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Geospatial Assessment of Wetland Changes in the Fringe Area of Dhaka City: Past, Present and Future Scenarios

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ABSTRACT: This study examines the changes in wetlands in the fringe area of Dhaka city using geospatial assessment techniques. The wetland in the area is crucial as they serve as a buffer zone for the Dhaka Metropolitan Area (DMA) and play a significant role in maintaining the region's ecological balance. Thirty-meter NASA Landsat 4-5TM and Landsat 8 OLI satellite imagery were used to extract wetland features in the fringe area of Dhaka city. The Modified Normalized Difference Water Index (MNDWI) was applied to delineate wetland features. Finally, ArcGIS geometric computing was used to detect yearly changes, and a Cellular Automaton (CA) Markov Model was applied to predict future transitions. The research findings reveal that wetlands in the Dhaka Metropolitan Area are declining at a rate of 1.1% between 1991 and 2016, indicating the urgency of addressing this issue to ensure the sustainability of the region's natural resources. The percentage of wetlands in the fringe area has been decreasing significantly over the years, with wetlands making up only 12.98% of the fringe area in 2022, down from 28.22% in 1989. This trend is predicted to continue, with wetlands accounting for only 8.02% of the total area by 2034. The strong negative correlation coefficient between the year and wetland area suggests that the trend of decreasing wetland is likely to continue unless significant measures are taken to protect wetlands. The study highlights the importance of conserving and restoring wetlands in Dhaka's fringe areas to maintain the ecological balance of the region and support the well-being of both humans and wildlife.

Keywords: Geospatial Assessment; GIS and Remote Sensing; CA Markov Matrix Model; Simulation; Wetland

INTRODUCTION

Wetlands are the most invaluable components of the natural environment, primarily the soil covered by water. According to the Environmental Protection Agency (EPA), wetlands are areas where water persistently covers the soil. Wetlands include a diverse array of landscapes, from marshes to peatlands. These ecosystems play a crucial role in ecological balance and provide vital services such as water purification, flood control, and habitat for diverse ecosystems (EPA, 2022; Curie et al., 2007). However, the global landscape has witnessed a concerning trend, with approximately 70% of wetland ecosystems facing destruction since the 1990s, attributed largely to factors like agriculture, urbanization, and industrial development (Everard, 2017).

Due to differences in soil composition, topography, hydrology, water properties, vegetation coverage, and human intervention, wetlands exhibit significant local and regional variations. The climate conditions such as climate change is another important factor that is affecting the wetlands in Dhaka. Rising temperatures and changes in rainfall patterns are causing changes in the hydrological cycle, which is leading to the drying up of wetlands (Siddique et al., 2019). In addition, extreme weather events such as floods and storms are becoming more frequent, causing damage to the remaining wetlands (Zaman et al., 2017).

Undoubtedly, wetlands can be found on every continent except Antarctica, ranging from frigid tundras to steamy tropics (Ramsar Convention Secretariat, 2018). Wetland can be divided into two main groups: (1) coastal or tidal wetland and (2) inland or non-tidal wetland. Wetlands are usually located in areas where water flows with slow velocity, largely because the terrain is relatively flat in these regions (Orme, 1990). As wetlands occupy flat landscapes, their surface area tends to expand and contract as water levels change. Consequently, wetlands can store large volumes of water, allowing them to regulate hydrological

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variability by storing floodwaters and reducing flow velocities (US EPA, 2008).

Dhaka, the bustling capital of Bangladesh, vividly exemplifies the repercussions of this global trend. Unplanned urban growth and infrastructure development have precipitated irreversible human-induced impacts, resulting in the shrinkage and compartmentalization of wetland. The consequences of such changes manifest during the wet season, exacerbating waterlogging and drainage congestion issues (Dewan et al., 2006). To comprehend and mitigate these environmental shifts, there arises a pressing need for a comprehensive geospatial assessment.

Justification of the Study

The study proposes a comprehensive geospatial assessment to investigate the impact of rapid urbanization on wetland ecosystems (Wu and Hobbs, 2002; Elmqvist et al., 2013) in Bangladesh. It emphasizes the crucial role wetlands play in maintaining ecological balance (Mitsch and Gosselink, 2007; Zedler and Kercher, 2005) and providing essential services like water purification and flood control. Despite their significance, global trends show a concerning decline in wetland ecosystems (Davidson, 2014; Mitsch et al., 2019) due to factors such as agriculture and urban development.

The study focuses on Dhaka City, where unplanned urban growth has led to the shrinkage and fragmentation of wetlands, exacerbating waterlogging and drainage issues during the wet season. To address these challenges, the research proposes utilizing geospatial tools to analyse historical transformations, current dynamics, and future trajectories of wetlands from 1989 to 2022, with simulations extending to 2028 and 2034 using advanced techniques.

By identifying wetland changes over time and simulating future scenarios, the study aims to provide insights into the complex interactions between urbanization and wetland preservation. It seeks to contribute to both academic knowledge and practical conservation and urban planning efforts by filling a knowledge gap in post-2010 wetland changes in Dhaka's fringe area. Ultimately, the study aims to guide sustainable urban development practices and foster coexistence between urbanization and environmental preservation in Dhaka and beyond.

LITERATURE REVIEW

Wetlands possess significant ecological and economic value, crucial for enhancing water quality, mitigating floods, replenishing groundwater, and retaining sediments. (Curie et al., 2007). Wetlands, vital for diverse ecosystems and human livelihoods, face significant human-induced changes impacting their quality and function. These water-land interfaces play crucial roles in addressing social, economic, and environmental challenges naturally, including carbon storage and climate regulation. Efforts in wetland management and restoration are increasingly integrated into local, national, and international initiatives to mitigate and adapt to climate change, with major complexes like the Sundarban, Mekong river delta, and southern Ontario experiencing evolving effects (Koetze, 1996; Howard, 1995; Roggeri, 1995; Thorslund et al., 2017; McInnes, 2016; Erwin, 2009).

In spite of the critical role of wetlands, since the 1990s, approximately 70% of the wetland ecosystems have been destroyed globally. The degradation of wetlands is often caused by several factors some of which can be site based while others are regional or global (Everard, 2017). One such factor driving the loss of wetlands is agriculture (Everard, 2017). The production of food and other agricultural products consumes up to 70% of freshwater from rivers and groundwater in contrast to only 20% and 10% from the industry and municipalities respectively. These pressures are also set to rise as the economy expands and the demographic grows, which has been predominantly transforming the wetlands (Comprehensive Assessment of Water Management in Agriculture, 2007).

With the increasing rate of urbanization in developing countries (Cox and Watt, 2002; Gerten et al., 2019) such as Bangladesh (Cus and Zuperl, 2006), irreversible human-induced (drainage for agriculture and filling for industrial or residential development) impacts are caused towards wetlands. Dhaka, the capital of Bangladesh, had a record of several wetlands which were drastically reduced over decades as the development of urban areas grew (Kamal and Midorikawa, 2004; Dewan et al., 2006). The development of urbanization or housing projects when unplanned has destroyed the connectivity of water bodies and compartmentalized wetlands resulting in severe waterlogging and drainage congestion in Dhaka during the wet season (Dewan et al., 2006). It is also worth mentioning that due to the infilling of wetland areas, recharge areas for groundwater have decreased dramatically, which will eventually lead to the depletion of the groundwater level (Mahmud et al., 2011) thus emphasizing the importance of the conservation of wetland areas. Wetlands are important for maintaining the ecological balance of a region, providing various ecosystem services such as water purification, flood control, and habitat for biodiversity. However, the wetlands are under threat due to rapid urbanization and industrialization in recent years (Alam et al., 2018).

In monitoring changes in wetlands especially in areas where little information is being collected, remote sensing can be of significant use. Through the derivation of multi-source satellite images, spatial science such as remote sensing has been used with various advantages for assessing wetland dynamics, especially for large areas (Orimoloye et al., 2019). Both the feature classification method and thematic information detection method can be used to monitor wetlands where several indices are employed within the thematic information detection method such as the Normalized Difference Water Index (NDWI), Normalized Difference Moisture Index (NDMI), Modified Normalized Difference Water Index (MNDWI), and Automated Water Extraction Index (AWEI) (McFeeters, 1996; Rouse et al., 1973; Wilson and Sader, 2002). Furthermore, in principle, when a chain of chance experiments is being monitored, all past outcomes can influence the predictions for the next experiment (García-Mora et al., 2010; Carmen et al., 2009), making a continuous-time Markov process suitable for wetland simulation of dynamic change. Consequently, studies have integrated Remote Sensing, GIS and the Markov chain model to simulate the land-use changes in continuous periods and discrete-time periods (Aaviksoo, 1993; Muller and Middleton, 1994; Zhang et al., 2011). Even though the role of wetlands in climate changes adaptation and mitigation has been recognized (Hossain and Szabo, 2017), not many studies have addressed the time-series nature of the dynamics of wetlands.

