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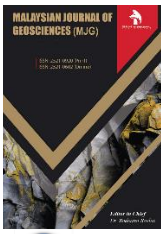

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RESEARCH ARTICLE

GEOSPATIAL-BASED MULTI-TEMPORAL CHANGE ANALYSIS OF URBAN WATERBODIES IN DHAKA CITY OF BANGLADESH

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ABSTRACT

Dhaka the capital city of Bangladesh has experienced a steady loss of waterbodies over the last few decades due to unsustainable urbanization and climate change. This study employs remote sensing and geospatial technology to investigate the spatial-temporal changes of waterbodies of Dhaka city over a 30-year period. This study relied, primarily, on the Normalized Difference Water Index (NDWI) method for the identification and classification of the waterbodies (and non-waterbodies) followed by change detection and accuracy assessment. In addition to this NDWI approach, a supervised LULC classification -followed by change detection has been undertaken for the evaluation of the spatial and temporal dynamics of the LULC classes (Bare Land, Built-up Area, Vegetation and Waterbody). The results of the NDWI-based assessment primarily demonstrate that the extent of the waterbody area has disappeared significantly, from 84.19 km2 in 1992 to 37.20 km2 in 2022. This indicates that more than half of the waterbody area has been lost over these 30 years. The overall classification accuracy was 88%, 92% and 90% respectively for the study years 1992, 2007 and 2022, with kappa values of 0.84, 0.88 and 0.86 for each respective study year. The supervised LULC classification and change detection present a dynamic picture of the LULC transition, which reveals that the growth of built-up areas is the principal driver leading to the loss of 15.083 km^2 of waterbodies and 27.483 km^2 of vegetation over the study period. Finally, based on the findings, this study provides a briefing on the likely reasons underlying this dynamic LULC transformation as well as plausible policy strategies to reverse the trend. The findings of this study could be useful to policymakers for the long-term planning and management of urban water resources as well as sustainable urban planning and environmental management of this capital city.

KEYWORDS

Waterbody, NDWI, Vegetation, GIS, Remote Sensing, Bangladesh

1. Introduction

The rapid urbanization and economic development process are closely connected since they play an increasingly significant role in contributing to the whole national and urban economy, which further contributes to the gross domestic product (GDP). (Xu et al., 2024). In the last decades, it has been unacceptable to witness unplanned developmental activities occurring in numerous cities worldwide like Europe, Africa, the United States as well as Asia including Dhaka which have additionally been disturbed by this problem (Halder and Majed, 2023; Ibrahim Mahmoud et al., 2016; Zhong et al., 2023). Landscape alteration has led to a domino effect on biodiversity, water quality, and carbon emissions have been multifaceted and far-reaching in the local climate in terms of temperature, precipitation and cloudiness causing harm to both aquatic and terrestrial ecosystems. (Tabassum et al., 2023). The growing demands on the utilization of water, surface energy equilibrium, the function of the ecosystem, groundwater replenishment, and economic growth all highlight how critical it is to attain water sustainability in the context of human civilization. (Abbass et al., 2022). Since Bangladesh is one of the most densely populated countries in the world, it is facing the challenges of rapid and uncontrolled urban growth, resulting in significant environmental deterioration like as waterbody changes (Mondal, 2019). (Zarin and Zannat, 2023). The swift rise in urban population poses difficulties by straining resources and impeding efficient governance and response. (Baffoe and Roy, 2023). The prevalence of these contemporary challenges is significantly higher in developing countries such as Bangladesh. (Amani et al., 2020).

Dhaka is a famous city for its interconnected network of canals and lakes, which are linked to the three major rivers that surround it. (Jinia Sharmeen, 2014). In the past few decades, a multitude of low-lying areas,

