Heliyon 10 (2024) e34327

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Spatio-temporal assessment and prediction of wetlands: Examining the changes in ecosystem service value of RAJUK DAP area using Artificial Neural Network and Geospatial Techniques

Mohd Fardeen Khan [a], Md Kamrul Islam [a], Md Arif Chowdhury [b,*]

[a] Department of Urban and Regional Planning, Chittagong University of Engineering & Technology, Chattogram-4349, Bangladesh
[b] Department of Climate and Disaster Management, Jashore University of Science and Technology, Jashore, 7408, Bangladesh

ARTICLE INFO

Keywords:
Ecosystem service
Spatio-temporal assessment
Wetlands
Artificial Neural Network
RAJUK DAP

ABSTRACT

Wetlands are a crucial component of the earth's socio-ecological structure, providing significant ecosystem services to people. Changes in wetlands, driven by both natural and manmade causes, are altering these ecosystem services. Although Bangladesh is developing, natural resources like wetlands are changing in the country at different scales, with urban areas experiencing significant impacts. This study intends to evaluate the past, present, and future scenarios of wetlands and examine the changes in ecosystem service value (ESV) of the RAJUK (Rajdhani Unnayan Kartripakkha or Capital Development Authority) Detailed Area Plan (DAP) region. This research examined the effects of five different Land Use and Land Cover (LULC) classes on ESVs for 27 years from 1995 to 2022. Findings reveal that the current wetland area is 80.16 km^2 in the post-monsoon season and 306.67 km^2 in the pre-monsoon season. Composite post-monsoon wetland map from 1995 to 2015 that 19.48 km^2 of wetlands are classified as hydro-ecologically consistent wetlands. Wetland area has decreased by 140.926 km^2 between 1995 and 2022, according to simulations, and is predicted to do so by another 27.11 km^2 during the following eight years. The total ESV of wetlands dropped by about 26.72 percent between 1995 and 2022, primarily due to conversion to habitation and agricultural use. Also, the projection of LULC and associated ESV for the year 2030 demonstrates how ESV evolves throughout this period and which LULC classes are more susceptible to change, while the kappa coefficient was used to compare the simulated models to the actual wetland area. The current study will undoubtedly be helpful to decision-makers who make a substantial contribution to preserving ecosystem services and the wetland landscape.

1. Introduction

Wetlands and the ecosystem services they offer are significantly valuable to people worldwide in various ways, for example, for livelihoods, biodiversity and existence values, and economic benefits [1]. Ecosystem services are the benefits that human populations derive, directly or indirectly, from the functions of ecosystems [2]. Here, urban ecosystem services contribute directly or indirectly to human well-being by providing numerous functions, including food and water supply, waste treatment, regulation of the urban heat island effect, clean air, water filtration, noise reduction, pollination, and climate regulation, among others [3,4].

* Corresponding author.
E-mail addresses: arifchowdhury065@gmail.com, ar.chowdhury@just.edu.bd (M.A. Chowdhury).

https://doi.org/10.1016/j.heliyon.2024.e34327
Received 13 March 2024; Received in revised form 8 July 2024; Accepted 8 July 2024
Available online 9 July 2024

To meet the growing needs of people for accommodation, food, fresh water, fuel, etc., human activities have extensively and rapidly altered ecosystems, resulting in an irreversible loss of ecosystem services [5]. Wetlands cover 4–6.6 % of the earth's surface [6], while between 1970 and 2015, natural wetlands declined by 35 %. The value of wetland ecosystem services is gaining popularity in ecological economics [7]. A degraded urban ecosystem will lead to environmental contamination, biodiversity and land degradation, extreme climatic events, heightened urban heat island effects, and increased public health risks, among other issues [8,9]. A spatial as well as an environmental examination of a region is required for regional and national planning and management. Effective land assessment systems that employ differentiated management of soil fertility and agricultural production based on landform units hold significant promise for practical application [10].