The study conducted by Islam et al., 2017 aimed to assess the spatial changes of wetlands in the Dhaka fringe area of Bangladesh using remote sensing and GIS techniques. The authors analyzed satellite images from 1989, 2000, and 2010 and found that the total wetland area decreased by 36% over the period, with a significant loss in the northeast and southwest parts. The study highlights the importance of understanding wetland change patterns and its implications for environmental management and conservation efforts.

Remote sensing and GIS techniques have been widely used to monitor and assess the changes in wetland extent and composition in the fringe areas of Dhaka. Several studies have revealed that the wetland area in Dhaka has decreased significantly over the years, with some wetlands disappearing altogether (Siddiqui et al., 2018; Kamal et al., 2019).

One of the main reasons for wetland loss is the conversion of wetlands to other land uses such as agriculture, urbanization, and infrastructure development (Islam et al., 2018; Islam et al., 2020). The wetlands in the urban fringe areas are particularly vulnerable to conversion due to the increasing demand for land (Haq et al., 2019). The loss of wetlands has significant implications for the ecosystem services they provide, such as flood control and water purification. Furthermore, it has an impact on the region's biodiversity.

Efforts have been made to conserve and restore the wetlands in Dhaka. The Bangladesh government has established wetland conservation policies and programs to protect the remaining wetlands (The Bangladesh Water Act, 2013). However, the effectiveness of these policies and programs needs to be evaluated, and more action is needed to prevent the further loss of wetlands in Dhaka (Hossain et al., 2018).

The other important study suggests that the amount of land has decreased by around 2% from 1998 to 2010 (Rahman, 2022). The ecological balance and local population welfare are significantly impacted by the loss of wetlands. After 2010, however, there are no documentation of the wetland change in the Dhaka Fringe Area (Chikodzi et al., 2014). Due to the loss of the city's wetlands and other natural areas, the fringe area is already being approached. Therefore, it is of utmost importance to researchers and policy makers to raise awareness of the need to protect Dhaka's ecological landscape.

Objectives of the Study

The primary aim of this study is to identify changes in wetland from 1989 to 2022 and make predictions for the years 2028 and 2034 in the fringe areas of Dhaka to maintain its ecological sustainability. The specific objectives are:

(i) To identify the wetland areas and its changes for the years 1989, 1995, 2006, 2016 and 2022.

(ii) To simulate wetlands for the years 2028 and 2034 using a Cellular Automaton CA Markov Matrix.

(iii) To create a matrix showing how pixels shift between land and wetlands over different time periods.

The preceding section will discuss the materials and methods of the study, followed by the results section, and finally, the summary and conclusion will be discussed.

MATERIALS AND METHOD

Study Area

Over the last five decades, Dhaka has witnessed unprecedented level of urbanization. Dhaka, as the capital and a city surrounded by rivers, seems to have a high migration rate of people seeking greater services from other cities; as a result, the strain on the fringe areas has grown spatially in all directions. Urban sprawl, also known as unplanned urbanization, is a market-driven phenomenon characterized by the inefficient spatial expansion of urban, peri-urban, and natural territories. The fringe region of Dhaka city has been chosen as the study area to measure the effects of urbanization on wetland areas. It is located between the latitudes of 23.53°N and 24.05°N, and the longitudes of 90.18°E and 90.64°E, respectively. The overall area is 1322.69 km^2 and is divided into five zones (Fig. 1). The northern region is under Gazipur, the eastern region is under Rupganj and partially Kaliganj, the southern region is under Sonargaon and Narayanganj Sadar, the southwestern region is under Sonargaon and Narayanganj Sadar, and the western region is under Savar. The area is bordered on the north by the Turag, Bangshi, Balu River, and Tongi Khal; on the east by the Turag, Bangshi, Balu River, and Tongi Khal; on the south by the Dhakeshwary, Brahamaputra, Meghna, Ichamati, and Buriganga River; and on the west by the Dhakeshwary River, Karnatali River, Buri River, and Buriganga River.

The geological features of the Dhaka city fringe area reflect its diverse landscape primarily shaped by the presence of various rivers. It mainly comprises flat alluvial plains formed by sediment deposition carried by the surrounding rivers, enriching the soil and supporting agricultural activities. Situated within the Bengal Basin, the area is characterized by thick sedimentary deposits of sands, silts, and clays resulting from the convergence of the Ganges, Brahmaputra, and Meghna rivers.

Rivers such as the Turag, Bangshi, Balu, Dhaleshwari, Brahmaputra, Meghna, Ichamati, and Buriganga have played a significant role in shaping the landscape through erosion, sedimentation, and meandering patterns. They not only serve as water sources for irrigation and transportation but also influence the distribution of wetlands and floodplains.

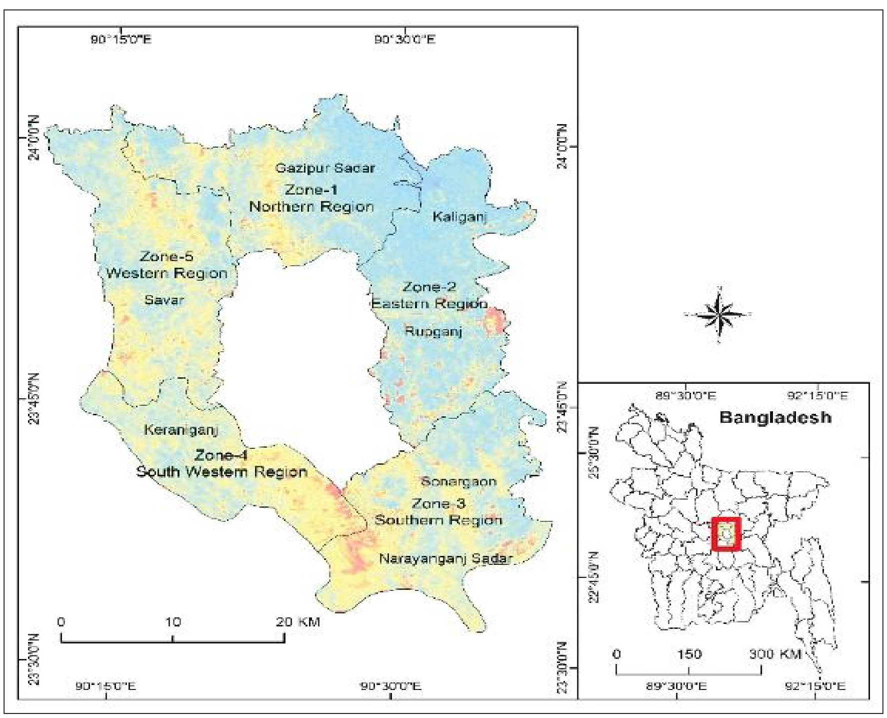


Figure 1: Dhaka City Fringe Area: The Present Study Area

Based on the SRTM DEM data, the elevation of the Dhaka city fringe area ranges from 1 meter to 58 meters (SRTM DEM, 2000). The southern and southwestern regions of the area are characterized by lower elevations, while the northern, eastern, and western regions exhibit gradually increasing elevation. The majority of the study area lies between the 5 to 10-meter contour lines, which primarily comprise wetlands. A significant portion of the area falls within the 10 to 20-meter contour lines, with only a small fraction of the area exceeding the 20-meter contour line.

Data Sources

In this study, both primary and secondary sources of data were taken into account. The primary data were obtained from topo sheets with a scale of 1:50,000, which were collected from the cartographic lab in the Department of Geography and Environment at the University of Dhaka. The secondary data included satellite imagery, specifically Landsat 4-5 TM data for the years 1991, 2001, and 2011, as well as Landsat 8 OLI data for 2016 and Landsat 9 OLI for 2022. All satellite data were obtained from USGS GloVis with 30m spatial resolution and the details of those are summarized in Table 1. The images were collected in November, taking into consideration the clear sky conditions at that time.