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canals, and waterways both within and surrounding Dhaka served the purpose of the ecological and cultural heritage effectively draining the city, facilitating transportation, and supplying water for agricultural purposes (Hossain et al., 2023; Kandekar et al., 2021). However, in the present era, the circumstances have undergone a completely different. A substantial amount of the khals have vanished, and the banks of the adjacent rivers are being infringed upon or grabbed gradually owing to multiple factors (Parvin et al., 2024). Potable water shortages are already occurring because of uncontrolled growth. Dhaka city areas have grown by 618% in 36 years, which is a very fast rate of growth. This has caused massive changes to the land cover, with 56% of it changing mostly because of expanding built-up areas and human activities (Hassan and Nazem, 2016). Because of this modification, the natural landscape was disrupted, leading to waterlogging and urban floods, which are induced by rainfall and these issues pose significant challenges for the urban population of Dhaka city (Rabbani et al., 2011). According to the Strategic Environment Assessment, water logging is a significant issue in the urban city of Dhaka (Subrina and Chowdhury, 2018). The southern and southwestern regions of Dhaka were particularly vulnerable to waterlogging hazards as a result of extensive rainfall (Alam et al., 2023). The urbanized regions had a noticeable expansion towards the northern part of Dhaka and were subjected to significant problems with water logging issues.

Conducting water resources assessments in the field is arduous and expe nsive because of the challenging natural conditions, and obtaining consist ent long-term data sets is much more difficult. Satellite remote sensing (RS) and Geographical Information Systems (GIS) provide efficient and precise monitoring of large-scale water bodies (Hossain et al., 2023). The mapping and monitoring of water bodies can have diverse appropriate solutions for policy measures, developmental activities, identification of sensitive segments, civil engineering projects, and disaster management (Thirumurthy et al., 2022). It is crucial to detect changes in water bodiesat a regional level to evaluate the characteristics and types of changes that are affecting the drivers, as well as future patterns of change. However, as far as our knowledge, very few studies have evaluated targeting change of waterbodies through the lens of GIS and a remote sensing integrated approach in recent years as the changing process of waterbodies is a continuous process. It is urgent to specify a map or well-documented records of the condition of waterbodies, wetlands, built-up areas, and the trend of changes and their consequences on Dhaka city. Hence, the present study aimed to assess spatiotemporal changes of urban waterbodies in the last 30 years and also to explore causes and factors affecting urban waterbody changes in the Dhaka Metropolitan area.

2. METHODOLOGY

2.1 Study Location: Dhaka City

The location of Bangladesh's Dhaka Metropolitan Area (DMA) lies between latitudes 23°42' and 23°54'N and longitudes 90°20' and 90°28'E. As the biggest metropolis in the countries surrounding the Bay of Bengal, Dhaka the capital city of Bangladesh is a major hub for both culture and commerce, making it one of the megacities of South Asia. The metropolitan region, which spans 315 km² (Figure 1), is bordered to the north by the Tongi Canal, to the south by the Buriganga River, to the west by the Turag River, and to the east by the Balu River (Bodrud-Doza et al., 2019). Dhaka is experiencing one of the fastest rates of population growth in Asian cities, with the central and southern regions of the city experiencing significant urbanization. The city's annual growth rate is approximately 4% (Imran et al., 2021). The city corporation of Dhaka was divided into two divisions, namely Dhaka North City Corporation (DNCC) and Dhaka South City Corporation (DSCC). The topographical characteristics of Dhaka indicate that its elevation ranges from 2 to 13 meters above sea level.

