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ANALYZING THE SPATIO-TEMPORAL DYNAMICS OF SURFACE WATER BODIES IN DHAKA CITY FROM 1988-2024

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Abstract

Rapid and largely unplanned urban growth has significantly altered the hydrological system of Dhaka, resulting in a substantial decline in surface water bodies. This study examines the spatio-temporal dynamics of surface water extent in the Dhaka Metropolitan Area (DMA) from 1988 to 2024, with the objectives of quantifying seasonal and long-term changes and identifying the key drivers of water body loss. Multi-temporal Landsat imagery was processed in Google Earth Engine using the Modified Normalized Difference Water Index (MNDWI) to extract surface water extent. Subsequent spatial analyses were conducted in ArcGIS. Land use and land cover (LULC) classification was performed using a supervised approach, while rainfall data were analyzed using Microsoft Excel and Python to assess hydro-climatic context. The results reveal a pronounced decline in surface water bodies over the study period. In the post-monsoon season, water extent decreased sharply from 121.89 km² in 1988 to 17.70 km² in 2024. LULC analysis further indicates a substantial reduction in water bodies (from 25.6% to 9.3%) and vegetation cover (from 51.6% to 25.8%), alongside a marked increase in built-up areas (from 22.7% to 64.9%). Visual analysis shows that the eastern and northwestern parts of the city have experienced the most significant loss of surface water. Although seasonal rainfall and flooding patterns contribute to short-term variability in water extent, the long-term trend demonstrates a decline that may be associated with rapid urban expansion, wetland encroachment, and landfilling. The loss of surface water bodies has critical environmental implications, including increased urban flooding and waterlogging, altered microclimatic conditions, intensified urban heat island effects, reduced groundwater recharge, and loss of biodiversity and ecosystem services. This study highlights the urgent need for integrated urban planning strategies that prioritize wetland conservation, regulate land use change, and promote sustainable water management to enhance urban resilience in Dhaka.

Key words: Surface water bodies, Urbanization, Urban wetland, Dhaka, Bangladesh.

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Introduction

Dhaka city, the capital of Bangladesh, is growing rapidly often in an unplanned manner, both in terms of population and area, through haphazard spatial expansion and transformation (Roy *et al.*, 2019). This unplanned urban growth may lead to rapid filling and encroachment on wetlands and the city's open spaces (Abdullah *et al.*, 2024; Hossein *et al.*, 2023; The Daily Star, 2025). As a result, the city's surface water bodies are disappearing rapidly (Mahmud *et al.*, 2011, Paul *et al.*, 2019, Faridatul *et al.*, 2019, Abdullah *et al.*, 2024, Rayhan *et al.*, 2025). The existence of unpolluted urban surface water bodies is essential for groundwater recharge, heat absorption, ecosystem balance, better health conditions for city dwellers, and urban sustainability (Biggs *et al.*, 2017; Kafy, 2018; Kurochkina, 2020; Imran *et al.*, 2021; Jandaghian and Colombo, 2024; Rayhan *et al.*, 2025). It is reported that Dhaka has lost 60% of its water bodies over the last 44 years (The Daily Star, 2025). The protection of surface water bodies and their water quality is crucial for densely populated urban areas like Dhaka to maintain environmental balance and the well-being of city inhabitants. Few studies indicated the reduction of surface water bodies in Dhaka, particularly their investigation on land use and land cover changes over time, water logging risk management in Dhaka, and urban water management: Dewan and Yamaguchi, 2009a; Dewan and Yamaguchi, 2009b; Subrina and Chowdhury, 2018; Imran *et al.*, 2021; Halder and Majed, 2023; Haque *et al.*, 2023; Hossein *et al.*, 2023; Iftekhar and Islam 2023; Miah *et al.*, 2024. Despite the importance of the issue, only a few previous works have been found solely on the depletion of wetland/surface water bodies in Dhaka: Mahmud *et al.*, 2011; Paul *et al.*, 2019; Faridatul *et al.*, 2019; Hossain *et al.*, 2023; Abdullah *et al.*, 2024; Rayhan *et al.*, 2025. In particular, previous Dhaka-focused studies have rarely compared surface water extent across winter, pre-monsoon, and post-monsoon seasons while also linking long-term waterbody loss with LULC transition evidence.

Despite important prior research, significant research gaps remain in the surface water dynamics of the Dhaka metropolitan area. First, many previous studies have focused on changes in water bodies as part of broader land use/land cover analyses rather than on the loss of surface water bodies as the central research focus. Second, several studies were limited to shorter time periods or earlier end years, leaving the most recent change up to 2024 insufficiently documented. Third, only a few studies combined long-term spatio-temporal analysis with an explicit investigation of the drivers responsible for surface water losses in Dhaka.

Therefore, the long-term spatio-temporal dynamics of surface water bodies in Dhaka from 1988 to 2024 remain insufficiently understood. It is also still unclear where the most

significant losses have occurred, and which urbanization-related factors have contributed most. To address these gaps, the study uses multi-temporal Landsat imagery to assess spatio-temporal dynamics of surface water bodies in the Dhaka metropolitan area from 1988 to 2024. Specific objectives of this research are: (1) quantify long-term change of surface water bodies in Dhaka, (2) investigate the long-term spatio-temporal dynamics in surface water bodies in Dhaka, (3) identify major anthropogenic and urban expansion-related drivers associated with surface water changes.

