	2020	Shapefile	Drainage and catchment mapping
Rainfall data	Bangladesh Meteorological Department	1990–2024	CSV	Trend and time-series analysis
Water level data	Bangladesh Water Development Board	2005–2024	CSV	Hydrological trend analysis
Field observations	Authors' survey	2024	Photos, GPS	Verification of drainage conditions and model results
Hatirjheel project documentation	Akter <i>et al.</i> ¹⁴ detention study	2015	Conference paper	Retention capacity parameters
Groundwater data	Akram <i>et al.</i> ¹⁷ review	Published 2024	Review article	Groundwater trend analysis

Notes: All images were acquired during the dry season (January–March) to minimize cloud cover; All datasets were projected to WGS 84 UTM Zone 46N (EPSG: 32646).

Abbreviations: DNCC: Dhaka North City Corporation; EPSG: European Petroleum Survey Group; GPS: Global positioning system; MSI: Multispectral Instrument; OLI/TIRS: Operational Land Imager/Thermal Infrared Sensor; RAJUK: Rajdhani Unnayan Katiripakkha; TM: Thematic Mapper; USGS: United States Geological Survey; UTM: Universal Transverse Mercator; WGS: World Geodetic System.

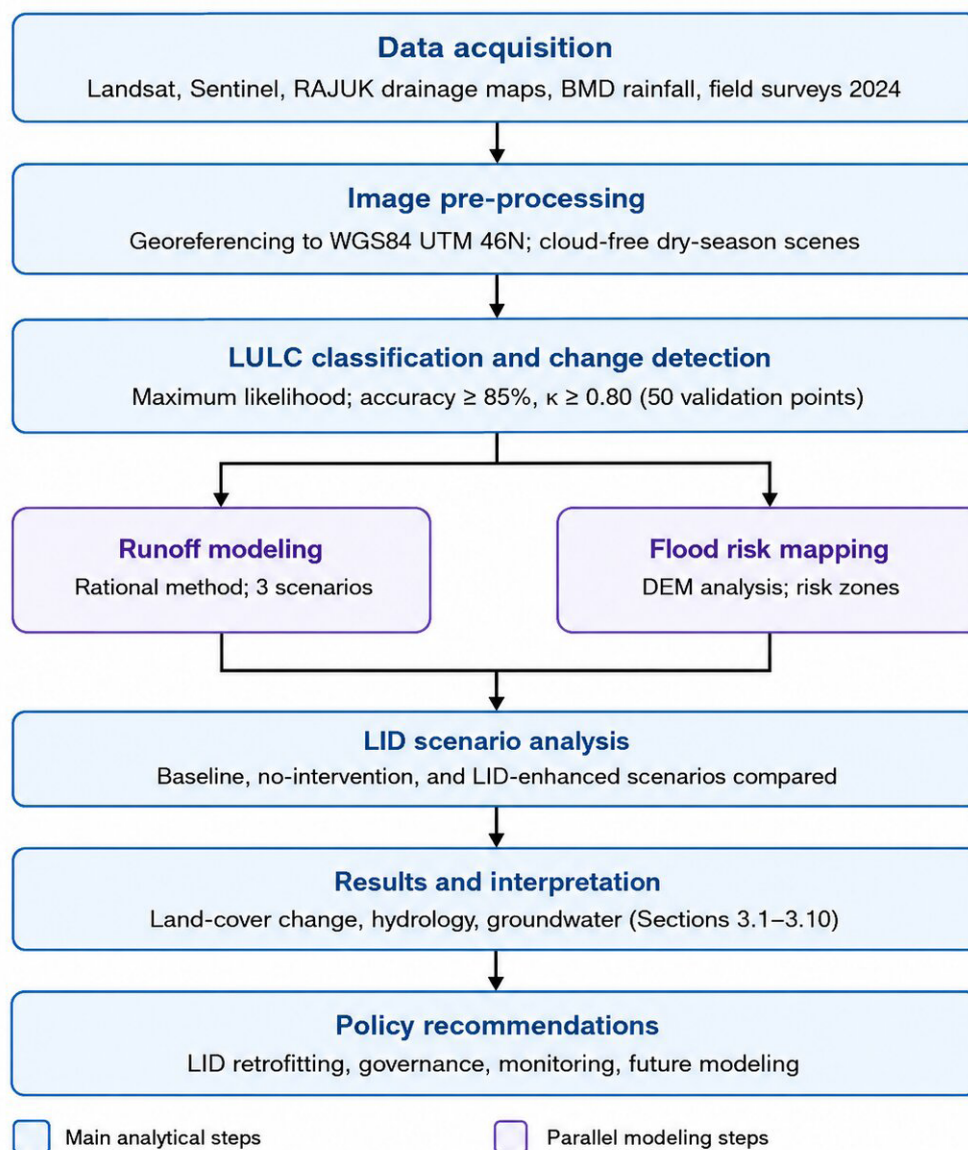


Figure 5. Methodological flowchart

Abbreviations: BMD: Bangladesh Meteorological Department; DEM: Digital elevation model; LID: Low-impact development; LULC: Land use/land cover; RAJUK: Rajdhani Unnayan Katripakkhya; UTM: Universal Transverse Mercator; WGS: World Geodetic System.