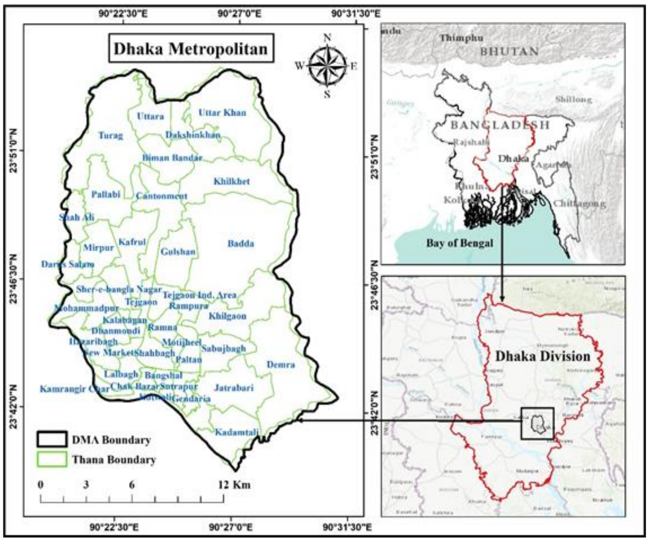

Figure 1: Study Area of Dhaka Metropolitan Area

2.2 Image Acquisition

This study provides a comprehensive analysis of waterbody modifications of Dhaka Metropolitan Area (DMA) over 30 years (1992–2022) using multitemporal Landsat Satellite data which was 1992, 2007, and 2022. The United States Geological Survey (USGS) provided the data, which were collected using Thematic Mapper (TM), Enhance Thematic Mapper (ETM), Operational Land Imager (OLI), and Thermal Infrared Sensor (TIRS) sensors. Images were taken throughout the same month to eliminate seasonal fluctuations with cloud cover of less than 10. The detailed information is shown in (Table 1).

2.3 Normalized Difference Water Index (NDWI)

Normalized Difference Water Index (NDWI) is a process that helps to identify the water portion area from the other features and this process requires the specific band to perform depending on the green and near-infrared bands (Das et al., 2021). Landsat 5 (TM), and Landsat 7 (ETM) have the same band combination as band 2 (Green), and band 4 (NIR). Landsat 9 has the band combination of band 3 (Green), and band 5 (NIR). The NDWI method is defined by,

$$\mathrm{NDWI} = \frac{(\mathrm{Green} - \mathrm{NIR})}{(\mathrm{Green} + \mathrm{NIR})} = \frac{(\mathrm{band}\ 2 - \mathrm{band}\ 4)}{(\mathrm{band}\ 2 + \mathrm{band}\ 5)} \quad (1)$$

$$\mathrm{NDWI} = \frac{(\mathrm{Green} - \mathrm{NIR})}{(\mathrm{Green} + \mathrm{NIR})} = \frac{(\mathrm{band}\ 3 - \mathrm{band}\ 5)}{(\mathrm{band}\ 3 + \mathrm{band}\ 5)} \quad (2)$$

This process is mainly used for the observation of water bodies, and the range is from -1 to +1. The positive values show that which is greater than 0 is observed in the waterbody and negative values represent the land area of the study area.

2.4 Change Detection and Transition Analysis

In this research, GIS and Remote Sensing techniques are used for extracting the waterbody from the Landsat data. The specific year period is considered to observe the waterbody change during (1992 to 2022). NDWI is a process that helps to identify the waterbody from the other features. This study shows the waterbody is decreasing due to rapid urbanization in the Dhaka Metropolitan Area in the last 20 years (Sresto et al., 2022). The change detection analysis requires the approximate method, and then raster data is converted to vector data using the raster to polygon tool (Das et al., 2021). Moreover, the dissolve tool is used for combining the same features in a specific class. After extracting the waterbody feature, the waterbody change detection calculation was done, and generated the change detection map from 1992 to 2007, 2007 to 2022, and 1992 to 2022. Transition analysis is a special method, it helps to understand the features that are changing over time from 1992 to 2022. At the time of applying this method, the intersect is a necessary tool for calculating the changed area. This process is mainly used for visualizing the previous and the present features that are altered from one feature to another feature within a specific period. The transition matrix calculation and the transition map were generated in the ArcGIS 10.8 environment.

2.5 Accuracy Assessment

There are a total of four types of calculations to get accurate accuracy values. User accuracy and producer accuracy are the common calculations that describe the specific class percentages in the classified images. User accuracy, producer accuracy, overall accuracy, and Kappa coefficient formulas were derived from,

$$\text{User accuracy} = \frac{\text{Correctly classified pixels in each category (diagonal)}}{\text{total reference pixels in each category (column total)} * 100}$$

$$\text{Producer accuracy} = \frac{\text{correctly classified pixels in each category (diagonal)}}{\text{total reference pixels in each category (column total)} * 100}$$

$$\text{Overall accuracy} = \frac{\text{total correctly classified pixels (diagonal)}}{\text{total reference pixels} * 100}$$

$$\text{Kappa coefficient} = \frac{(\text{total sample} * \text{total correct sample}) - \sum(\text{column total} * \text{row total})}{(\text{total sample})2 - \sum(\text{column total} * \text{row total}) * 100}$$

The Kappa coefficient provides the most accurate values (Table 2) and the range of the values is -1 to +1, this measurement is constant, and if those values are near 1, then it is considered to be the best accuracy. Higher values are observed as similar to the Google Earth imageries.