Study area: The Dhaka metropolitan area (DMA) was selected as the study area for this research. It is located in the center of Bangladesh (23.6° N to 24.0° N and 90.2° E to 90.6° E) (Fig. 1). The area is surrounded by rivers and canals: Buriganga River, Balu River, Turag River, Tongi Khal (canal) (Fig. 1). The land area of DMA is around 300.16 km²- 306 km² (Mahmud *et al.*, 2011; Ahmed *et al*., 2013). Approximately 23.94 million people reside in Dhaka (Ahmad *et al.,* 2025). Dhaka receives around 2000 mm of rainfall annually and more than 80% of rainfall occurs during monsoon season (June to September) (Pramanik and Stathakis, 2016). Surface elevation of Dhaka ranges between 1-14 m above sea level and most of the built-up areas are located at the elevation between 6 and 8 m (Dewan *et al.*, 2012; Moniruzzaman *et al.*, 2020).



Fig.1. Study area map of Dhaka city showing Dhaka Metropolitan Area (DMA) (Source: Banglapedia, 2021).

Materials and Methods

Three distinct seasons, namely, winter (December-February), pre-monsoon (March-May) and post-monsoon (October-November) were considered for this study. The monsoon season (June-September) was excluded because persistent cloud cover and extensive seasonal inundation in Dhaka's low-lying areas obscure the detection of permanent and semi-permanent water bodies. Landsat scenes with less than 10% cloud cover were selected for each season, and cloud-contaminated pixels were further removed using the QA_PIXEL band. Composites were generated from median value of pixels within each seasonal window. Images (see Table 1) were filtered according to the study period and clipped to the study area boundary. Surface water extent was extracted using MNDWI in the GEE platform, which is widely used for urban water extent calculation. The following formula proposed by Xu (2006) was used to generate MNDWI in GEE:

$$MNDWI=(Green-Mid\text{-}IR)/(Green+Mid\text{-}IR)$$

Surface water dynamics in Dhaka City were analyzed using Landsat Collection 2 Level-2 Surface Reflectance imagery available through Google Earth Engine (GEE). Landsat 5 TM and Landsat 8 OLI datasets were utilized depending on data availability for the selected years. For Landsat 5 TM, the Green and SWIR1 bands correspond to Bands 2 and 5, respectively; for Landsat 8 OLI, they correspond to Bands 3 and 6, respectively. All datasets were standardized to a common band order prior to analysis to ensure consistency among sensors.

As image characteristics vary across sensors, and over time, a single fixed MNDWI threshold could not be applied to all images. Instead, an image-specific threshold was selected for each seasonal composite. Each threshold value was determined after being visually checked by comparing with false-color composites and corresponding high-resolution Google Earth imagery. Pixels with MNDWI values greater than the selected threshold were classified as water, while pixels below the threshold were classified as non-water. Initially, 0 was the selected threshold for all cases, then thresholds were adjusted to find the best match based on visual comparison. The threshold value range from negative 0.1 to positive 0.1 for all cases.

MNDWI raster files were then transformed into vector files. All further spatial analyses and mapping were conducted using ArcGIS 10.8. The study used five benchmark years, 1988, 1998, 2008, 2018, and 2024, to represent long-term changes in surface water extent over a multi-decadal period. These years were selected to provide approximately decadal intervals across the study period. Monthly rainfall data for the respective years (1988, 1998, 2008, 2018, 2024) were incorporated to examine the influence of rainfall on the

extent of surface water in Dhaka city. All graphs were generated and visualized using Microsoft Excel and Python.

Table 1. Landsat datasets used in surface water mapping in Dhaka city (1988-2024). Three images were taken for each year. All images were seasonal composites, namely, winter (December-February), pre-monsoon (March-May) and post-monsoon (October-November).

Year	Satellite	Sensor	Resolution
1988	Landsat 5	TM	30 m
1998	Landsat 5	TM	30 m
2008	Landsat 5	TM	30 m
2018	Landsat 8	OLI	30 m
2024	Landsat 8	OLI	30 m

In addition, land-use and land-cover (LULC) analyses of Dhaka were carried out for 1988 and 2024 to evaluate long-term transformations in the city's land use and their impacts on surface water bodies. A supervised classification technique was applied to Landsat imagery to categorize land into built-up areas, water bodies, and vegetation (including any croplands). The classified images were then used to quantify changes in built-up areas and water bodies over time. The Matrix Union tool was used to calculate a transition matrix along with Microsoft Excel.

Accuracy assessment was carried out to evaluate the reliability of the supervised LULC classification. For both classified images, a set of 60 validation points was generated using a stratified random sampling approach with 20 points per class so that all land-cover classes, including built-up area, vegetation, and water bodies, were adequately represented. The reference class of each validation point was determined through visual interpretation of Landsat multi-band composites (i.e., commonly used band combinations that highlights specific land-cover classes) and corresponding-date high-resolution Google Earth imagery. Eventually, overall accuracy, and the Kappa coefficient were calculated to assess classification performance. Overall accuracy indicates the proportion of correctly classified validation samples, while Kappa coefficient is a statistical metric used to evaluate the accuracy of classification, adjusting for the likelihood that pixels were classified correctly purely by random chance, making it more reliable than overall accuracy. This assessment provided a quantitative measure of the reliability of the maps used to observe long-term changes in surface water bodies in Dhaka.

In addition, related literature was used to interpret the findings of this research. By combining hydrological and land-use analyses, the study distinguishes between natural variability and anthropogenic drivers of surface water loss in Dhaka.

Results and Discussion

Spatio-temporal dynamics of the surface water bodies: In this study, Surface water bodies in Dhaka include ephemeral wetlands (fill seasonally and dry out completely or partially during summer/dry season, i.e., low-lying areas, lakes, and low-lying floodplains along rivers) and permanent wetlands (rivers, canals, lakes). Figure 2 illustrates the water bodies (water bodies that retain water throughout the year) in the winter season from 1988-2024. In 1988, the water bodies in Dhaka were around 15 km² (Fig. 3). In 2024, the extent of the water bodies had decreased to around 11 km². However, in 1998 and 2018, the extent of the water was 39 km² and 20 km², respectively (Fig. 3).