Green.¹⁸ Results showed overall accuracy of 85% or higher, and a kappa coefficient of 0.80 or higher across all four image years, which are acceptable for studies involving land use/land cover classification. It is recognized that a 100% split-sample design (i.e., training–validation split with separate confusion matrices for training and validation data) would be more stringent; this is suggested for further study. The classification maps were compared across years to identify changes. The flood-prone areas were determined using 30 m Shuttle Radar Topography Mission elevation data and flow-accumulation tools. The same elevation data were

then used to delineate watershed boundaries to define the catchment areas for the flood model (Figure 5).

2.3.2. Flood-risk mapping

Flood-risk zones were delineated by combining elevation-based flow accumulation maps, drainage network files, and hard-surface layers. Sub-catchments were defined using ArcGIS watershed tools. Any area where runoff during a 50 mm/h design storm would overflow local canals was marked as high risk. Areas with a moderate chance of overflow were marked as medium risk, and the rest as

low risk. Population density data were added to identify which high-risk areas have the highest population density. This map guided the selection of priority areas for LID retrofitting.

2.3.3. Paired single-year runoff modeling with the rational method

To isolate the modeled LID contribution from urbanization, peak discharge was evaluated in two paired scenarios that represent the same 2024 land-use condition. The rational method was applied in SI units as $Q = 0.278 CiA$, where Q is the peak discharge (m^3/s), C is the dimensionless composite runoff coefficient, i is the rainfall intensity (mm/h), and A is the drainage area (km^2). The Hatirjheel and Gulshan–Banani sub-catchments were analyzed separately because their drainage areas and rainfall intensities differ.

The existing composite coefficient was calculated from the 2024 land-use proportions and coefficients reported in a Bangladesh University of Engineering and Technology drainage-capacity study. The LID scenario retained the same total built-up area and divided it into untreated and treated portions. Therefore, LID is represented as a change in hydrological response within existing urban land, not as a reduction in urbanization. Table 2 shows the land use and runoff coefficient inputs for the paired 2024 scenarios.

The existing-condition composite runoff coefficient was calculated as follows: $C_{\text{existing}} = (0.60 \times 0.5643) + (0.25 \times 0.3211) + (1.00 \times 0.1146) = 0.534$. For the central LID scenario, 30% of the existing built-up land was assumed to receive treatment. The treated fraction of the total catchment was $0.5643 \times 0.30 = 0.16929$. The LID composite coefficient was $C_{\text{LID}} = 0.534 - [0.16929 \times (0.60 - 0.25)] = 0.47475$, rounded to 0.475 for reporting. The 2024 existing and LID scenarios used identical land-use totals, drainage areas, return period, and rainfall intensities. Only the runoff coefficient of the treated portion changed.

The five-year rainfall intensities adopted from the local drainage study were 31.16 mm/h for Hatirjheel and 43.30 mm/h for Gulshan–Banani. Their corresponding drainage areas were 19.00 and 8.27 km^2 . The two sub-catchment peaks were reported separately because the available data do not indicate simultaneous peak discharges. The rational method provides a planning-level estimate of peak flow and does not represent storage routing, pipe hydraulics, water quality, or continuous storm response.

Since both simulations use one fixed year and identical rainfall and catchment inputs, the calculated difference represents the modeled effect of the specified LID retrofit within this simplified framework. It is not a measured field reduction. Future monitoring and a calibrated stormwater management model (SWMM) or hydrologic engineering center–hydrologic modeling system (HEC–HMS) are required to test actual performance and route flows through lakes, canals, and sewer pipes.

2.3.4. Retention capacity assessment

The storage volume of each lake was computed as shown in Equation 1:¹⁴

$$V = (L_c - L_i) \times A_w \quad (1)$$

where V is the detention volume (m^3) of the lake, L_c is the upper water level (m PWD), L_i is the lower water level (m PWD), and A_w is the lake surface area (m^2) at the water level. The useful detention range was determined by calculating volumes at + 5.5 m PWD (design high level) and + 2.5 m PWD (dry season minimum).

2.3.5. Hydrological connectivity

Eleven major storm sewer outfalls, the canals connecting Gulshan and Banani lakes, and the downstream flow path through the control gate into Begunbari Khal and Balu River were traced to map the drainage connections.

Table 2. Land use and runoff coefficient inputs for the paired 2024 scenarios

Land-use component	2024 area (%)	Existing C	LID-scenario C/treatment	Source or role
Built-up: untreated portion	56.43% total	0.60	0.60 on the untreated portion	Afrin <i>et al.</i> ¹⁹
Built-up: LID-treated portion	30% of built-up (16.929% of total)	Included in the built-up	0.25 central case (0.20–0.35 sensitivity)	Planning-level retrofit proxy
Open and cultivated land	32.11%	0.25	0.25	Afrin <i>et al.</i> ¹⁹
Water bodies and wetlands	11.46%	1.00	1.00	Afrin <i>et al.</i> ¹⁹

Notes: The treated-surface coefficient of 0.25 is a planning-level proxy representing a mixed permeable and vegetated retrofit response; Because it is not a field-calibrated coefficient for one specific LID technology, sensitivity tests were conducted using treated-surface coefficients of 0.20, 0.25, 0.30, and 0.35. Abbreviations: C: Composite runoff coefficient; LID: Low-impact development.