3. Results Interpretation

3.1 Changes in Waterbodies from 1982 to 2022

The analysis of spatiotemporal changes in urban water bodies within the Dhaka metropolitan area was conducted through the utilization of available Landsat imagery and the NDWI (Normalized Difference Water Index) methodology. NDWI techniques were primarily employed for water body identification, supplemented by supervised image classification techniques to ensure data accuracy through pixel-based accuracy assessments. The combined use of NDWI and supervised image classification confirmed the validation of the data. The status of water bodies in the Dhaka metropolitan area was assessed for the years 1992, 2007, and 2022, and the findings were presented in both tabular (Table 3) and graphical (Figure 2) formats. In 1992, the total water body coverage was 84.19 km^2, accounting for 67.30 km^2 and 37.20 km^2 in 2007 and 2022, respectively. Correspondingly, the land surface area in 1992 was 231.31 km^2, increasing to 248.20 km^2 in 2007 and further to 278.30 km^2 in 2022 (Figure 3). The results highlight the dynamic changes in water body extent over the specified time periods and provide valuable insights into the evolving urban landscape of the Dhaka metropolitan area.

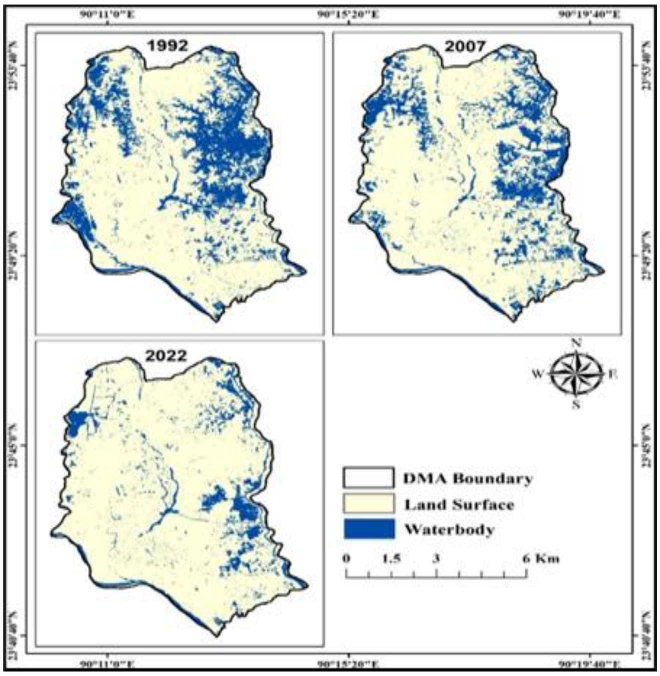

Figure 2: Status of waterbodies during 1992, 2007 and 2022

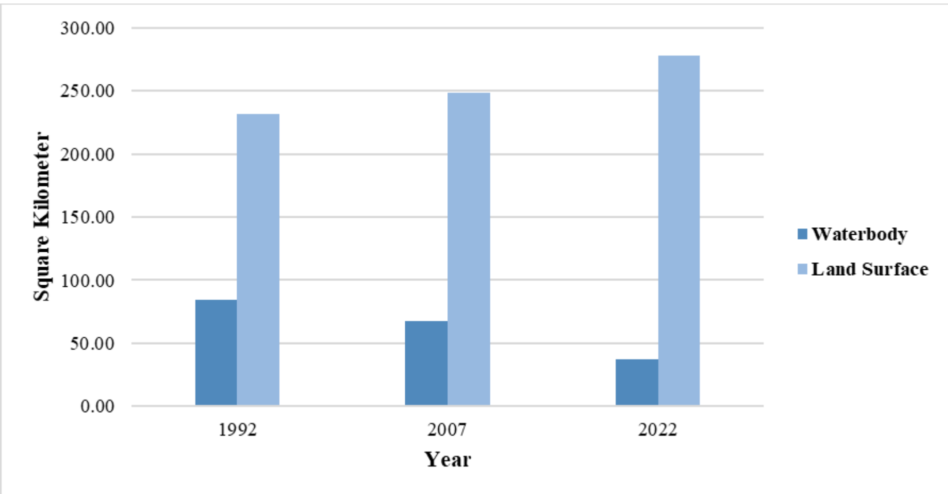

Figure 2: Variations of waterbodies and land surface during last 30 years

3.2 Change Detection Based on NDWI Analysis (1992 to 2022)

Change detection studies were conducted using both NDWI and supervised classification land cover analysis to identify alterations in water bodies from 1992 to 2022. Figure 4 illustrates the declining trend in water bodies over this period. Notably, there was a reduction of 32.79 km^2, 41.28 km^2, and 60.74 km^2 in water bodies from 1992 to 2007, 2007 to 2022, and 1992 to 2022, respectively. Examining the gains, the study revealed an increase of 15.91 km^2 in water bodies from 1992 to 2007,

followed by an additional gain of 11.18 km^2 from 2007 to 2022. The overall gain in water bodies between 1992 and 2022 amounted to 13.75

km² (Table 4). Alongside these changes, areas of stability were identified, with 51.39 km², 26.02 km², and 23.44 km² remaining unchanged during the periods 1992 to 2007, 2007 to 2022, and 1992 to 2022, respectively. These findings offer valuable insights into the dynamics of water body changes, emphasizing both losses and gains, and highlight areas of consistency over the specified time intervals.