Table 1: Specification of Satellite Data

Satellite	Sensor	Path/ Row	Acquisition Date	Cloud Cover	Land Cloud Cover	Resolution
Landsat 4-5	TM	137/44	20/11/1989	0`	0	30m
			21/11/1995	0	0	
			19/11/2006	0	0	
Landsat 8	OLI	137/44	14/11/2016	0.19	0.19	
Landsat 9			01/12/2022	0.19	0.19	

Source: https://glovis.usgs.gov/

Method

The following method was used to identify and analyze wetland changes in the Dhaka city fringe areas using satellite images and can be broken down into several steps (Fig. 2). **Firstly**, the acquired images were downloaded and processed using layer stacking, mosaicking, and rectification corrections to enhance their quality and align them spatially. **Secondly**, the area of interest (AOI) was separated from the datasets. **Thirdly**, the iso cluster unsupervised classification and maximum likelihood classification techniques were used to extract information on land and wetlands based on their spectral values. Wetlands were specifically identified using the NDWI (Normalized Difference Water Index) and MNDWI (Modified Normalized Difference Water Index). **Fourthly**, the extracted data on land and wetlands were validated and classified into two groups: land and wetlands. **Fifthly**, maps, tabular reports, and tests were conducted to analyze the data and identify changes in the wetlands over time. **Sixthly**, land and wetlands scenarios were simulated for the years 2028 and 2034 using the Markov model based on the data from 2016 and 2022. **Seventh**, the ArcGIS combinatorial analysis tools were used to identify shifting land and wetlands over time periods ranging from 1989 to 1995, 1995 to 2006, 2006 to 2016, and 2016 to 2022, as well as to make predictions for 2022-2028 and 2028-2034. Finally, the results of the analysis were used to interpret the changes in wetlands in the Dhaka city fringe areas over the years. The identified land and wetlands were classified according to the given information in Table 2.

Cellular Automaton (CA) Markov Model

In this research study, a sophisticated modeling approach known as the Cellular Automaton (CA) Markov model (Wolfram, 1983; Pizzi and Gattuso, 1997; Tang et al., 2013) was employed to simulate and forecast wetland changes in the fringe area of Dhaka City for the years 2028 and 2034. This approach enables a comprehensive understanding of how wetlands in this region may evolve over time, aiding in effective land management and conservation planning.

- **Input Data and Variables:** The modeling process heavily relies on robust input variables derived from Wetland Change data, covering the years 2016 to 2022. These critical input variables encompass three main components:

Firstly, the Transitional Rules govern how individual wetland cells transition from their current state to a new state in each time step (Traill et al., 2011). These rules are essential as they capture the local dynamics of wetland changes, providing insights into the underlying mechanisms driving wetland evolution.

Secondly, the Transition Area Matrix (Remond-Noa et al., 2022) for the year 2028 plays a pivotal role in the modeling process. This matrix outlines the probabilities of transitioning from one wetland state to another during the modeling process. By incorporating data specific to the year 2028, it facilitates the projection of future wetland scenarios, aiding in understanding potential changes over time.

Lastly, the Markovian Conditional Probability Image for 2028 serves as a foundational element in the modeling framework. This image provides a probabilistic representation of how wetland states may evolve over time. By guiding the CA Markov model's (Gagniuc, 2017; Ross, 2014; Ross, 1995; Meyn and Tweedie, 2012; Ethier and Kurtz, 1986) decision-making process, it enhances the accuracy and reliability of the projected wetland scenarios, enabling better-informed land management and conservation planning efforts.

- **Modeling Process:** The modeling process commences with an Initialization phase, where the foundational conditions of the wetland landscape as of 2016 are set as the basis for the simulation (Memarian et al, 2012). Following this, the CA Markov Model (Beroho et al., 2023) for the year 2028 is engaged. This step encompasses the utilization of the CA Markov model to foresee the state of the wetlands in 2028. It involves a systematic assessment and adjustment of individual wetland cells, guided by the transitional rules and the transition area matrix specific to the year 2028. Subsequently, a simulated wetland map is generated, illustrating the anticipated conditions for 2028.

Post-simulation, the Evaluation and Validation (Verbitsky and Crucifix, 2023; Hsieh, W. W., 2023) stage for 2028 ensues. This phase entails a meticulous examination of the simulated outcomes for 2028, comparing them rigorously with real-world observations or ground truth data. Furthermore, the validation process is fortified by actively engaging with local communities and stakeholders, thereby ensuring the precision and dependability of the simulated results.

Following this, the modeling process repeats for the CA Markov Model for the year 2034. Here, the same framework and input data are employed to project the wetland scenario (Yusoff et al., 2023) for 2034. This iterative process involves scrutinizing transitional rules and leveraging the transition area matrix tailored to 2034.

The detailed workflow of the data analysis method is given below (Fig. 2).

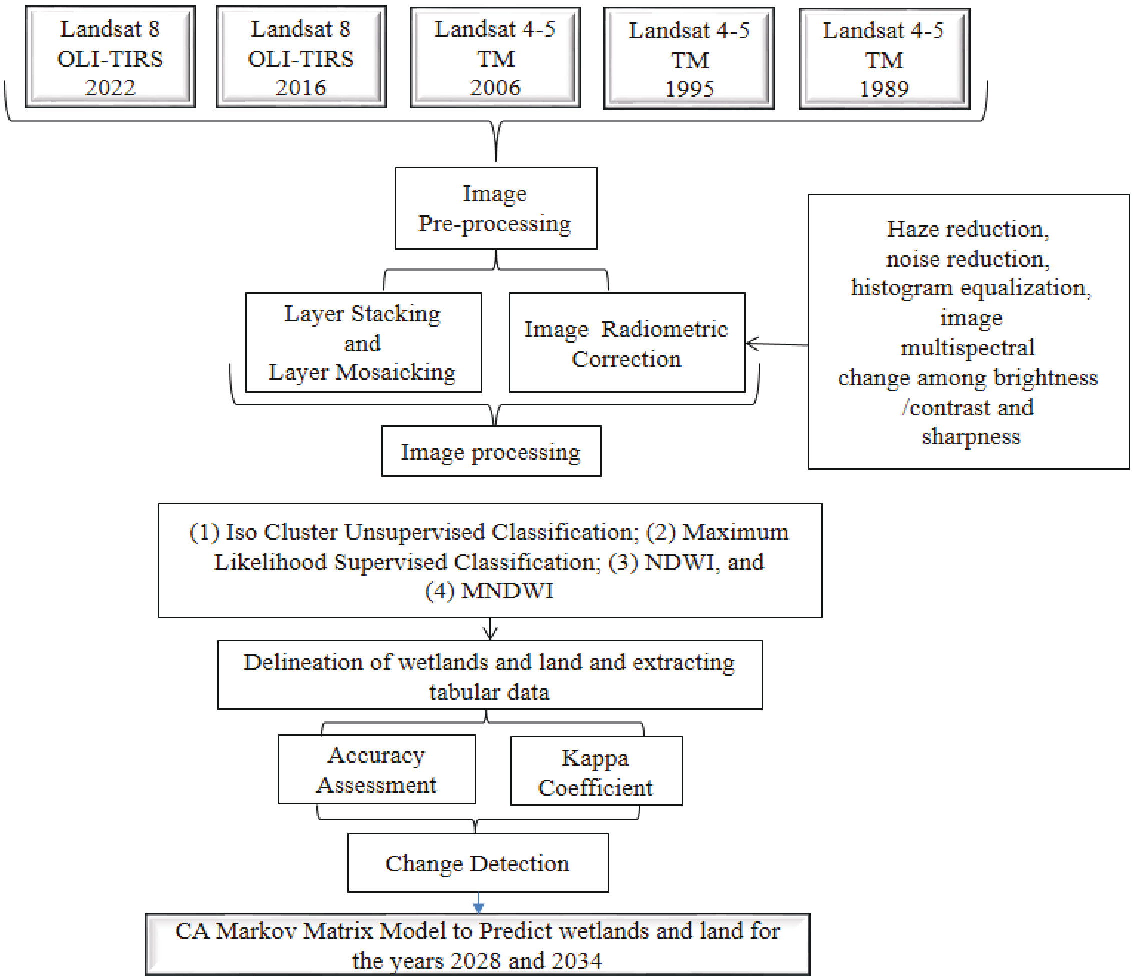


Figure 2: Flow Chart of Research Method

Table 2: Description of Land and Wetlands

Land and Wetlands	**Description**
Land	This category includes landfills and bare areas, as well as areas used for residential, commercial, service, transport, communication, and crop fields. It also includes areas covered by natural and man-made forests, as well as other types of vegetation.
Wetlands	This category encompasses permanent and seasonal wetlands, low-lying areas, marshy lands, rivers, and khal (water channels).