Rainfall depth (R), catchment area (A_c), and runoff coefficient (r) were used to estimate inflow volumes based on Equation 2:²⁰

$$Q = R \times A_c \times r \quad (2)$$

A limitation of the study should be mentioned: inflow volume was not analyzed by individual sewer pipes or their capacity. DWASA pipe network information should be added to future assessments.

2.3.6. Time-series analysis

Rainfall and water level records were sorted and analyzed using Excel (2024, Microsoft Corporation, USA), and summary statistics were calculated; water level trends were plotted, showing variations by season and year. The baseline was the current land-use state (2010), which was ~40% hard surfaces and $C = \sim 0.60$, while the forward scenario was the projected land-use state by 2025 (~50% hard surfaces, $C = \sim 0.75$).

3. Results

3.1. Land-use change (2010 to 2024)

The land-cover analysis (Table 3 and Figure 6) shows clear and steady urban growth in the Hatirjheel–Gulshan–Banani catchment. Between 2010 and 2024, built-up land grew by 30–35%. Green areas and bare land shrank by roughly the same amount. Hard surfaces now cover 50–55% of the catchment. This matches a wider Dhaka study that found 51% impervious cover by 2020.²¹ The Gulshan and Banani areas are now almost fully urbanized, whereas the area immediately surrounding Hatirjheel still retains parks and lower-density uses.

This shift in land cover pushed the runoff coefficient from about 0.60 in 2010 to about 0.75 by 2025 (Table 4). Increased hard surfaces are associated with more runoff, less water soaking into the ground, and less natural storage. Other research on South Asian cities has shown the same pattern.^{21,22} Field surveys in 2024 also confirmed a visible loss of canal width due to silting and illegal construction, further exacerbating the drainage problem. All of these point to the need to retrofit LID tools across the catchment.

Accuracy was checked using 50 ground-truth points per year, with overall accuracy above 85% and kappa above 0.80, meeting accepted standards. However, there is some uncertainty in the exact hard-surface figures because Landsat's 30 m resolution can mix urban and bare-soil land types; this is a known limitation in satellite-based mapping.

3.2. Drainage and flood-risk mapping

Flood-risk zones were mapped by combining elevation data, drainage network files, and hard-surface layers as

explained in Section 2.3.2. The output identifies where a 50 mm/h storm would overflow local canals. The most at-risk spots are in southern Banani and along the northeastern end of Hatirjheel, where narrow canals flow through dense development. In the 2025 no-intervention scenario, water would back up in local drains before reaching Hatirjheel, flooding nearby streets. The central part of Gulshan Lake provides natural buffering that helps slow the peaks.

The 2010 baseline shows a peak flow of about 0.90×10^6 m³/h at the Hatirjheel inlet. By 2025, without any action, this rises to about 1.13×10^6 m³/h, a 25% increase. Without more storage, this extra flow would flood blocks in Banani (Figure 7). Three drainage bottlenecks stand out: the channel at the south end of Banani Lake, the feeder canal from Gulshan-2, and the outfall pipes along the northern edge of Hatirjheel. Clearing and widening these are top priorities.

3.3. Rainfall and runoff trends

Rainfall in Dhaka has been climbing steadily over the study period, rising from about 1,600 mm per year in 1980 to about 2,250 mm by 2023, a 40% increase (Figure 8). At the same time, peak runoff has grown faster and lag time has shortened. This shows the catchment is responding more sharply to each storm, mainly because of more hard surfaces and less infiltration.

It is important to note that rising rainfall itself increases flood risk, independent of land-use change. The 25% increase in peak flow shown in Table 5 is due solely to land-cover change, with rainfall intensity held fixed. If the full upward rainfall trend were also built into the model, peak flows would be even higher. This means the risk figures in Table 5 are conservative. The combined pressures of expanding impervious surfaces and increasing rainfall act synergistically to elevate flood risk well beyond the effects of either factor individually.^{1,23}

3.4. Paired single-year low-impact development scenario results

The paired 2024 assessment produced an existing-condition composite runoff coefficient of 0.534 and a central LID-scenario coefficient of 0.475. In the 19.00 km² Hatirjheel sub-catchment, with a five-year rainfall intensity of 31.16 mm/h, peak discharge decreased from 87.89 to 78.14 m³/s. In the 8.27 km² Gulshan–Banani sub-catchment, with a five-year rainfall intensity of 43.30 mm/h, peak discharge decreased from 53.16 to 47.26 m³/s. The reduction was 11.1% in both cases because the same proportional change in C was applied while rainfall and area remained fixed within each sub-catchment.