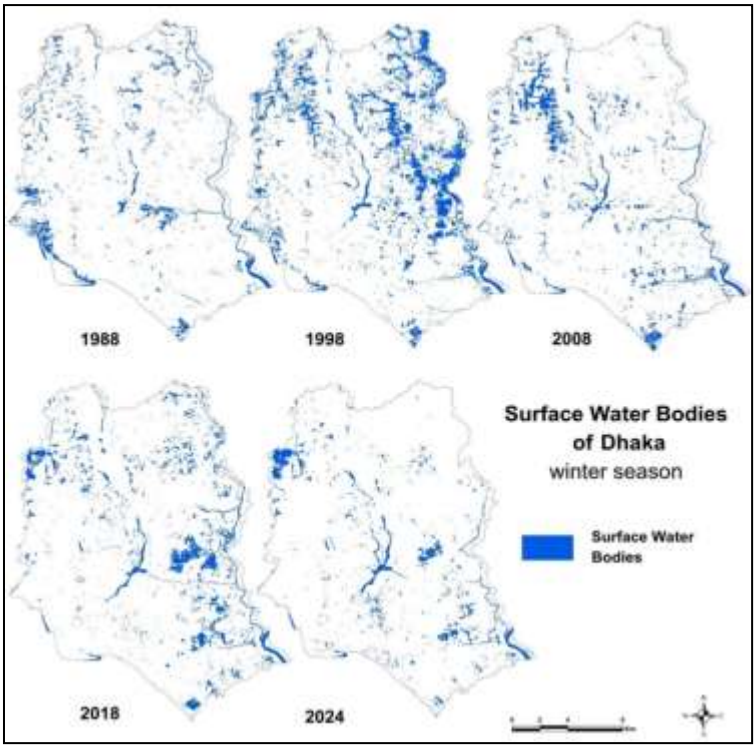


Fig. 2. Change in surface water bodies in Dhaka during winter season (December-February, 1988-2024).

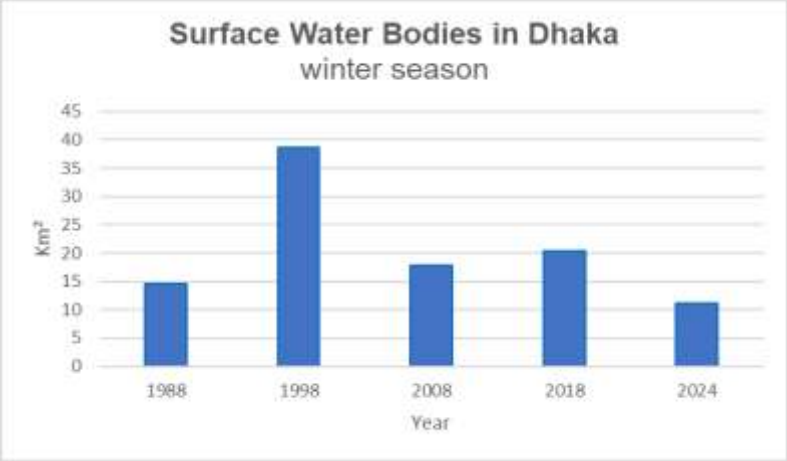


Fig. 3. Surface water bodies in Dhaka in winter seasons showing the total area coverage

The flooding conditions (monsoon and post-monsoon season) and local rainfall patterns possibly affected the extent of the water bodies. The eastern and northwestern sides of Dhaka were abundant in surface water bodies, which have been gradually disappearing.

The extent of water bodies typically ranges from 6 to 15 km² during the pre-monsoon season. In 1988, the total water area was 5.89 km². It was the highest in 2008 (15.46 km²); however, it reached 9.71 km² in 2024 (Figs 4 and 5). This suggests local rainfall patterns, such as severe pre-monsoon thunderstorms (Nor'westers), and other factors (i.e., runoff from upstream) influenced the area of water extent during the pre-monsoon season in 2008 and 2018.

Figure 6 illustrates water bodies during the post-monsoon season from 1988 to 2024. A pronounce and progressive decline of water bodies is evident in the images presented in Figure 6. The extent of surface water bodies was 121.89 km² in 1988. It was 105.66 km², 62.99 km², 26.04 km², and 17.70 km² in 1998, 2008, 2018, and 2024, respectively (see Figure 7). This represents a loss of 104.19 km² over 36 years, equivalent to an average loss rate of approximately 2.89 km²/year. The highest concentration of water bodies is on the eastern side of the city, distributed almost continuously along a north-to-south axis. The second-highest water concentration is located on the northwestern side, followed by the southwestern side. Dhaka has experienced significant declines in surface water extent (Figures 6, 7 and 8). Specifically, the decline of water extent is pronounced across the eastern and northwestern sides of Dhaka (Figure 8).