Source: Based on image analysis

Accuracy Assessment

To assess the accuracy, 385 samples were verified for various years using historical images and Google Earth Pro. For this purpose, absolute errors (misclassification), overall accuracy, and Kappa coefficient (agreement between the predicted and actual classifications) were calculated using following formulas.

$$\text{Overall Accuracy} = \frac{\text{Total number of correctly classified pixels (diagonal)}}{\text{total number of reference pixels}} \times 100$$

$$\text{Kappa Coefficient (T)} = \frac{(TS \times TCS) - \sum(Col.tot \times Row.tot)}{TS^2 - \sum(\text{col. tot} \times \text{Row. tot})} \times 100$$

RESULTS AND DISCUSSION

Accuracy Assessment

According to the assessment, in 1989, there was a 5.0% absolute error, meaning the same amount of wetland areas were misclassified, while 95.0% were correctly classified, and the Kappa coefficient was 0.90. In 1995, there was a 3.33% absolute error, with 96.67% of the wetland areas being correctly classified, and the Kappa coefficient was 0.93. Furthermore, in 2006, the absolute error was 5.0%, with 95.0% overall accuracy, and the Kappa coefficient was 0.90. In 2016, there was a 1.67% absolute error, with 98.33% of the wetland areas being correctly classified, and the Kappa coefficient was 0.97. Finally, in 2022, the misclassification rate was 3.33%, with 96.67% overall accuracy, and the Kappa coefficient was 0.93 (Table 3).

Overall, the accuracy assessment indicates consistently high overall accuracy and Kappa coefficient values for all years, indicating a high degree of agreement between the predicted and actual classifications of wetland areas. The misclassification rates (absolute accuracy) show some variability over time, with the lowest rate observed in 2016, indicating a higher degree of accuracy in predicting wetland changes for that year.

Table 3: Accuracy Assessment

Year	Absolute Errors (Percent)	Overall Accuracy (Percent)	Kappa Coefficient (T)
1989	5.0	95	0.9
1995	3.33	96.67	0.93
2006	5.0	95	0.9
2016	1.67	98.33	0.97
2022	3.33	96.67	0.93

Source: Satellite images and Google Earth Pro

Land and Wetlands in the Fringe Area of Dhaka City: Past and Present Scenarios

The fringe area of Dhaka comprises a network of wetlands, which are important for maintaining the local ecology, providing habitat for aquatic flora and fauna, and serving as a buffer against natural disasters.

Table 4 and Figure 3 indicate that the land area has been steadily increasing over the years 1989–2022 in the fringe areas of Dhaka city. In 1989, the land area in the fringe area was 71.78% (Fig. 3a), which rose slightly to 75.03% by 1995 (Fig. 3b). By 2016, the percentage had risen to 82.51% (Fig. 3d) from an earlier figure of 80.30% (Fig. 3c). The land area in the fringe area finally expanded to 87.02% in 2022 (Fig. 3e). Over the entire duration, spanning from 1989 to 2022, the wetland area experienced a cumulative reduction of 15.24%. Consequently, the average annual decrease in wetland area from 1989 to 2022 was approximately 0.46% (Table 4). This pattern suggests that the area has undergone significant urbanization and development, with an increase in the conversion of land for residential, commercial, and industrial uses. The correlation coefficient (r) between the year and land area is very high at 0.99, indicating a strong positive relationship between the two variables (Fig. 4).

Table 4: Land and Wetlands in the Fringe Area of Dhaka City from 1989 to 2022

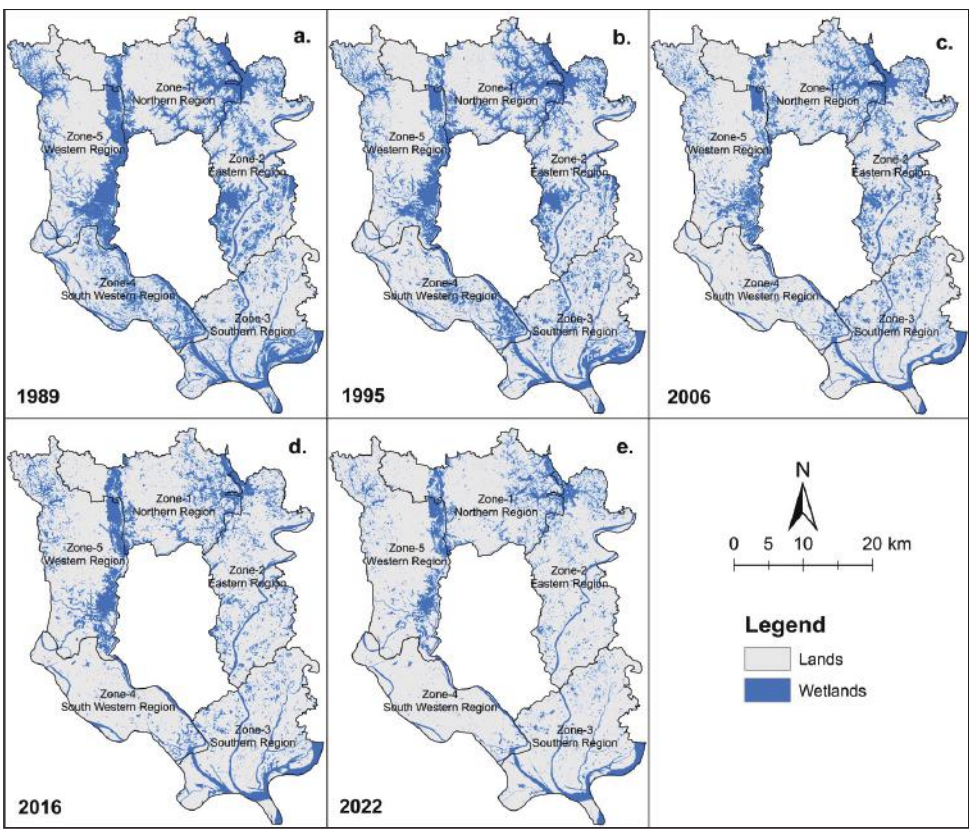
Year	Land (km^2)	Per-cent	Wetlands (km^2)	Percent
1989	949.43	71.78	373.26	28.22
1995	992.37	75.03	330.32	24.97
2006	1062.08	80.3	260.61	19.7
2016	1091.33	82.51	231.36	17.49
2022	1151.03	87.02	171.66	12.98

Source: Result of Landsat image analysis from https://earthexplorer.usgs.gov/

However, the negative environmental effects of such rapid urbanization, including increased air and water pollution, a loss of biodiversity, and the destruction of natural ecosystems, must be taken into consideration. Thus, it is crucial for policymakers and urban planners to adopt a balanced approach to development that considers the social, economic, and environmental effects of urbanization. On the other hand, Dhaka's fringe wetlands have been threatened by rapid urbanization and industry, which has resulted in significant encroachment and degradation of the wetlands. The data analysis results indicate a continuous decline in the extent of wetlands in the fringe area of Dhaka over the years (Table 4).

By 1995 the wetlands' share of the fringe area had dropped to 24.97% from its 1989 level of 28.22. By 2006, this percentage had decreased further to 19.70%, and by 2016, it stood at a mere 17.49%. Eventually, in 2022, wetlands only made up 12.98% of the fringe area, showing that they have significantly decreased over the previous few decades (Fig. 4). The correlation coefficient (r) between the year and the amount of wetlands is also very high, at -0.987, with a p-value of 0.0002, indicating a strong negative relationship between the two variables. (Fig. 4).

Furthermore, the strong negative correlation coefficient (r = -0.987) value suggests that the percentage of wetlands in the Dhaka fringe area has been decreasing significantly over the years (Fig. 4), and this trend is likely to continue unless significant measures are taken to protect and conserve the remaining wetlands. Policymakers and urban planners must take a more balanced approach to development that takes into account the social, economic, and environmental impacts of urbanization.