Sensitivity testing showed that the result depended

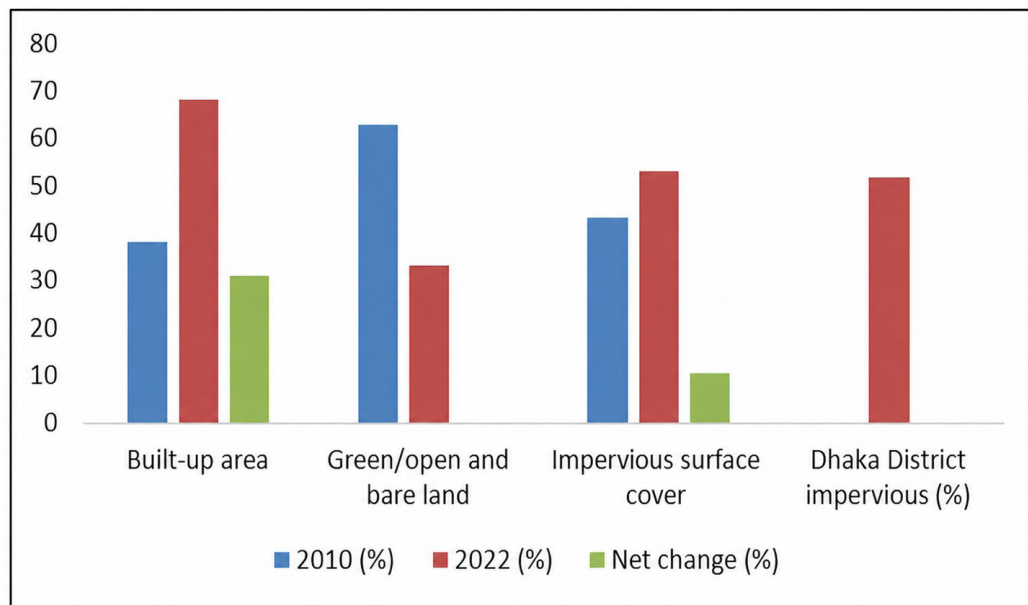


Figure 6. Land-cover percentages in the Hatirjheel–Gulshan–Banani catchment, 2010 to 2024

Table 3. Land-cover change in the Hatirjheel–Gulshan–Banani catchment, 2010 to 2024

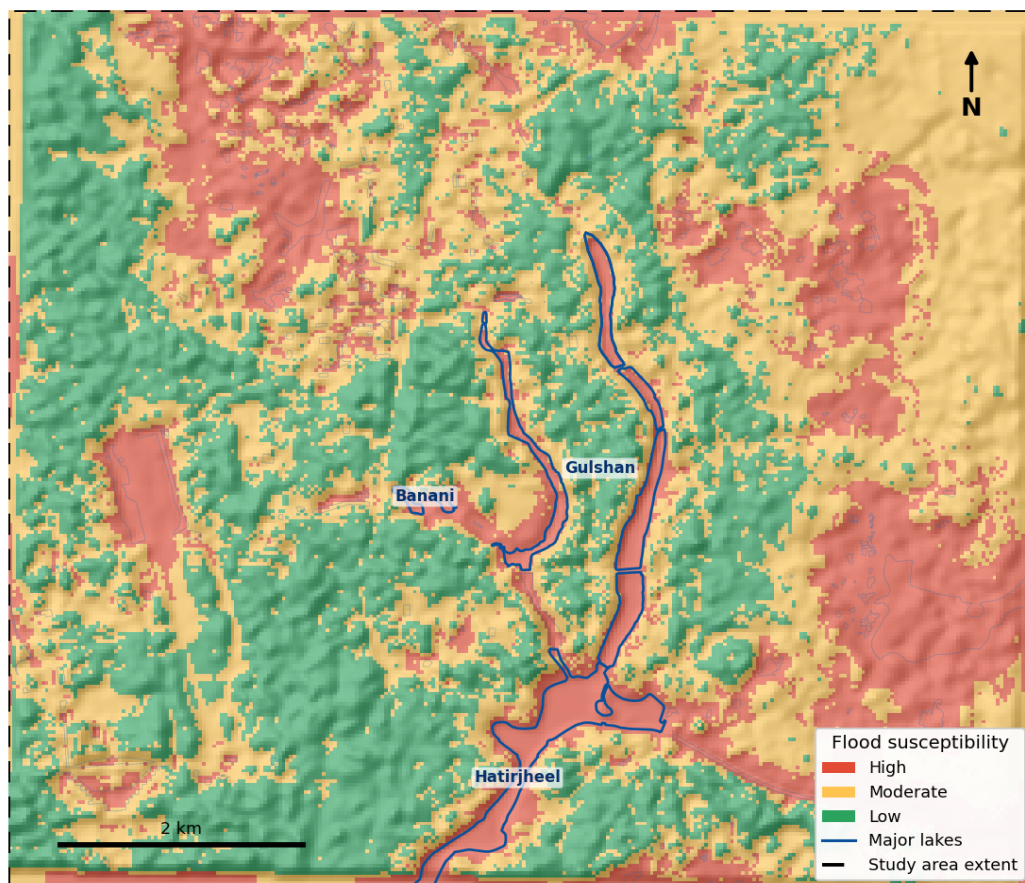
Parameter	Change (2010–2024)	Notes
Built-up area	+30–35%	Steady growth in Gulshan, Banani, and Tejgaon corridors
Green and open land	–30–35%	Wetlands and open fields converted to urban use
Hard surface cover	+10–15% (from 40–45% to 50–55%)	Roads, rooftops, and paved surfaces, consistent with district-wide data
Dhaka District hard surfaces (reference)	51% by 2020	District-level figure from Moniruzzaman <i>et al.</i> , ²¹ confirming local estimates