Wetlands are the world's most productive ecosystem, providing economic, sociological, and ecological benefits [11]. They provide livelihoods for millions of disadvantaged people, control floods and erosion, and offer economic and social advantages on local, regional, and national scales [12]. The capital of Bangladesh, Dhaka, is experiencing rapid urbanization, leading to significant changes in land cover and infrastructure [13]. The city's expansion into floodplains and low-lying areas has destroyed water bodies and flow patterns, causing flooding and congestion in the city's drainage system. In addition, rising buildings both within and outside of cities have filled up these canals, marshes, and depressions [14]. The unplanned expansion of urban areas has significantly disrupted natural water systems, leading to increased flooding and congestion within the city's drainage infrastructure in numerous locations [15].

The expansion of urban areas significantly affects ecosystem services, particularly wetlands, considered areas of low economic value. Dhaka's wetlands are declining due to unplanned and uncontrolled construction, leading to fires and resource loss [6,11]. Dhaka city is one of the most populated areas in Bangladesh, while the number of wetlands areas is being diminished due to unplanned and uncontrolled construction. In 2023, Dhaka city experienced several numbers of fire accidents causing major losses of resources due to less availability of water [16,17]. It is vital to understand the scenarios of wetlands from the past, present, and future to examine the changes in ecosystem service value (ESV) of the RAJUK (Rajdhani Unnayan Kartripakkha or Capital Development Authority) Detailed Area Plan (DAP) region, which may guide to formulate an updated plan for the urban area. On the other hand, several studies were conducted on ecosystem services in Bangladesh [16,17], different issues of Dhaka like water and sanitation [18], solid waste management [19], groundwater pollution [20], etc., but studies on Ecosystem services for DAP is not conducted yet, which is one of the prime issues to address in policy and practice. This study aims to understand past, present and future wetland scenarios to examine changes in the value of ecosystem services in the RAJUK (Rajdhani Unnayan Kartripakkha) Detailed Area Plan (DAP) region between 1995 and 2030. Objectives include identifying wetlands of the past, present and future. Objectives include identifying wetlands of the past, present and future. current scenario (1995–2022) of wetlands, predict the future scenario of wetlands (2030) using an artificial neural network (ANN) and evaluate the changes in the value of ecosystem services of wetlands in 1995, 2022 and 2030 based on ecosystem service functions. Following the background, this study aims to estimate the future of wetlands in the Rajuk DAP (Detailed Area Plan) region using Landsat satellite images and Operational Land Imager (OLI) and Thematic Mapper images (TM). The images used in this work are fully described in Table 1. Wetland maps were verified using Google Earth photographs and defined using the Normalized Difference Water Index (NDWI) approach. The Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built-up Index (NDBI) measurements were obtained for the projection years 2010 and 2022. The projection for 2030 was incorporated into the using the ANN model.

2. Methodology

2.1. Study area

The official gazette of the Bangladesh government has published the Detailed Area Plan (DAP) of Dhaka city, covering 590 square miles (Fig. 1) [21]. The DAP comprises the expanded Gazipur City Corporation and the rest of the Dhamsona Union of Savar Upazila, allocating 89,471.1 acres for agricultural use and 19.76 percent for urban residential use [22]. The DAP includes towns, townships, industrial areas, permanent bodies of water, woodlands and agricultural fields, as well as numerous waterways essential for balanced water flow [23].

2.2. Data processing

Wetlands in the DAP area were identified using Landsat satellite images from 1995, 2005, 2015 and 2022 throughout the pre- and post-monsoon seasons. Thematic Mapper (TM) and Operational Land Imager (OLI) photos have both been taken into consideration for

Table 1
Data description in this study.