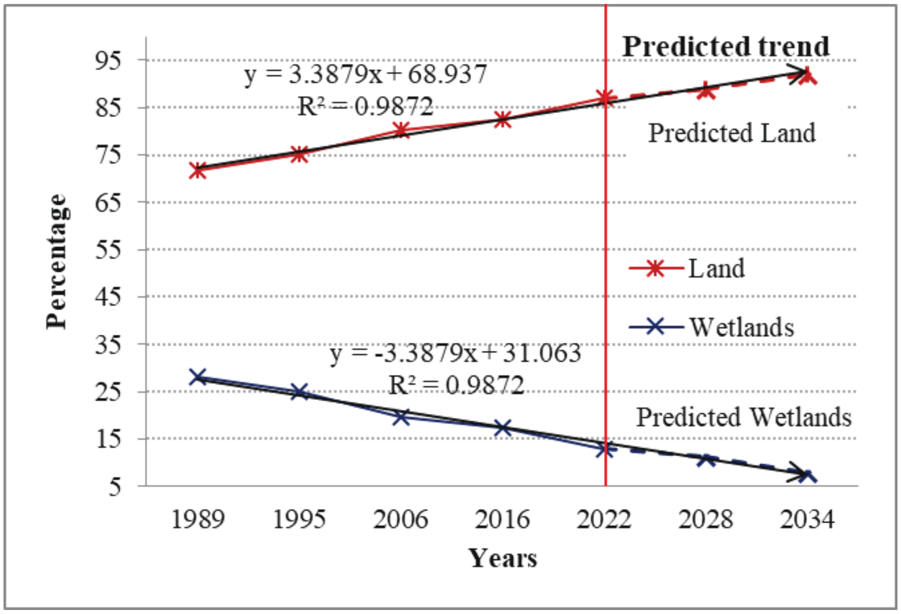


Source: Results of Landsat image analysis from https://earthexplorer.usgs.gov/

Figure 3: Spatial Distribution of Land and Wetlands in the Dhaka City Fringe Area a) 1989, b) 1995, c) 2006, d) 2016 and e) 2022

Based on this information, we can conclude that the size of the wetlands in the Dhaka fringe area has been decreasing rapidly over the past few decades. This trend is likely to continue unless significant measures are taken to protect and conserve the wetlands.

It is important to note that correlation does not necessarily imply causation, so further investigation would be needed to determine the underlying reasons for the decrease in the size of the wetlands. However, this information can serve as a warning of the potential environmental impact of human activities and can help guide efforts to protect and preserve these important natural resources.



Source: Results from Landsat image analysis from https://earthexplorer.usgs.gov/

Figure 4: Trends of Land and Wetlands Changes in the Dhaka City Fringe

Future Scenario of Wetlands Change in the Fringe Area of Dhaka City

According to the data, there is a significant increase in the percentage of land area and a corresponding decrease in the percentage of wetlands area. In 2028, land accounts for 88.8% of the total area, while wetlands account for 11.2%. By 2034, the percentage of land increases to 91.98%, while the percentage of wetlands decreases to 8.02% (Table 5 and Fig. 5).

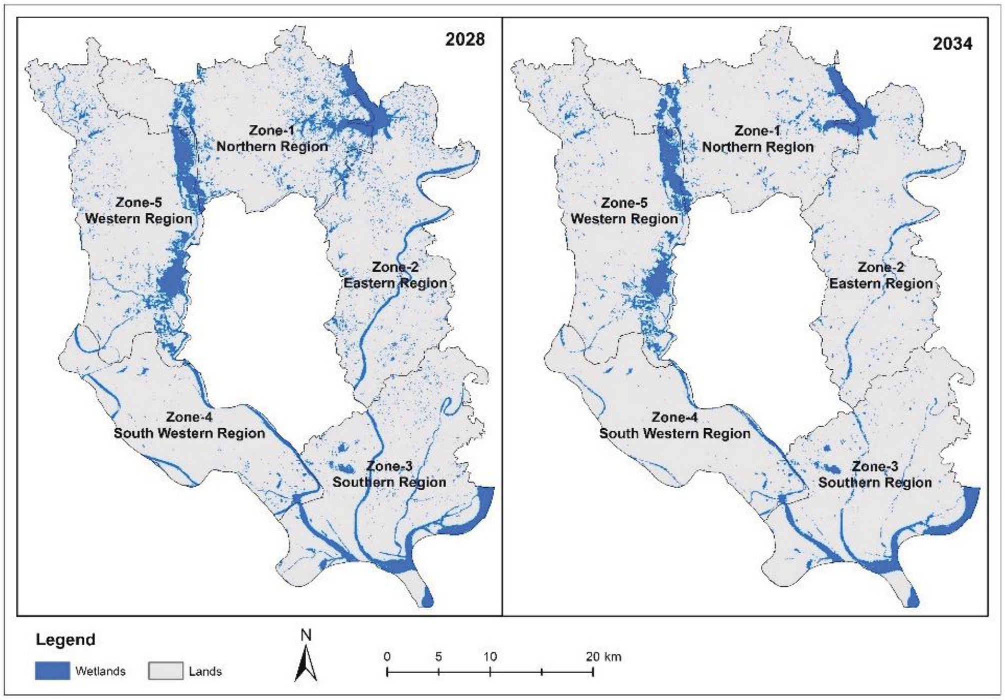
This trend indicates that there is a clear shift towards land development and urbanization in the Dhaka city fringe area. This can have several implications, including the loss of important ecosystems, potential negative impacts on biodiversity, and increased risk of flooding and other natural disasters.

It is important to carefully consider the long-term effects of such development and to implement sustainable and environmentally responsible practices to mitigate any negative impacts. Conservation and restoration efforts should also be considered to protect and preserve the remaining wetlands in the area.

Table 5: The Predicted Statistics of Land and Wetlands in the Dhaka City Fringe Area for the Year 2028 and 2034

Year	Land (km^2)	Percent	Wetlands (km^2)	Percent
2028	1174.54	88.80	148.15	11.20
2034	1216.61	91.98	106.08	8.02

Source: Results simulated using Markov Matrix Model from Landsat image analysis from https://earthexplorer.usgs.gov/



Source: Results simulated using Markov Matrix Model from Landsat image analysis from https://earthexplorer.usgs.gov/

Figure 5: The Predicted Spatial Distribution of Land and Wetlands in the Dhaka City Fringe Area for the Year 2028 and 2034

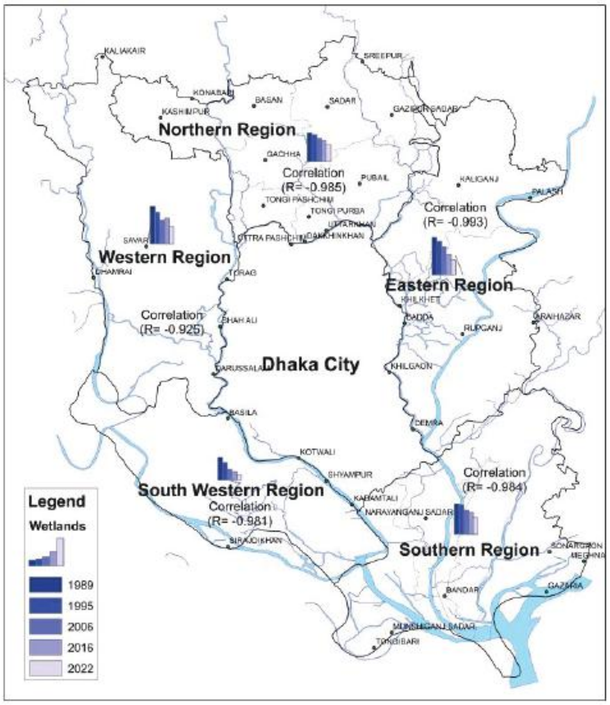
Zonal Statistics of Wetlands in the Fringe Area of Dhaka City: Past and Present

According to the data, the wetlands in the fringe areas of Dhaka city have been decreasing in different regions and years, as shown in Figures 6 and 7 and Table 6. The wetlands of the northern region were at 5.19% in 1989, which experienced a slight decline from 4.85% in 1995 to 4.17% in 2006. Furthermore, there was a significant change in wetland changes between 2016 and 2022. In 2016, the wetlands of the northern region accounted for 3.82%, which will be followed by 3.06% in 2022. So, we can say that the encroachment started significantly in 2016 and increased over the period of time. On the contrary, the southern region tended to be almost the same between 1989 (5.475%) and 1995 (5.3%). It drastically dropped from 4.26% in 2006 to 3.87% in 2016. The wetland changes in 2022 were a modest 3.01% decrease.