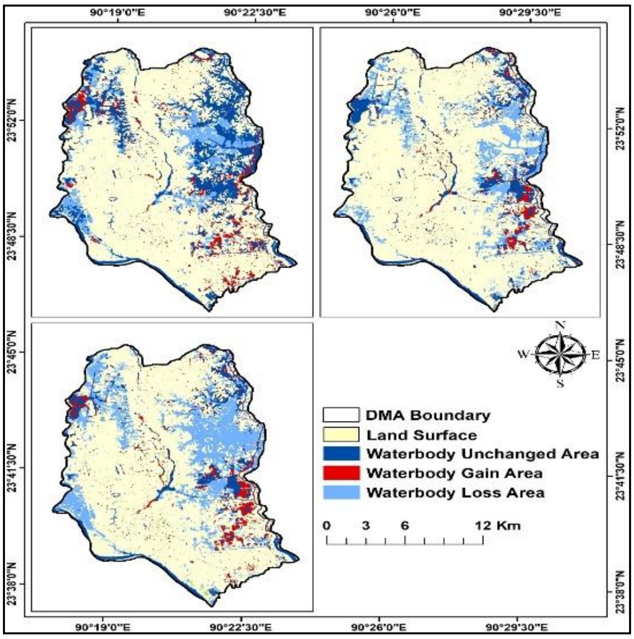

Figure 3: Waterbodies Gain, Loss and Unchanged status during 1992 to 2022

3.3 Change Detection Based on Supervised Classification of Land Cover Analysis Between 1992 to 2022

Change detection analysis of water bodies from 1992 to 2022 was conducted using supervised image classification techniques. Initially, land use and land cover change maps were created for the years 1992, 2007, and 2022 (Figure 5). Subsequently, change maps for the periods 1992 to 2007, 2007 to 2022, and cumulatively from 1992 to 2022 were generated using the Intersect tools of ArcGIS 10.8 software. The transformation of Land Use and Land Cover (LULC) classes from one year to another was visually represented in maps, and data extraction was performed based on changes in land classes. Following the methodology outlined by Islam et al., the magnitude of land use change was calculated using the formula: magnitude of land use change = magnitude of the new year - magnitude of the previous year. The assessment of image classification accuracy and kappa coefficient results confirmed the overall accuracy of the classified images, indicating a satisfactory level of precision in depicting the changes in water bodies over the specified time period. The transition analysis spanning from 1992 to 2022 revealed notable land use changes in the Dhaka metropolitan area. Approximately 33.748 km² of land underwent a transformation from Bare land to Built-up areas, while a more modest 1.065 km² shifted from Bare land to water bodies. The conversion from Vegetation to Built-up areas also exhibited significant changes over the past 30 years, with 18.123 km² of water bodies being converted to Bare land. Built-up areas emerged as a major factor, contributing to the loss of 15.083 km² in water bodies and 27.483 km² in vegetation during the study period (Table 5). Despite these transformations, 23.444 km² of water bodies remained unchanged from 1992 to 2022. These findings underscore the dynamic nature of land use changes, particularly the impact of urbanization on water bodies and vegetation in the Dhaka metropolitan area over the specified study period.