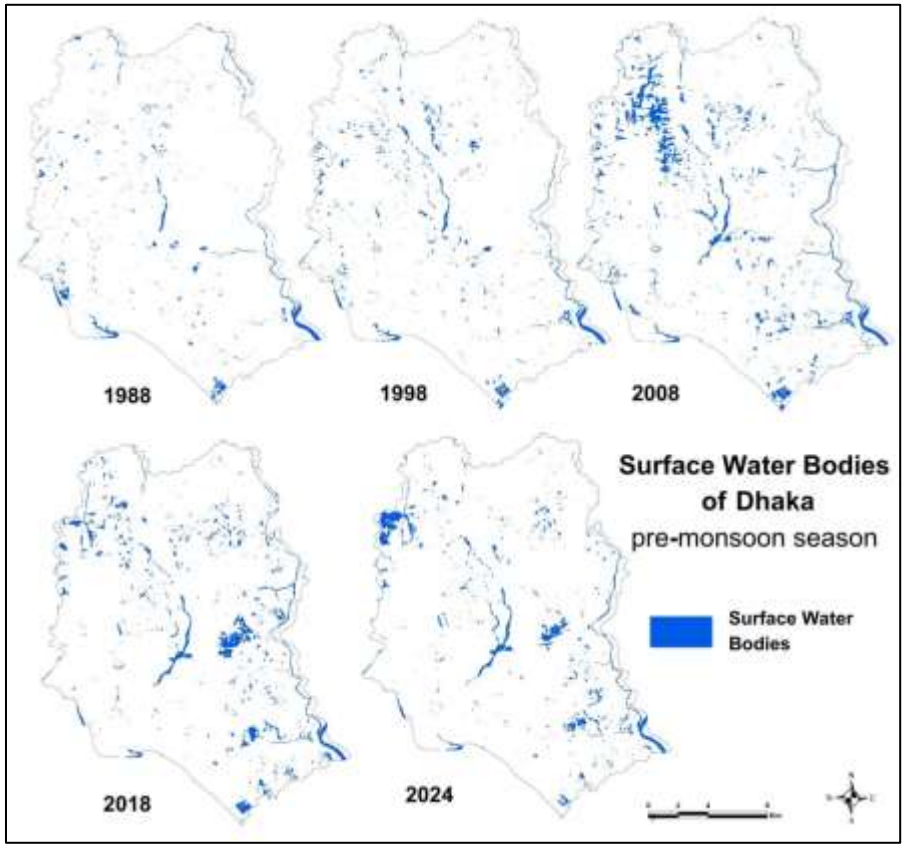


Fig. 4. Changes in surface water bodies in Dhaka during pre-monsoon season (March-May, 1988-2024)

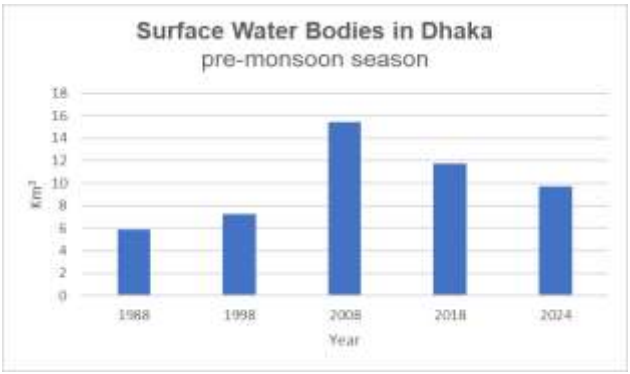


Fig. 5. Surface water bodies in Dhaka in pre-monsoon seasons.

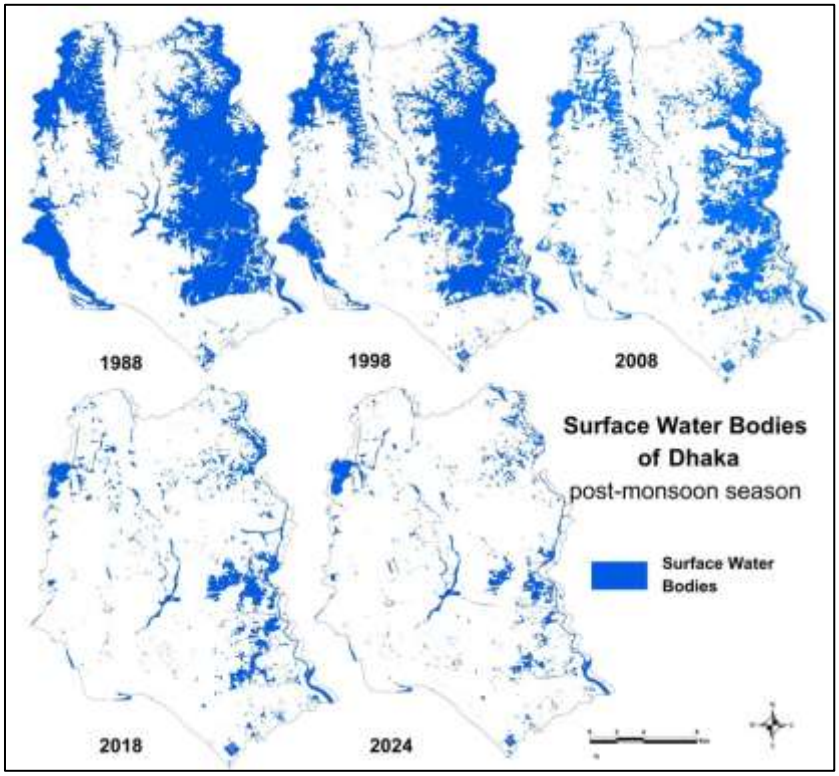


Fig. 6. Surface water bodies in Dhaka in post-monsoon seasons
(October-November, 1988-2024)

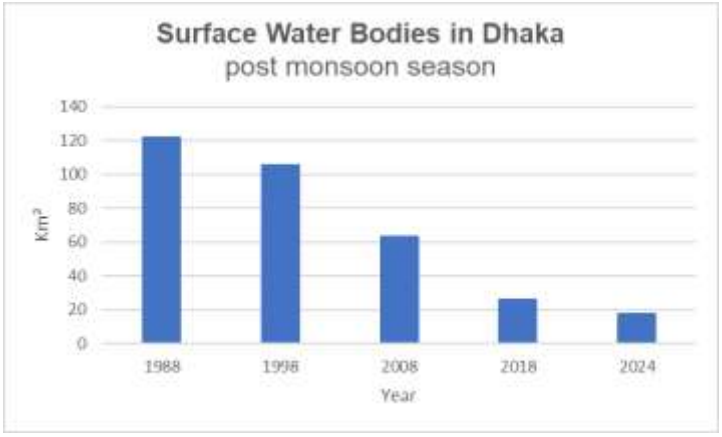


Fig. 7. Surface water bodies in Dhaka in post-monsoon seasons.