In the eastern region, the wetland was 6.77% in 1989, which was changed negligibly to 6.01% in 1995. In 2006, there was a 5.11% decrease in the change of wetlands. Furthermore, the eastern region's wetland decreased dramatically from 3.7% in 2016 to 2.71% in 2022. Besides, wetland coverage in the south-western region was 4.05% in 1989; it had considerably decreased to 3.2% by 1995. The change of wetlands had a sharp reduction in 2006, dropping by 1.91%. Moreover, the wetland in the south-western area had a dramatic decline, from 1.47% in 2016 to 1.01% in 2022. In contrast, wetland cover in the western region was 6.74% in 1989, a modest decrease from 5.61% in 1995. In the year 2006, it decreased to 4.26%. Further, the changes to the wetland between 2016 and 2022 underwent a significant change. Wetlands in the western area made up 4.64% of the area in 2016, and are expected to increase to 3.18% by 2022.

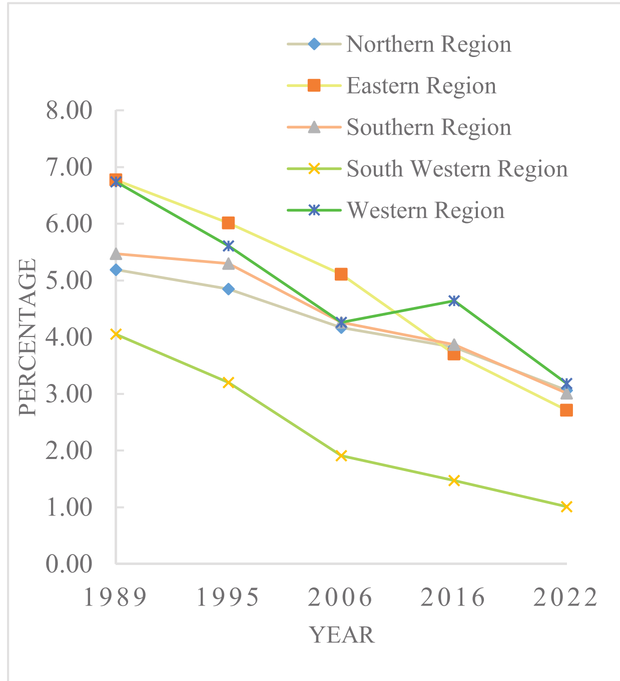
According to the data, it indicates that the wetlands in each part of the study area have a strong negative correlation. Over the period of time, the wetland shifting of the eastern region has shown the strongest correction (R = -0.993). Following this, the northern region has exhibited almost the same trend (R = -0.985). Additionally, the southern (R = -0.984) and south-western (R = -0.981) regions have illustrated a larger negative association than the western region (R = -0.925).

Overall, encroachment is greater in the northern and eastern regions than in other regions over time. The southern and south-western regions presented a moderate encroachment, while a slight encroachment was made by the western region in comparison to the others.



Source: Results from Landsat image analysis from https://earthexplorer.usgs.gov/

Figure 6: Zonal Wetlands Changes between 1989 and 2022 in the Fringe Area of Dhaka City



Source: Results from Landsat image analysis from https://earthexplorer.usgs.gov/

Figure 7: Trends of Zonal Wetlands Changes in Dhaka City Fringe Area

Table 6: Zonal Change and Distribution of Wetlands in the Fringe Area of Dhaka from 1989 to 2022

Regions/Zones	1989	1995	2006	2016	2022	Correlation, R
Northern Region	5.19	4.85	4.17	3.82	3.06	-0.985
Eastern Region	6.77	6.01	5.11	3.7	2.71	-0.993
Southern Region	5.47	5.3	4.26	3.87	3.01	-0.984
South Western Region	4.05	3.2	1.91	1.47	1.01	-0.981
Western Region	6.74	5.61	4.26	4.64	3.18	-0.925

Source: Results from Landsat image analysis from https://earthexplorer.usgs.gov/

Past and Present Scenarios of Land and Wetlands Transition Matrix

The data shows that during the period of 1989-1995, a significant amount (67.13%) of the land was fixed in the land sector. Additionally, a small portion (4.48%) of the land was converted to wetlands during this period, while 20.37% of the wetlands remained fixed in the wetlands sector. Moreover, a significant portion (8.01%) of the wetlands was converted to land between 1989 and 1995 (Fig. 8 and 9 and Table 7).

In the next period, between 1995 and 2006, 71.59 percent of the land remained in the land sector, while the percentage of land converted to wetlands decreased slightly to 3.44%. Furthermore, the wetlands sector decreased to 16.27%, while the conversion of wetlands to land increased to 8.71%.

Furthermore, from 2006 to 2016, the percentage of land cover increased to 74.03%, while the percentage of land converted to wetlands increased significantly to 6.23%. On the other hand, the coverage of wetlands continued to decrease to 11.34%, while the significance of wetlands converted to land was 8.40%, and this trend has slightly decreased.

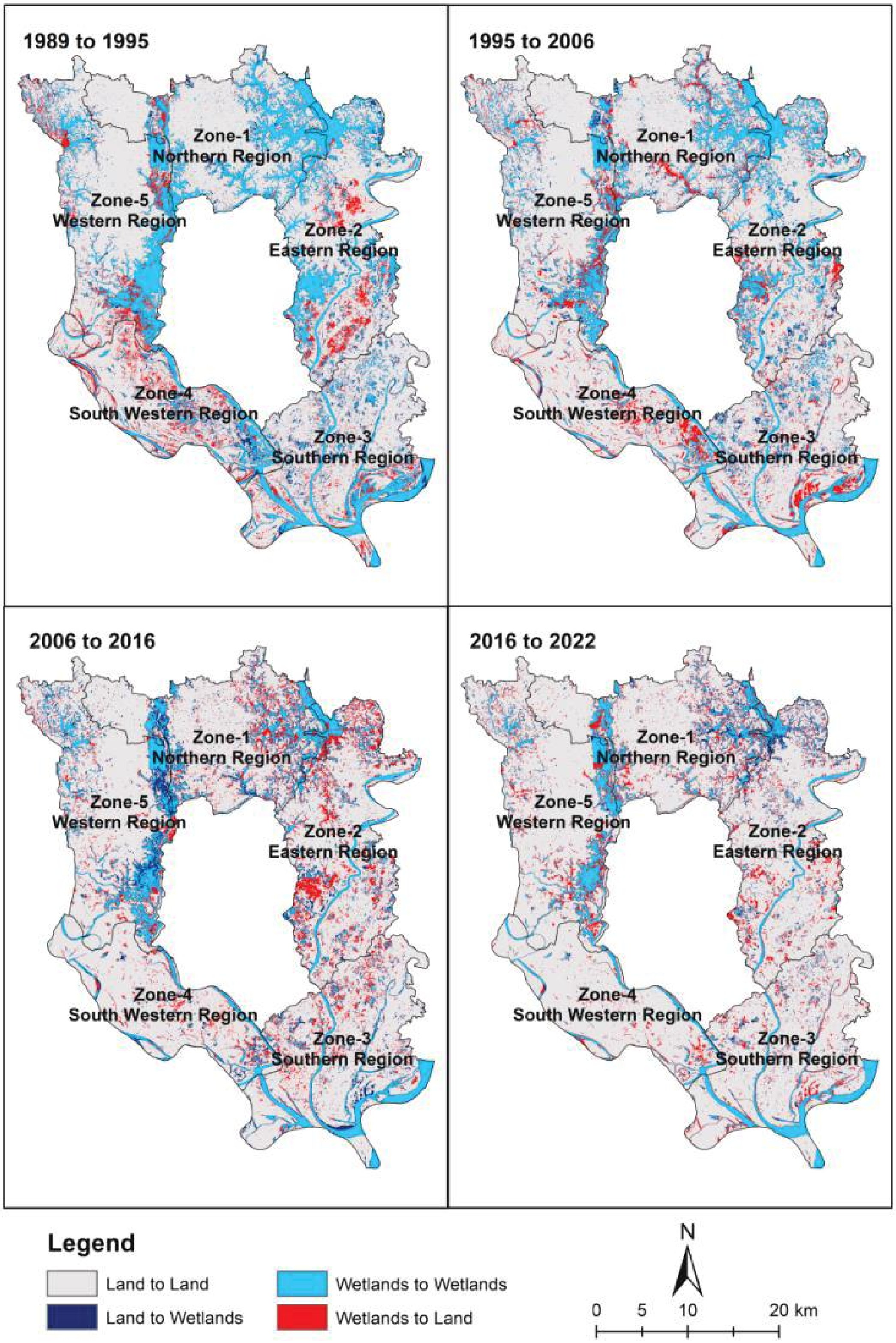
Finally, from 2016 to 2022, the percentage of land area has increased to 79.33%, while the percentage of land area converted to wetlands has decreased significantly to 2.97%. Additionally, the percentage of wetlands has continued to decrease to 10.24%, while the conversion of wetlands to land area has decreased slightly to 7.47%.