Table 4. Changes in catchment hydrology resulting from urbanization

Hydrological factor	2010 baseline	2025 projected	Change	Indications
Runoff coefficient	0.60	0.75	+0.15 (25% increase)	More rain becomes runoff under the same storm
Infiltration capacity	Moderate	Reduced	Clear drop	Less groundwater recharge, more overland flow
Surface storage	Higher	Lower	Reduced	Less room to hold water on site
Flow pattern	Spread out	Concentrated	More concentrated	Higher flood peaks at lake inlets

on the assumed performance of the treated surfaces. For treated-surface coefficients of 0.20, 0.25, 0.30, and 0.35, the catchment composite C values were approximately 0.466, 0.475, 0.483, and 0.492, corresponding to peak-flow reductions of about 12.7%, 11.1%, 9.5%, and 7.9%, respectively. This range was reported to avoid presenting the central coefficient as a locally calibrated measurement.

The calculation indicated that distributed LID retrofits reduced the estimated design peak, but the result did not quantify detention routing through the lakes or hydraulic restrictions in individual sewer pipes. Consequently, LID was interpreted as a complement to canal restoration, outfall maintenance, dredging, and conventional drainage upgrades.



AHP-weighted multi-criteria overlay (elevation 0.47, distance-to-water 0.28, drainage density 0.16, slope 0.09; CR=0.01) on Copernicus GLO-30 DEM. Base: DEM hillshade. Illustrative — land use/imperviousness not included; 30 m surface model over flat urban terrain; not a calibrated hydrodynamic flood model.

Figure 7. Flood susceptibility of the Hatirjheel–Gulshan–Banani lake system assessed via analytic hierarchy process-based multi-criteria evaluation of four conditioning factors (elevation, slope, distance to water bodies, drainage density) derived from the Copernicus GLO-30 digital elevation model and OpenStreetMap water layers, combined by weighted overlay (weights 0.47/0.28/0.16/0.09; consistency ratio = 0.01) and classified into low, moderate, and high zones by natural breaks.

Note: Analysis resolution: 30 m.

Table 5. Paired 2024 peak-discharge results under existing and LID-retrofit conditions

Sub-catchment	Area (km ²)	Rainfall intensity (mm/h)	Existing: C; Q (m ³ /s)	With LID: C; Q (m ³ /s)	Reduction
Hatirjheel	19.00	31.16	0.534; 87.89	0.475; 78.14	11.1%
Gulshan–Banani	8.27	43.30	0.534; 53.16	0.475; 47.26	11.1%

Notes: The analysis year, land-use totals, rainfall intensity, return period, and drainage area were fixed between paired scenarios; The treated-surface coefficient was a planning assumption, and the results are not field-calibrated measurements.

Abbreviations: C: Composite runoff coefficient; LID: Low-impact development; Q: Peak discharge.

3.5. Spatial analysis of the lake system

Satellite imagery confirmed rapid urban expansion across the catchment, mainly along the Gulshan, Banani, and

Tejgaon corridors. Green land had shrunk, and hard surfaces had expanded. As a result, less rain soaks into the ground, and more reaches the lake system as runoff. The three water bodies themselves did not shrink noticeably,

but the pressure on them and their connecting canals has grown substantially. Table 3 presents the numbers, and Figure 9 shows the change maps.

3.6. Time-series trends

Year-by-year satellite imagery from 2010 to 2024 showed a steady shift from open and green land to buildings and