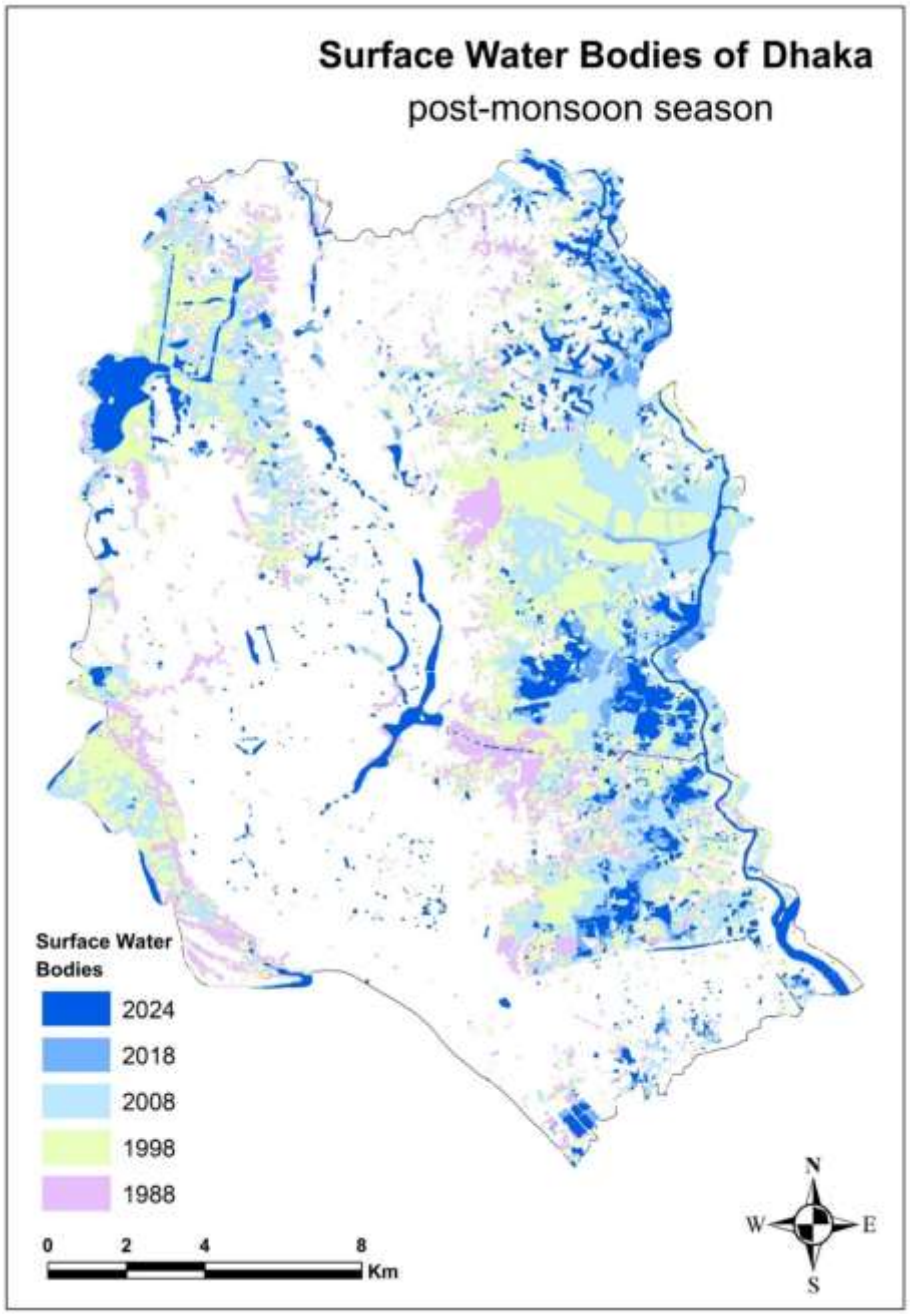


Fig. 8. Disappearance of surface water bodies (post-monsoon) in Dhaka (1988-2024).