Overall, the data suggests that there has been a significant amount of land conversion in the fringe area of Dhaka city, particularly from land to land. There has also been some conversion of wetlands to both land and other wetlands, although this has fluctuated over the years. The decrease in wetland conversion between 2016 and 2022 may be a positive development for the preservation of the area's natural resources.

Table 7: Transitional Matrix of Land and Wetlands in the Dhaka City Fringe Area from 1989 to 2022

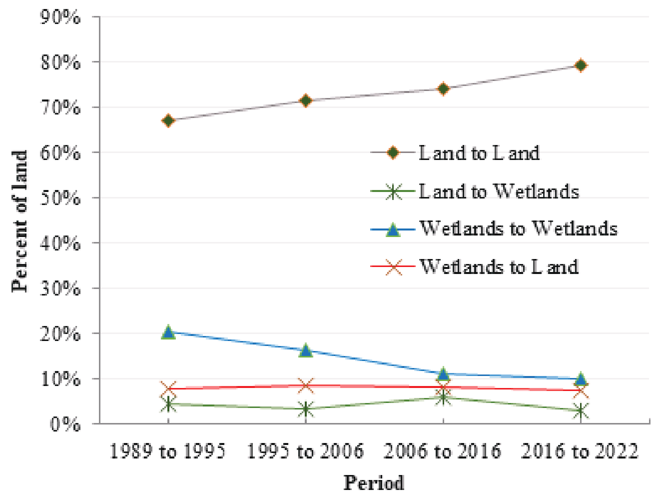
Duration	1989 to 1995		1995 to 2006		2006 to 2016		2016 to 2022	
Categories	Area (km^2)	(%)	Area (km^2)	(%)	Area (km^2)	(%)	Area (km^2)	(%)
Land → Land	887.98	67.13	946.92	71.59	979.25	74.03	1049.28	79.33
Land→ Wetlands	59.26	4.48	45.46	3.44	82.43	6.23	39.23	2.97
Wetlands → Wetlands	269.45	20.37	215.16	16.27	149.96	11.34	135.40	10.24
Wetlands → Land	105.99	8.01	115.16	8.71	111.04	8.40	98.79	7.47
Total	1322.69	100	1322.69	100	1322.69	100	1322.69	100

Source: Results from Landsat image analysis from https://earthexplorer.usgs.gov/



Source: Results from Landsat image analysis from https://earthexplorer.usgs.gov/

Figure 8: Matrix of Land and Wetlands Changes from 1989 to 2022



Source: Results from Landsat image analysis from https://earthexplorer.usgs.gov/

Figure 9: Trend of Land and Wetlands Transitional Matrix in the Fringe Area of Dhaka City from 1989 to 2022

Future Scenarios of Land and Wetlands Transitional Matrix

Looking at the data (in Table 8 and Fig. 10), we can see that there is a slight increase in the percentage of land-to-land changes from 83.82% in 2022 to 87.39% in 2028–2034. This indicates that most of the land in the Dhaka city fringe area is likely to remain as land in the coming years.

The percentage of land converted to wetlands also decreases, from 3.06% in 2022-2028 to 1.09% in 2028-2034.This suggests that the conversion of land into wetlands is expected to decrease over time.

The percentage of wetland to wetland changes remains relatively stable, with a slight decrease from 8.26% in 2022–2028 to 7.22% in 2028–2034. This indicates that the wetlands in the area are likely to remain relatively stable in the coming years.

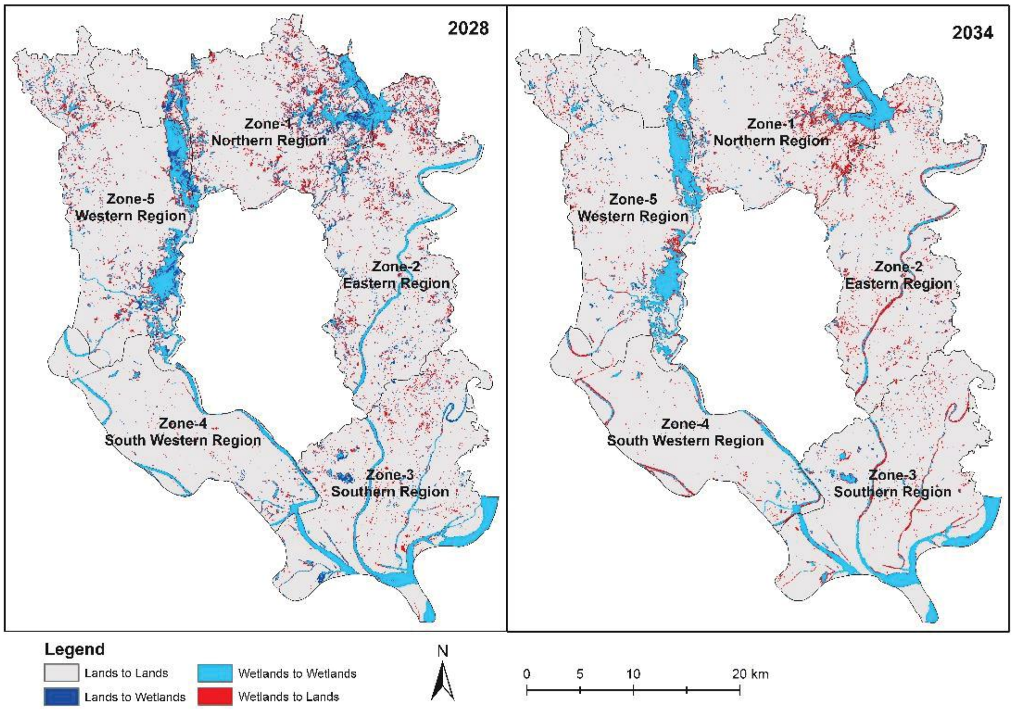
Finally, the percentage of wetland to land changes is expected to decrease slightly from 4.86% in 2022–2028 to 4.31% in 2028–2034. This suggests that the conversion of wetlands into land is likely to decrease over time.

Overall, the data indicates that the Dhaka city fringe area wetlands are likely to remain relatively stable in the coming years, with a slight decrease in the conversion of land to wetlands and wetlands to land. However, it is important to note that this is a prediction, and actual changes may differ due to various factors such as urbanization, land use policies, and climate change.

Table 8: The Predicted Statistics and Transitional Matrix for Land and Wetlands for the Years 2022 to 2034

Class Name	2022 to 2028		2028 to 2034	
	Area (in km^2)	(%)	Area (in km2)	(%)
Land → Land	1108.6232	83.82	1155.84	87.39
Land → Wetlands	40.4507	3.06	14.40	1.09
Wetlands → Wetlands	109.2812	8.26	95.48	7.22
Wetlands → Land	64.338	4.86	56.97	4.31
Total	1322.69	100	1322.69	100

Source: Results from Landsat image analysis from https://earthexplorer.usgs.gov/



Source: Results from Landsat image analysis from https://earthexplorer.usgs.gov/

Figure 10: Predicted Sectoral Changes between Land and Wetlands in the Fringe Area of Dhaka City for the Years 2028 and 2034

SUMMARY

The fringe area of Dhaka, encompassing vital wetland, plays a crucial role in local ecology, serving as habitat for aquatic life and acting as a natural buffer against disasters. However, an analysis of data spanning from 1989 to 2022 reveals a worrisome trend of increased land area at the expense of wetland. The land area steadily rose from 71.78% in 1989 to 87.02% in 2022, indicating significant urbanization and development. The strong positive correlation (r = 0.99) between the year and land area underscores this concerning trend.