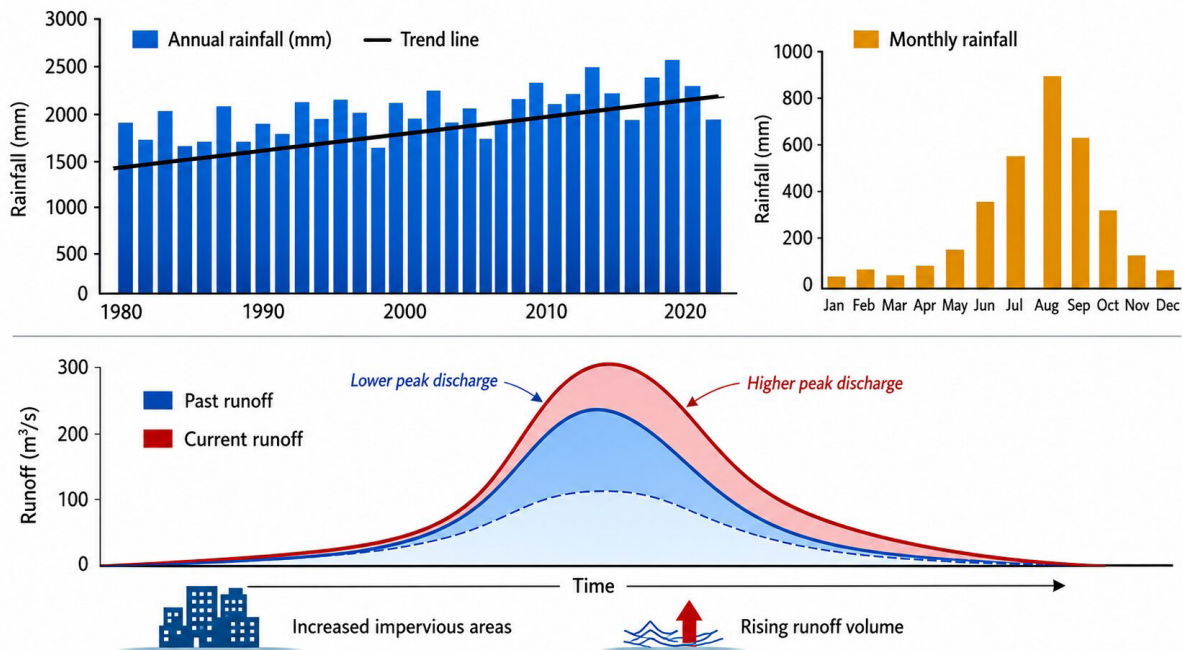


Figure 8. Rainfall and runoff trends in Dhaka. Rainfall data from the Bangladesh Meteorological Department (Dhaka station, 1980 to 2023). Runoff trends estimated from hydrological modeling and Bangladesh Water Development Board data. The chart shows the rainfall trend alongside upper and lower modeled peak discharge curves across the study period.

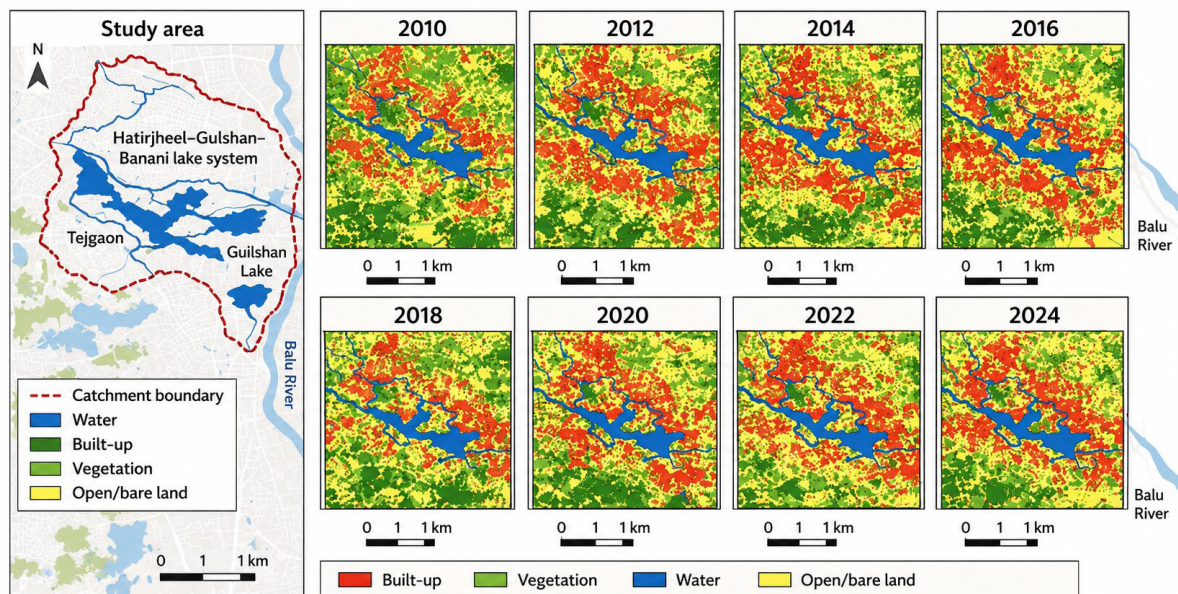


Figure 9. Land-cover change maps for the Hatirjheel-Gulshan-Banani catchment, 2010 to 2024, based on Landsat and Sentinel satellite images. Area statistics by category are shown in Table 3.

pavement. Hard surfaces expanded from about 40–45% in 2010 to about 50–55% by 2024. Rainfall and lake water-level records showed that peak runoff during monsoon events increased alongside this shift. Collectively, these findings confirm that urbanization has altered the catchment's hydrological response, resulting in greater runoff volumes and more rapid conveyance to the interconnected lake system.