Primary Data	Field observation		
	Mach the analytical evaluation with the actual field (After analysis)		
Secondary data	**Season**	**Satellite**	**Year**
	Pre-monsoon (March–May)	Landsat 4-5	1995, 2005
		Landsat 8	2015, 2022
	Post-monsoon (October–December)	Landsat 4-5	1995, 2005
		Landsat 8	2015, 2022
	Study area shape file which is collected from LGED		

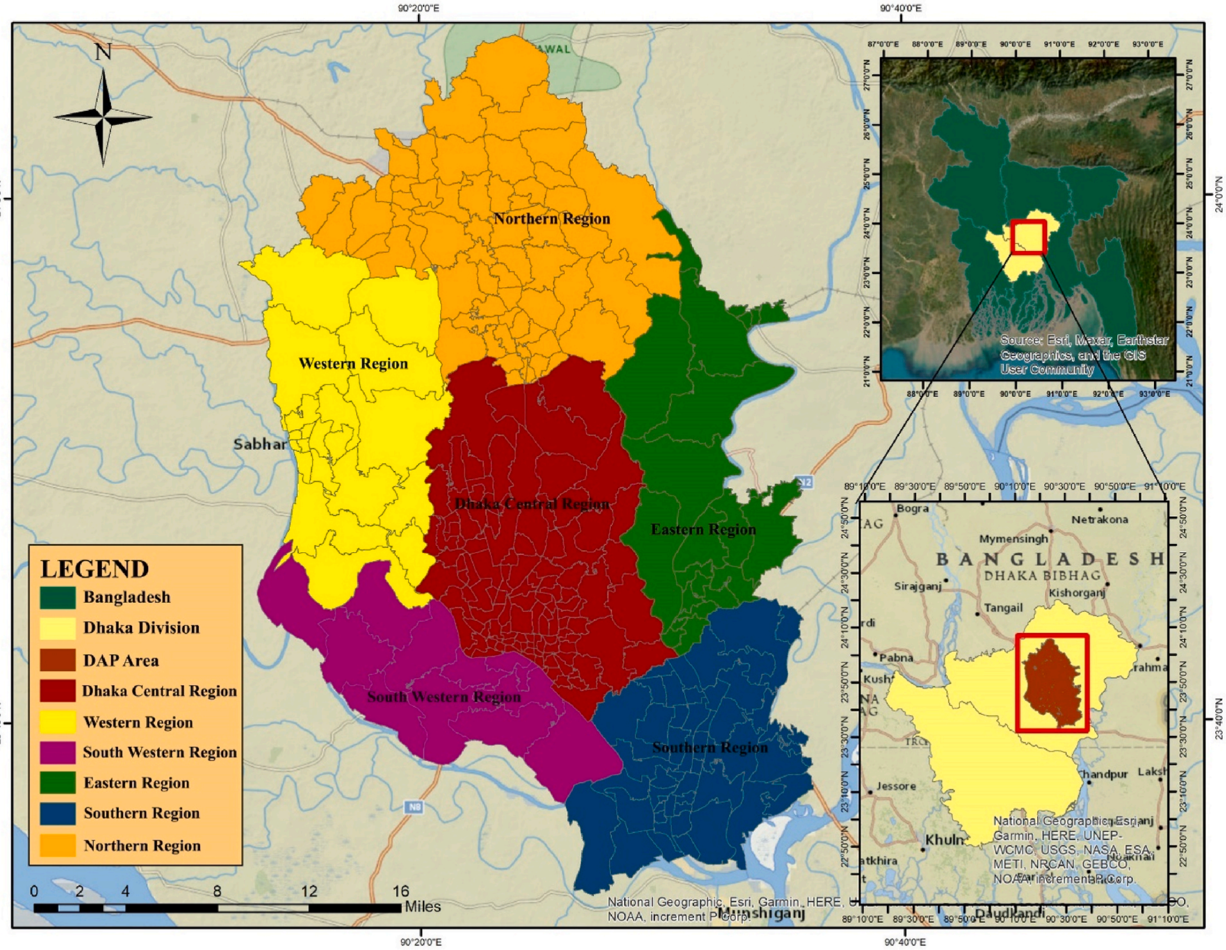

Fig. 1. Location of Detailed Area Plan (DAP) region of RAJUK (Rajdhani Unnayan Kartripakkha or Capital Development Authority) (Study area).

wetland mapping from 1995, 2005, 2015, and 2022. The exact information about the photographs utilized in the current study is displayed in Table 1 in detail. Additionally, the basin map is verified using the 2018 Google Earth map. Additionally, the wetland maps created from Landsat satellite images are validated using Google Earth maps.