Drivers of the disappearance of surface water bodies:
Rainfall patterns

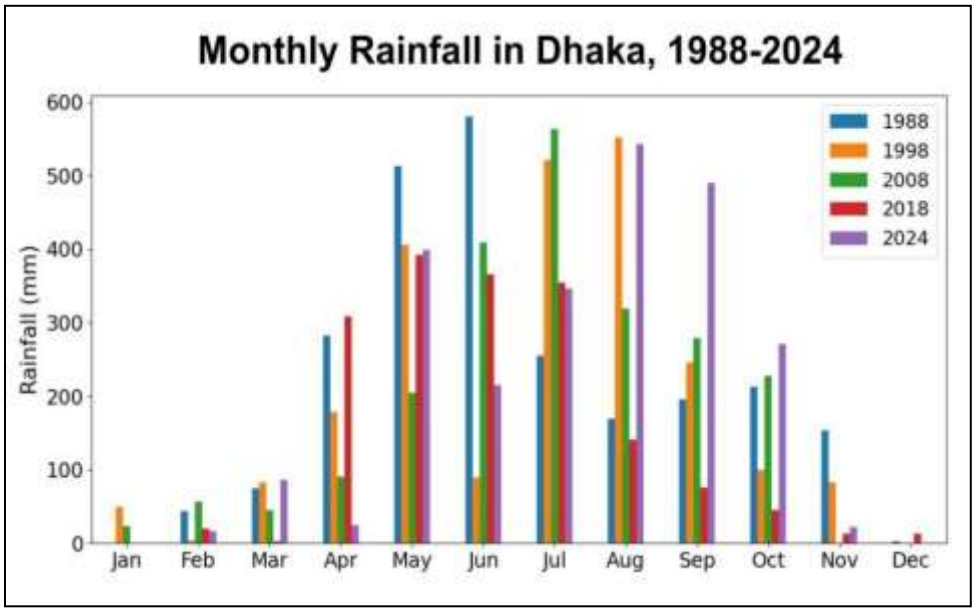


Fig. 9. Monthly total rainfall in Dhaka, 1988-2024.

The chart in Figure 9 depicts the monthly rainfall patterns in Dhaka across the selected years 1988, 1998, 2008, 2018, and 2024. It shows a clear and consistent seasonal trend in rainfall patterns in Dhaka. Rainfall remains lowest during the winter months of December to February. However, it gradually increases from the pre-monsoon months of March to May. A sharp rise was observed during the monsoon months of June to August in all years. Rainfall declines from September through the post-monsoon months of October and November, reaching its lowest level during the winter months.

Because the study used five selected benchmark years and seasonal waterbody estimates rather than a continuous annual time series, formal rainfall–waterbody correlation analysis, such as Pearson or Spearman correlation, was not performed. The rainfall analysis was therefore used as contextual evidence to support interpretation of short-term seasonal variability rather than as a statistical test of climate influence.

Figures 3 and 9 illustrate that other local factors beyond rainfall may have contributed to the higher water extent during the winters of 1998 and 2018, as no significant amount of

rainfall occurred in either year. High water extent may be due to flooding caused by upstream inflow and/or waterlogging or other local factors. From Figures 3 and 9 it can be seen that pre-monsoon rainfall is lowest in 2008, whereas water extent is greatest in 2008 among all years. Local factors, such as pre-monsoon floods, may be responsible.

Figures 7 and 9 provides useful context for interpreting seasonal variation in surface water extent. Rainfall was lowest during the winter months and increased during the pre-monsoon and monsoon periods, followed by a decline during the post-monsoon months. For 2024, which received comparatively higher rainfall during the post-monsoon (Figure 9), no corresponding increase of water extent can be observed (Figure 7), that suggests post-monsoon rainfall may have less influence in water extent. These seasonal rainfall patterns may partly explain short-term variation in mapped surface water extent, particularly in winter and pre-monsoon periods when shallow or temporary wetlands may expand or dry out depending on recent rainfall, upstream inflow, drainage conditions, and local waterlogging. However, the available data do not support a formal statistical attribution of surface water change to rainfall variability. The next section will highlight how urban expansion is responsible for the decrease in surface water bodies in Dhaka.

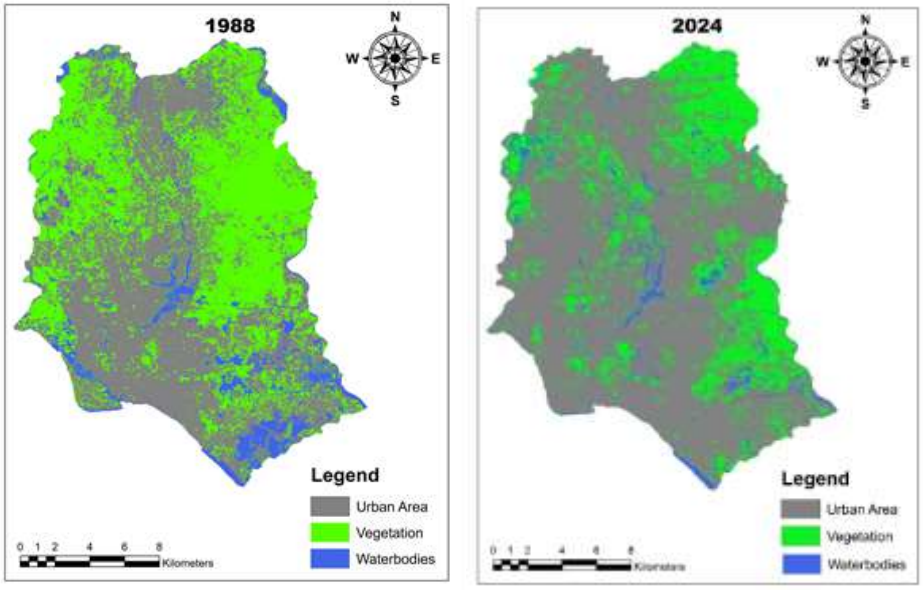


Fig. 10. Land use land cover (LULC) maps for Dhaka for 1988 (left) and 2024 (right).

Urban expansion

Urban land-use and land-cover (LULC) change is a critical indicator of environmental transformation, particularly in rapidly growing cities of the developing world. Dhaka, one of the fastest-growing megacities, has experienced significant spatial expansion and landscape modification over the past few decades. These changes have led to the conversion of natural and semi-natural land covers, such as vegetation, cropland, open spaces and water bodies, into built-up areas.