3.7. Wetlands and water bodies

Wetland and low-lying areas shrank by about 30–35% between 2010 and 2024. The three main water bodies maintained their size, but their ability to store and convey water declined due to silt, encroachment, and lost canal links, as evidenced by the rise in the runoff coefficient from 0.60 to 0.75. Fewer wetlands are associated with less natural buffering, higher peak flows, and a greater risk of urban flooding across the catchment.

3.8. Comparison with sponge city principles

Comparing the Hatirjheel–Gulshan–Banani system against ideal sponge city benchmarks showed a mixed picture. Strengths include large-scale water detention and some infiltration provided by Hatirjheel, while all three lakes contribute blue space and biodiversity to the city. Limitations include extensive impervious cover throughout most of the basin, reduced green space, and storm drainage systems dominated by concrete channels rather than vegetated or bioretention infrastructure. The mixing of wastewater with stormwater further compromised the system's filtration and retention capacity. Despite incorporating several sponge city features, the system remains far from achieving its full potential.

The most practical fixes would be adding pocket wetlands and bioretention cells along canal corridors, installing permeable paving in new roads, offering incentives for green roofs, and restoring sections of degraded canals. These measures align with recommendations from international sponge city reviews that emphasize local adaptation over direct copying of the Chinese model.²⁴ Good planning guidance indicates that LID targets should be set in steps, first managing frequent one-to-two-year storms, then gradually building capacity for rarer extreme events.

On the governance side, DNCC and RAJUK need to make these green tools part of official planning rules. New developments should require the incorporation of rainwater harvesting systems. Lake boundaries must be legally protected from further encroachment. GIS-based monitoring can help enforce designated buffer zones. Additionally, coordinated action among DNCC, DWASA,

RAJUK, and the Department of Environment is needed to align initiatives such as park development and canal restoration with clearly defined flood mitigation objectives.

3.9. Combined storage and drainage capacity

At the design high water level of + 5.5 m PWD, the three connected lakes hold about 5.74 million m³ of water. At the dry-season minimum of + 2.5 m PWD, the water level drops to about 3.07 million m³. The useful detention space between these two levels is therefore about 2.67 million m³ for all three connected lakes, and about 2.67 million m³ for the whole connected system.

The Hatirjheel system collects stormwater from a catchment area of about 23.2 km² through 11 main outfall pipes and connecting canals, discharging into Gulshan and Banani lakes. Water leaves the system through a flow-control gate into Begunbari Khal, then into the Balu River. This gate controls the release rate and helps reduce flood peaks reaching western Dhaka.

3.10. Groundwater levels before and after Hatirjheel

Groundwater levels in central Dhaka were compared for the periods before Hatirjheel was built (2005 to 2010) and after (2013 to 2024), using data from BWDB and DWASA. Before 2013, groundwater in Tejgaon, Gulshan–Banani, and Motijheel was already 40–50 m below the surface, a sign of heavy over-pumping. After completion of the lake project, the rate of groundwater decline decreased slightly near Hatirjheel, potentially reflecting localized groundwater recharge associated with the lake. However, groundwater level across the wider city continued to decline (Table 6).

These groundwater data are important for LID planning. Even a modest rise in infiltration from lake recharge or LID tools could help offset the depletion, especially if infiltration trenches, soakwells, and permeable pavements are added at scale. Green infrastructure does not just reduce flood peaks; it also helps replenish the aquifer, which could ease Dhaka's heavy reliance on deep groundwater for its water supply. LID design should therefore consider groundwater recharge as a real benefit alongside flood control.

4. Discussion

The results confirm that rapid urban growth changed how the Hatirjheel–Gulshan–Banani catchment functions during rain events. Satellite imagery showed that built-up land continued to expand from 2010 to 2024, while green and open land continued to shrink. More roads, rooftops, and paved surfaces reduced the amount of rain that soaks in. This same pattern has been observed across numerous fast-growing South Asian cities.^{21,22}

Table 6. Groundwater levels in central Dhaka before and after the construction of Hatirjheel

Period	Monitoring area	Average groundwater depth	Trend	Source
2005–2010 (before Hatirjheel)	Tejgaon	40–50 m below surface (dry season)	Rapid fall from heavy groundwater pumping	25,26
2005–2010 (before Hatirjheel)	Gulshan–Banani	About 40 m below the surface	Steady depletion	27
2005–2010 (before Hatirjheel)	Motijheel	About 50 m below the surface	A large cone of depression is forming in central Dhaka	28
2013–2024 (after Hatirjheel)	Hatirjheel–Tejgaon belt	45–55 m below the surface	Slight local slowdown, likely from lake recharge	17
2013–2024 (after Hatirjheel)	Banani monitoring well	Falling at about 0.96 m per year	Still falling, but slower than central Dhaka	27
2013–2024 (after Hatirjheel)	Khilgaon monitoring well	Falling at about 1.34 m per year	Continued decline	27
2013–2024 (after Hatirjheel)	Nikunja monitoring well	Falling at about 2.06 m per year	Heavy groundwater loss continues	27

The runoff coefficient rose from about 0.60 to about 0.75 over the study period. Under the same design storm, this increased peak flow by about 25%. The existing drainage infrastructure is therefore required to convey this additional runoff without any corresponding increase in hydraulic capacity. Accordingly, even under unchanged rainfall conditions, land-use change alone imposes a substantially greater hydraulic burden on the drainage system.