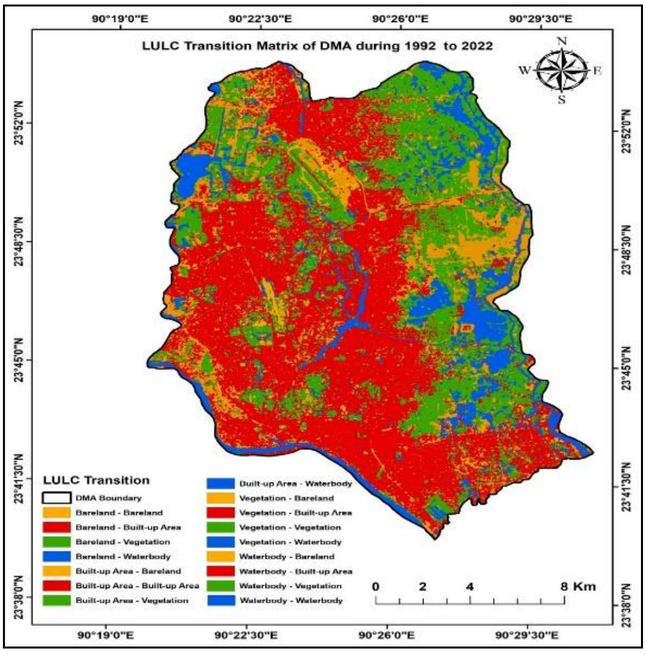

Figure 4: LULC Transition matrix during 1992 to 2022

4. Discussions

As shown in Figure 2, a substantial portion of the metropolitan area was occupied by waterbodies in the eastern and western regions in 1992. By 2007, a discernible decline in waterbodies had been identified, and by 2022, the image depicts the astounding demolition of waterbodies. Speaking about the findings, the city has lost 60.74 sq kilometers of its waterbodies within a period of just 30 years (Table 4). More than half of its waterbodies have disappeared within the last 3 decades of the growth of the city. Md. Mostafizur Rahman also predicted in a study that the extent of waterbody disappearance in the city of Dhaka is severe, with the area decreasing from 85.85 square kilometers in 1990 to 34.94 square kilometers in 2020 (Rahman and Szabó, 2021). It is worth mentioning that this shrinking trend is not discontinuous rather it is following an increasing trend where the waterbodies are constantly being demolished (Figure 4). The loss of waterbodies is a significant problem in the western section of the metropolitan area, which is another cause for concern. Nearly all of the waterbodies of the western part have vanished. Waterbodies in the areas of Mohammadpur, Darus-Salam, and Hazaribag thana have vanished (Figure 4). In 1992, where the vast area of the Turag, Pallavi, Biman Bandar, and Uttara thana used to contain numerous waterbodies, now in 2022, only a small concentration of water is seen only in the Turag thana. As the city is expanding the main stress is being imposed on the peripheral waterbodies of Dhaka city. Especially the canals, lakes ponds, and associated lowlands of the rivers are being transformed into built-up regions to cope with the booming of the city population. It is not only the waterbodies that have been turned into built-up areas, a considerable amount of vegetation and bare land have also been converted into built-up areas (Table 5). But it is worth mentioning that land of vegetation has been tried to be regained as shown in the table, where 10. 420 sq km of bare land, 17.265 sq km of built-up area and 27.483 sq km of waterbodies are estimated to be turned into vegetation but yet the gross greenery of the city is observed to be disappearing (Figure 6).