We analyzed LULC changes in Dhaka over a long-term period spanning from 1988 to 2024 using Landsat imagery. The analysis focuses on three primary land cover classes: vegetation (inclusive of croplands), water bodies, and built-up areas. The classification and comparative assessment of images acquired from Landsat 5 (1988) and Landsat 8 (2024), reveals substantial transformation in the spatial distribution of major land cover classes, namely water bodies, vegetation, and urban areas.

In 1988, vegetation was the dominant land cover, occupying approximately 155.0 km² (51.6%) of the study area. Water bodies covered 76.9 km² (25.6%), while urban areas accounted for only 68.3 km² (22.7%) (Figure 10). However, by 2024, the land cover composition had changed dramatically. Urban areas became the predominant class, expanding to 194.7 km² (64.9%), whereas vegetation decreased to 77.6 km² (25.8%), and water bodies declined significantly to 27.9 km² (9.3%) (Figure 10). Accuracy assessment (Table 2 and Table 3) results for 1988 and 2024 were 81.7% and 85.0% respectively, in terms of overall accuracy. The corresponding values for kappa coefficients were 0.725 and 0.775.

Table 2. Confusion matrix for the LULC maps of 1988

1988	Built-up	Vegetation	Water bodies	Total	User's accuracy
Built-up	16	3	1	20	**80.0%**
Vegetation	4	16	0	20	**80.0%**
Water bodies	1	2	17	20	**85.0%**
Total	21	21	18	60	
Producer's accuracy	**76.2%**	**76.2%**	**94.4%**		

The most notable change is the rapid expansion of urban areas, which increased by 126.4 km² over the study period of 36 years (at an average rate of 3.51 km² gain per year) (Figure 10). This growth corresponds to a substantial rise in the proportion of built-up land, reflecting intense urbanization. Approximately 65% of the newly expanded built-up

area can be attributed to the loss of vegetation/cropland, while 35% can be attributed to the loss of water bodies. This pattern (Table 4) is broadly consistent with previous transition-matrix-based studies of Dhaka, which show that urban expansion has occurred mainly through the conversion of agricultural land, vegetation, wetlands, lowlands, and water bodies into built-up areas (Rahman and Szabó, 2021). In contrast, vegetation experienced a considerable loss of 77.4 km², indicating large-scale conversion of green spaces into built-up areas. Similarly, water bodies decreased by 49.0 km² (at an average rate of 1.36 km² loss per year). Around 80% (44.8 km^2) of the lost water bodies and wetlands were transformed into built-up area, and the rest of the change is attributable to vegetation (including croplands). Because long-term change was detected some nuances might have been simplified, such as, wetlands are often first converted into bare or reclaimed land through landfilling, and later into vegetation or built-up areas.

Table 3. Confusion matrix for the LULC maps of 2024.

2024	Built-up	Vegetation	Water bodies	Total	User's accuracy
Built-up	18	2	0	20	**90.0%**
Vegetation	4	15	1	20	**75.0%**
Water bodies	1	1	18	20	**90.0%**
Total	23	18	19	60	
Producer's accuracy	**78.3%**	**83.3%**	**94.7%**		

Table 4. Simplified Land Cover Transition Matrix.

Transform from 1988 to 2024	Built-up 2024	Vegetation 2024	Water 2024	1988 total
Built-up 1988	68.3	< 0.1	< 0.1	68.3
Vegetation 1988	81.6	65.3	8.1	155.0
Water 1988	44.8	12.3	19.8	76.9
2024 total	194.7	77.6	27.9	**300.2**

Overall, the results demonstrate a clear trend of land transformation from natural land covers (vegetation and water bodies) to urban areas. This pattern suggests that rapid and largely unplanned urban expansion has significantly altered the landscape of Dhaka, potentially leading to adverse environmental consequences such as loss of biodiversity, increased surface runoff, and urban heat island effects.

Discussion

Disappearance of surface water bodies in Dhaka: Water bodies are dominant on the eastern side and are continuous from north to south. Secondly, dominance is found in the north-western and north-eastern sides of Dhaka. Across Dhaka, water bodies are disappearing over time. The winter-season water bodies in Dhaka range from 11 to 20 km². However, there was an exception in 1998 (about 39 km²), possibly due to severe flooding and associated waterlogging. During the pre-monsoon season, it varied from 5.89 to 15.46 km² from 1988 to 2024. Rainfall patterns may be responsible for water levels during the pre-monsoon season. Overall, the lowest water extent was 6 km² in 1988 (Pre-monsoon), as the water bodies dried out, and the highest water extent was around 120 km² in 1988 (after a severe flood) during the post-monsoon season. All previous studies reported waterbody shrinkage in Dhaka over time; however, none explored seasonal variation in water extent (Mahmud *et al.*, 2011; Paul *et al.*, 2019; Faridatul *et al.*, 2019; Abdullah *et al.*, 2024; Rayhan *et al.*, 2025). Water levels in surface water bodies in Dhaka are possibly influenced by seasonal rainfall and flooding patterns. Dhaka received the least rainfall during the winter season. Dhaka faced severe fluvial flooding (caused by overflow of banks from rivers and streams) in both 1988 and 1998; however, in 1998, Dhaka also faced severe pluvial flooding (caused when excess rainfall exceeded the capacity of natural and engineered drainage systems) due to heavy rainfall and poor drainage systems that trapped water inside the embankment area (Sakib *et al.*, 2023). As a consequence, even in the winter season, the extent of surface water in Dhaka was significantly greater (39 km²) (Figures 2 and 3). However, in the pre-monsoon season, most of the water bodies dry out if there is no rain/delay in rain from pre-monsoon season thunderstorms. As a result, the lowest water levels in Dhaka city's water bodies were observed during the pre-monsoon season. The gradual disappearance of surface water bodies is apparent in the post-monsoon surface water extent. Although water levels are influenced by monsoon flooding and rainfall patterns, analysis of land-use and land-cover change confirms that water bodies in Dhaka are disappearing rapidly.