However, rainfall is unstable. Annual rainfall in Dhaka has risen by about 40% over the record period, and the monsoon is delivering more of this rain in shorter, more intense bursts.^{1,23} This intensification multiplies the flood risk from the increased paved surfaces. The interaction between these two pressures further exacerbates flood risk, exceeding the capacity of conventional drainage infrastructure for which it was originally designed.

The three-lake system remains a real asset. Its combined detention of about 2.67 million m³ between operational levels reduces peak flows meaningfully during moderate storms. However, silt, canal narrowing, and encroachment reduced the capacity over time.¹³ Without active intervention, the system's efficacy will drop as the city develops.

The LID scenario shows that green tools can reduce peak flow by 10–15% by lowering C from 0.75 to about 0.65. In a city where drains are already near their limit, even a 10–15% drop in peak flow can make a substantial difference in terms of flooded streets and damaged property. Permeable paving, vegetated swales, rain gardens, green roofs, and small detention basins all contribute. This

result fits with what has been seen in Chinese sponge city pilots,²⁴ Singapore's ABC Waters work,⁸ and South Asian trials.⁹ The lesson from all these cases is the same: LID complements, not replaces, conventional drainage.

Low-impact development also brings benefits beyond flood control. More infiltration can slow groundwater depletion, reduce the heat island effect, and support biodiversity in green corridors. In Dhaka, where groundwater levels are rapidly dropping, the recharge benefit is particularly valuable. These extra gains strengthen the economic case for LID investment and should be reflected in cost-benefit assessments.

Strong governance is equally important. Protecting the lake and canal boundaries from any further encroachment must be prioritized, given the substantial cost of replacing lost storage. Planning rules should require permeable surfaces, rainwater collection, and green space in all new developments. Regular maintenance of drains, canals, and outfalls is not optional; it is a prerequisite for the whole system to function.

This study has several limitations. The rational method yielded a simplified snapshot of peak flow but not a full dynamic simulation. The C values were derived from published tables rather than site-specific measurements, because local discharge data were limited. Higher-resolution satellite data or drone surveys would improve land-cover accuracy. Pipe-level sewer capacity was not assessed. Additionally, it was not possible to separate the rainfall increase effect from the land-use change effect within the current modeling framework. Future studies should address all of these gaps.

5. Conclusion

The Hatirjheel–Gulshan–Banani catchment has changed dramatically since 2010. Hard surfaces expanded by about 10–15%, from 40–45% to 50–55% of the catchment. This increased peak flood flow by about 25% under a standard design storm, from 0.90 to 1.13×10^6 m³/h. LID tools, including permeable paving, bioswales, rain gardens, and small detention wetlands, can reduce peak flow by 10–15% by lowering the composite runoff coefficient from about 0.75 to about 0.65.

The three-lake system stores about 2.67 million m³ of stormwater between operational levels, but silt, encroachment, and disconnected canals have weakened this capacity. Five priority actions can be implemented to address the issues: (i) permeable pavement along the main roads in Banani and Gulshan; (ii) bioretention cells and pocket wetlands along canal edges; (iii) strict enforcement of lake-boundary zones to stop further encroachment; (iv) regular dredging and clearing of outfalls and inter-lake canals; and (v) mandatory rainwater harvesting in all new large buildings.

China's sponge city model cannot be copied directly into Dhaka. The population density, governance structures, and drainage history differ. What is needed is a locally adapted combination of LID tools, WSUD principles, and green–blue infrastructure, backed by clear coordination between DNCC, RAJUK, and DWASA. The Hatirjheel–Gulshan–Banani system has real potential. With the right mix of technical upgrades and institutional support, Dhaka North could remarkably reduce waterlogging and become a reference point for climate-smart water management in South Asia.

The following steps would strengthen and extend the current study: (i) calibrated continuous simulation modeling using SWMM or HEC–HMS with measured discharge data; (ii) pipe-level sewer hydraulics using DWASA network GIS data; (iii) higher-resolution land-cover mapping with drone imagery; (iv) building and monitoring pilot LID installations such as permeable pavements and bioretention cells; (v) groundwater recharge modeling to put a number on the aquifer co-benefit of LID; and (vi) a full cost-benefit analysis of LID retrofitting to support DNCC and RAJUK investment decisions. All of these should be built into DNCC's master plan and RAJUK's WSUD agenda for Dhaka.

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Conflict of interest

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Availability of data

The publicly available satellite datasets used in this study can be accessed through the USGS EarthExplorer and Copernicus Data Space Ecosystem platforms. Rainfall, water-level, drainage, and topographic data were obtained from the respective institutions identified in the manuscript and remain subject to their applicable access conditions. The processed datasets and field-observation data supporting the findings of this study are available from the corresponding author upon reasonable request.

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