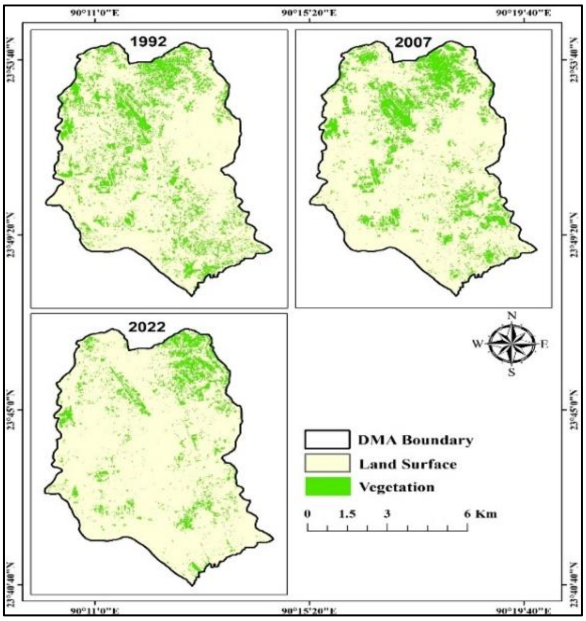

Figure 6: Vegetation coverage during last 30 years

However, in the case of waterbodies, the amount of regained land is negligible, thus we are constantly losing our waterbodies and it can be predicted that prompt and extensive action is badly required to regain and sustain the waterbodies of the Dhaka Metropolitan. Water sources, khals, lakes, canals, and peripheral rivers including the Buriganga, Balu, Turag, and Tongi nourish Dhaka's underground aquifers. For the last few decades, the city has been going through an uncontrolled and unplanned growth that is chaotic, insufficient, and environmentally unhealthy. The consequences of the lack of waterbodies have already been acutely felt by the city dwellers. When the monsoon season arrives, the city of Dhaka regularly sees water logging as a result of the buildup of water in retention areas. During the dry months, the city of Dhaka experiences water shortages, which causes a strain on firemen who are combating major fires. Due to the scarcity of waterbodies during arid seasons, the city's vegetation is also endangered. Certain lakes have been isolated from other components of the surface water systems, which further reduces their utility for holding flood waters and draining them. As a result of the absence of water sources, a variety of issues have arisen, including rising water levels, infections transmitted through the air, and diseases that are spread by mosquitoes. A great deal of complicated and unpredictable causes influences the transformation of Dhaka's waterbodies. Destruction of cropland, vegetation, and wetlands in favor of expanding concrete landscapes has become a characteristic shared by all megacities around the globe, including Dhaka. Human settlement and building construction have been indicated as the main cause of such disappearing nature of waterbodies in many research works by scholars (Amoako-attah et al., 2023; Patra et al., 2018; Priyanka and Priyadharshini, 2021). In the context of Dhaka Metropolitan City, this phenomenon is dominant over other factors, as shown in the Figure, it is clear that the built-up area has occupied most of the area of Dhaka city within the last 30 years (Figure 7). The increasing trend of the built-up area is also shown where estimated that within the timespan from 1989 to 2019, Dhaka Metropolitan has experienced an increase of the built-up area of about 5700.86 hectares (Habib et al., 2020; Habib et al., 2020). In his study Md. Mostafizur Rahman also showed that during the period of the last three decades, the built-up area has raised 188.35% (Rahman and Szabó, 2021).