Driver of the disappearance of surface water bodies: Water levels in surface water bodies in Dhaka are possibly influenced by seasonal rainfall and flooding patterns. As, Dhaka received the least rainfall during the winter season, in the pre-monsoon season, most of the water bodies dry out if there is no rain/delay in rain from early pre-monsoon season thunderstorms. As a result, the lowest water extent in Dhaka city's water bodies was observed during the pre-monsoon season. The gradual disappearance of surface water bodies is apparent in the post-monsoon surface water extent. Although water levels seem to be influenced by monsoon season flooding and rainfall patterns, analysis of land use

and land cover change confirms that water bodies in Dhaka are drastically disappearing over time. Seasonal rainfall and flooding variations influence the water levels of surface water bodies in Dhaka city. The rainfall analysis in this study is descriptive and contextual. Potential impact of climate change or microclimatic alteration, such as the urban heat island effect, on surface water bodies remains to be examined. Additionally, the impact of groundwater depletion on surface water levels of water bodies in Dhaka has yet to be identified. However, we found that the main driver of the disappearance of surface water bodies is unplanned urban expansion and encroachment (Figure 10). Previous studies also identified unplanned urban expansion as the main cause of the disappearance of water bodies in Dhaka city (Dewan and Yamaguchi, 2009b; Subrina and Chowdhury, 2018; Hossein et al., 2023; The Daily Star, 2025)

Implications of the disappearance of surface water bodies: The loss of wetlands and surface water bodies in Dhaka, driven by unplanned urbanization and encroachment, has already caused and is expected to further intensify significant environmental and socio-economic adverse consequences for the city and its residents (Mahmud *et al.*, 2011; Subrina and Chowdhury, 2018; Paul *et al.*, 2019; Imran *et al.*, 2021). These include destruction of natural drainage systems, resulting in waterlogging problems; increased urban flooding due to the loss of natural reservoirs and water channels; alteration of the microclimate, including intensified urban heat island effects and thermal discomfort; and groundwater depletion as a result of increased impermeable surfaces and the loss of wetlands that aid recharge; loss of biodiversity and ecosystem services, challenges in emergency water access (such as firefighting), deterioration in public health, and loss of the city's aesthetics and recreational areas (Mahmud *et al.*, 2011; Imran *et al.*, 2021; Haque *et al.*, 2023; Halder and Majed, 2023). Additionally, the risk of land subsidence and greater earthquake impact is expected for urban areas built on filled or encroached natural water bodies in Dhaka (Paul *et al.*, 2019).

Limitations: A limitation of this study is that the temporal analysis is based on five selected benchmark years rather than annual observations. Therefore, short-term inter-annual fluctuations caused by unusual rainfall, flooding, drought, or local hydrological conditions may not be fully captured. For example, a single observation year may reflect abnormal hydro-climatic conditions and may not represent the average condition of that decade. For this reason, the results are interpreted as representative long-term changes between selected periods rather than as a continuous annual trend.

Because the study used five selected benchmark years and seasonal waterbody estimates rather than a continuous annual time series, formal rainfall–waterbody correlation

analysis, such as Pearson or Spearman correlation, was not performed, due to possibility of weak or misrepresentative results. The rainfall analysis was therefore used as contextual evidence to support interpretation of short-term seasonal variability rather than as a statistical test of climate influence.

Future research should use annual or near-annual Landsat composites to construct a continuous time series of surface water extent. This would allow the application of formal trend tests, including Mann-Kendall trend analysis and Sen's slope estimation, to assess the magnitude and statistical significance of long-term surface water change in Dhaka.

Conclusion

Dhaka has experienced a significant decline in surface water bodies from 1988 to 2024. Variability in seasonal rainfall and flooding patterns influences water extent in Dhaka. However, in the long-term (1988-2024), water extent decreased substantially across nearly all observed periods (winter, pre-monsoon and post-monsoon), with the most prominent decline during the post-monsoon period. Spatially, the eastern side and northwestern side of the city experienced the greatest loss of water bodies.

Our findings confirm that urban expansion (possibly associated with landfilling and encroachment) are the main drivers of wetland disappearance in Dhaka. The natural drainage and hydrological systems are disrupted by the conversion of surface water bodies in Dhaka. The implications of this decline in water bodies include increased urban flooding, waterlogging, intensified urban heat-island effects, and loss of biodiversity and ecosystem services. This challenge is posing a major threat to the livability and environmental sustainability of Dhaka city. Overall, safeguarding remaining surface water bodies is crucial for a resilient, sustainable, climate-adaptive and livable future in Dhaka. Our study provides important evidence regarding the spatio-temporal dynamics of surface water bodies in Dhaka. Still, some limitations may be addressed in future research. Our analysis was based on a few selected years; as a result, formal trend significance tests, such as Mann–Kendall or Sen's slope, could not be applied. Moreover, rainfall was used mainly as contextual evidence, while the influence of climate change and variability, groundwater depletion, and microclimatic change on surface water dynamics was not examined quantitatively. Future research can address the above-mentioned limitation by using annual or higher-temporal-resolution satellite data, rainfall data, and hydrological datasets to conduct statistical trend and correlation analyses, identify spatial hotspots, and apply landscape-metric approaches to better identify vulnerable water-loss zones. A more comprehensive study of urban water management in Dhaka can be conducted by investigating interactions among surface water, groundwater,

land-use and land-cover change, and climate change. To address this issue immediately, a policy and planning intervention are required.

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