Despite the acknowledged benefits of urbanization, the negative environmental impact, including pollution and biodiversity loss, must be acknowledged. Wetland in Dhaka's fringe area faced encroachment and degradation due to rapid urbanization and industrial growth. The data demonstrates a continuous decline in wetland, dropping from 28.22% in 1989 to 12.98% in 2022. The strong negative correlation (r = -0.99) emphasizes the substantial decrease in wetland over the years.

The correlation coefficients suggest a crucial need for balanced development, considering social, economic, and environmental impacts. The data projects a concerning future, with land predicted to account for 91.98% by 2034, and wetland reduced to 8.02%. This shift towards urbanization raises alarms about potential ecosystem loss, biodiversity impacts, and heightened vulnerability to natural disasters.

The findings serve as a warning about the environmental consequences of unchecked urbanization, advocating for sustainable practices, conservation, and restoration efforts to safeguard the remaining wetland in Dhaka's fringe area.

Moving to a more detailed analysis of the data from 1989 to 2022, dynamic changes in land use in the fringe area of Dhaka City become apparent. Between 1989 and 1995, a substantial portion (67.13%) of land remained unchanged, with a minor conversion to wetland (4.48%). Notably, 8.01% of wetland were converted to land during this period. Between 1995 and 2006, land stability increased (71.59%), while land-to-wetland conversion decreased (3.44%). However, the conversion of wetland to land rose to 8.71%, signifying a shift in the trend.

The subsequent period (2006-2016) witnessed an expansion of land cover to 74.03%, accompanied by increased conversion to wetland (6.23%). Despite this, wetland coverage declined to 11.34%, and the conversion of wetland to land slightly decreased. From 2016 to 2022, the trend continued, with the land area increasing to 79.33%, but the conversion to wetland reduced significantly to 2.97%. Wetland coverage continued to decrease, yet the conversion of wetland to land slightly decreased to 7.47%.

The overall data indicates substantial land conversion in the fringe area, particularly from land to land. While wetland experienced varying degrees of conversion, there was a positive trend of decreased wetland conversion between 2016 and 2022, potentially contributing to natural resource preservation.

Analyzing future projections (2022-2034), the data suggests that land-to-land changes will increase from 83.82% to 87.39%, indicating stability in land use. The conversion of land to wetland is expected to decrease from 3.06% to 1.09%, signifying a declining trend. Wetland-to-wetland changes remain relatively stable, showing a minor decrease. Additionally, wetland-to-land changes are expected to decrease slightly from 4.86% to 4.31%.

The study projections anticipate relative stability in Dhaka's fringe area wetland, with a decrease in land-to-wetland and wetland-to-land conversions. However, it is crucial to recognize these as predictions, subject to potential variations due to factors like urbanization, land use policies, and climate change.

Shifting focus to the zonal scenario, the wetland in the fringe areas of Dhaka City have undergone dynamic changes from 1989 to 2022, revealing distinct patterns of encroachment and decline across various regions. In the northern region, wetland, which accounted for 5.19% in 1989, experienced a gradual reduction to 4.17% in 2006. The most significant change occurred between 2016 and 2022, witnessing a notable decline from 3.82% to 3.06%, indicating accelerated encroachment post-2016.

Conversely, the southern region demonstrated stability from 1989 (5.475%) to 1995 (5.3%) but faced a substantial decrease to 3.87% in 2016. The wetland changes in 2022 showed a more modest 3.01% decrease, indicating a notable shift.

The eastern region displayed a marginal decrease in wetland from 6.77% in 1989 to 6.01% in 1995, followed by a substantial 5.11% reduction in 2006. The wetland coverage in this region dramatically dropped from 3.7% in 2016 to 2.71% in 2022, highlighting a significant decline.

The south-western region witnessed a considerable decrease in wetland coverage, dropping from 4.05% in 1989 to 1.01% in 2022. Similarly, the western region experienced a modest decline from 6.74% in 1989 to 3.18% in 2022, indicating notable changes over the years.

Analyzing the correlations, each region displayed a strong negative correlation in wetland shifting. The eastern region exhibited the strongest negative correlation (R = -0.993), followed by the northern region (R = -0.985), while the southern (R = -0.984) and south-western (R = -0.981) regions demonstrated larger negative associations than the western region (R = -0.925).

The accuracy assessment of wetland classification, spanning various years and based on 385 samples verified through historical images and Google Earth Pro, reveals consistent high overall accuracy and Kappa coefficient values. In 1989, a 5.0% absolute error indicated misclassification, with a 95.0% correct classification rate and a Kappa coefficient of 0.90. In 1995, a 3.33% absolute error was recorded, achieving 96.67% overall accuracy and a Kappa coefficient of 0.93. The year 2006 displayed a 5.0% absolute error, 95.0% overall accuracy, and a Kappa coefficient of 0.90. Notably, 2016 exhibited a lower misclassification rate of 1.67%, with 98.33% overall accuracy and a high Kappa coefficient of 0.97. In 2022, a 3.33% misclassification rate was observed, with 96.67% overall accuracy and a Kappa coefficient of 0.93. The variable misclassification rates highlight the highest accuracy in predicting wetland changes in 2016, affirming the reliability of the geospatial model employed in this study.

CONCLUSION

This trend is likely to continue unless significant measures are taken to protect and conserve the wetland. Conservation and restoration efforts, as well as sustainable development practices, should be implemented to mitigate these impacts. The policy framework for this issue could focus on establishing protected areas, encouraging sustainable development, providing education and awareness, developing wetland restoration programs, and strengthening regulations. Prioritizing the conservation and restoration of wetland in the fringe area of Dhaka city through these policies can help mitigate the negative environmental impacts of wetland loss and preserve the ecological health of the area for future generations.

The loss of wetland in the Dhaka fringes has detrimental effects on the surrounding ecology, including an increase in flooding danger, a decline in biodiversity, and a decreased ability to filter and absorb pollutants. Although efforts are being made to preserve and restore these wetland, much work has to be done to undo the harm that has already been done. Efforts to conserve and restore wetland in Dhaka's fringe areas are important to maintain the ecological balance of the region and to support the well-being of both humans and wildlife.

LIMITATIONS OF THE STUDY

The study's foundation on remote sensing and GIS techniques brings forth limitations tied to the contingent nature of accuracy on data availability and quality. While the temporal scope from 1989 to 2022 provides a historical perspective, it might miss recent developments, and projections beyond 2022 introduce uncertainties that could impact the precision of future scenarios. Assumptions about wetland homogeneity and the application of Cellular Automaton CA Markov Matrix for simulations might oversimplify the intricate dynamics of wetland changes. Although the research incorporates ground truthing through Google Earth Pro and historical images, the absence of explicit mention of comprehensive validation through field surveys raises potential constraints in verifying the accuracy of wetland changes on the ground. The study's focus on environmental aspects, acknowledging the consequences of urbanization but not deeply delving into the socioeconomic drivers, limits its comprehensiveness. Furthermore, the research underplays an in-depth exploration of existing policies, their implementation dynamics, and potential barriers to their effectiveness, thereby potentially hindering the development of practical recommendations. Lastly, while climate change is acknowledged, the study does not extensively explore the complex interplay between climate change patterns, extreme weather events, and wetland changes, crucial for robust future predictions.

SUGGESTIONS FOR THE FUTURE STUDY

For a more nuanced understanding of wetland dynamics in Dhaka City's fringe area, future research could delve into fine-grained temporal analysis, exploring yearly or seasonal variations in wetland changes. Integrating socioeconomic factors into the study would involve collaboration with social scientists and policymakers to discern the human-driven influences on wetland alterations, such as urbanization and industrial growth. A comprehensive assessment of ecosystem services provided by wetland, including their economic value, would shed light on the broader ecological implications of wetland degradation. Moreover, engaging local communities through surveys and interviews would provide insights into the societal impact of wetland changes, aligning conservation efforts with community perspectives and needs. This multidisciplinary and community-oriented approach can offer a more holistic understanding of the complex interplay between human activities and wetland preservation in the evolving urban landscape.

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