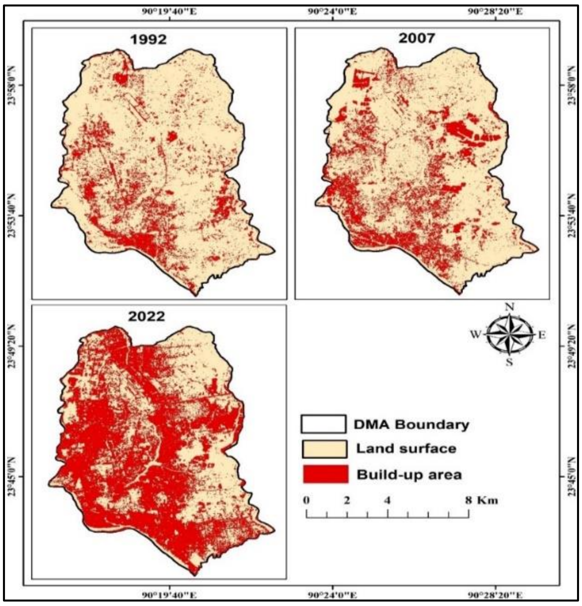

Figure 7: Spatiotemporal variations of built-up area during 1992, 2007 and 2022

Planned and well-managed construction activity would have reduced this rapid trend of waterbody shrinking. Illegal land acquisition of lakes, bills, canals and ponds is one of the major causes of the loss of the waterbody. Every single waterbody in the city is running through this problem. Unplanned domestic, commercial and industrial waste dumping is another prominent reason behind the problem. Some of them simply fill the waterbodies where enriched in chemical ingredients, especially industrial wastes creating phenomena like eutrophication which primarily gives rise to the algal boom that later indirectly results in the shrinkage of waterbody. The drainage system of the city works circling these waterbodies where most of the drains are exposed in these waterbodies which leads to higher sedimentation. Road construction and digging for the plantation of the utility lines make the soils more vulnerable to erosion which results in a higher rate of siltation in waterbodies. The capacity of municipal authorities to plan strategically for the social, environmental, and economic growth of the cities is a critical factor in the creation of sustainable cities (Takyi et al., 2022). Clear delineations of responsibilities among departments are imperative to facilitate the integration of disparate and fragmented local initiatives aimed at resolving water-related land issues within the region and at a local level. A water-sensitive design strategy that is implemented on-site can reduce the incremental building. These types of activities should additionally encourage public participation to facilitate consensus-building among all relevant stakeholders.

5. Conclusion

Dhaka, one of the world's largest cities, faces growing population density and rapid urbanization, which has resulted in a significant loss in urban waterbodies over time. This study combines satellite images and data from 1992, 2007, and 2022 to examine the spatiotemporal changes in these waterbodies and determine the reasons and variables affecting their changes. The study uses complex approaches such as NDWI and supervised classification to examine differences in waterbody coverage utilizing GIS and remote sensing technology. The findings' correctness is carefully validated using pixel-based accuracy tests in land cover categorization and NDWI procedures. The evaluation of waterbody status in the Dhaka metropolitan area over three decades shows a significant drop. The research shows a decline of 32.79 km^2, 41.28 km^2, and 60.74 km^2 in waterbodies between 1992 and 2007, 2007 to 2022, and 1992 to 2022, respectively. A transition study runs from 1992 to 2022 reveals considerable land use changes in the Dhaka metropolitan region. Urbanization, especially the growth of built-up areas, is a significant cause, leading to the loss of 15.083 km^2 of waterbodies and 27.483 km^2 of vegetation over the research period. One of the biggest challenges is the loss of waterbodies, especially in the western half of the city area where urbanization has put tremendous pressure on peripheral waterbodies. To accommodate the rising city population, built-up areas have been developed around canals, lakes, ponds, and the related lowlands of rivers. Human habitation, building development, and unauthorized land acquisition of lakes, canals, and ponds are some of the complex factors contributing to the alteration of waterbodies. Nevertheless, there are a number of drawbacks to using Landsat data to examine dynamic waterbody changes in a metropolis like Dhaka. Because Landsat imagery has a spatial resolution of only 30 meters, it might not be able to depict finely detailed changes within densely populated metropolitan areas or small-scale waterbodies. Another problem is cloud cover, which frequently obscures satellite pictures, especially in the monsoon season. Excluding these drawbacks, ground truth data, prior knowledge about the study location, previous relevant research and secondary data helped to achieve the accuracy of the image classification results for this study. The findings of this research can be used to guide zoning, infrastructure development, and land use planning laws, sustainable urban land use management, allowing for focused conservation and pollution control measures.

Author Contribution Statement

Irteja Hasan and Md Shafiqul Islam: Conceptualization, Formal analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review and editing.

Mehedi Hasan Ovi, Dhiman Kumar Roy, Md Mahmudul Hasan Rakib: Software, Supervision, Validation, Visualization, Writing – original draft,

Md. Touhiduzzaman, Md. Nazrul Islam, Md. Sagirul Islam Majumder and Tania Yeasmin: Contributed materials, Analyzed and interpreted the data; Wrote the paper.

Data Availability Statement

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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