Radiometric and atmospheric adjustments were made to the downloaded satellite images to produce high quality deliverables. Two radiometric fits were performed, determining the top-of-atmosphere radiances (TOA) and the TOA reflectance (TOAr) following Equations (1) and (2).

$$\mathrm{TOA} = \mathrm{axDN} + \mathrm{b} \qquad \text{(Equation 1)}$$

Here, the gain factor and offset factor, which are represented by the variables a and b, respectively, were retrieved from the metadata file, where DN stands for the digital number.

$$\frac{\pi \times TOAr \times D^2}{E_0 \times \cos \Theta} \qquad \text{(Equation 2)}$$

where, r = 3.14, is the solar zenith angle, D = distance between the earth and the sun, E_0 = the average exo-atmospheric solar irradiance.

2.3. Wetland delineation and validation

2.3.1. Validation using kappa coefficient

The NDWI method was used to locate the wetland of the Buriganga River basin. Equation (3) has been used to compute the NDWI for the Green and NIR bands of Landsat images using the raster calculator in ArcGIS 10.5 software. The reflectance from the water body is boosted by this method's design to a larger extent than other spectrally closer things, such as vegetation [24]. The NDWI frequently identifies the developed property in the riparian zone, which is one of the technique's drawbacks along with its benefits. It might be claimed that because the research region's percentage of built-up land is not particularly large, the reflectance issue between water and built-up areas does not result in any misconceptions. The NDWI approach is therefore quite appropriate and helpful in the region under examination for the reasons listed above.

$$NDWI = \frac{p\text{GREEN} - p\text{NIR}}{p\text{GREEN} + p\text{NIR}} \quad \text{(Equation 3)}$$

where, NIR = Near Infrared band 4 for TM and band 5 for OLI; NDWI = Normalized Difference Water Index; Green = Green band 2 for TM and band 3 for OLI;

The NDWI value is between −1 and 1. The water body is represented by NDWI values close to 1, while other land use characteristics are represented by negative values.

It is crucial to examine the wetted landscape obtained from Landsat satellite pictures to assess the accuracy of the wetland map [25]. The study focuses on the validation of wetland maps obtained from Landsat satellite images using the Kappa coefficient (K) using Equation (4).

$$\text{k} = \frac{N\sum_{i=1}^{r} xii - \sum_{i=1}^{r}(x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} \times x_{+i})} \quad \text{(Equation 4)}$$

where N = the total number of pixels; r = the number of rows in the matrix; Xii = the number of observations in row i and column i; xi+ and x + I are the marginal totals for the row I & column i, respectively.

2.3.2. Validation using receiver operating curve (ROC)

The area under the curve (AUC) of Receiver Operating Characteristics (ROC) curves is calculated to validate simulated models and compare their sensitivity to ground reality. ROC is used to determine the accuracy of the models' prediction abilities [26]. The ROC curve plots the true positive rate (sensitivity) against the false positive rate (1-specificity), which is shown on the X-axis [27]. Typically, AUC values range from 0 to 1. A value of 1 indicates a flawless diagnostic test, 0.5 represents a test with no predictive ability, and 0 indicates completely incorrect predictions [28]. When interpreting the ROC curve, an AUC of 0.90–1.00 suggests excellent accuracy, 0.80–0.90 indicates acceptable accuracy, 0.70–0.80 indicates fair accuracy, and 0.60–0.70 suggests poor accuracy. For this investigation, 1000 random points were chosen, and data were gathered from actual and simulated photos of 2022. The ROC test was successfully implemented in Google Colab.

2.4. ANN based future wetland area prediction

A neural network (ANN) based cellular automata model for wetland forecasting was developed using ArcGIS software and MOLUSCE tool. The ANN model uses raster data to estimate wetlands, with built-up and agricultural land being the main determining criteria. Variables should be predicted using historical data on relevant factors before forecasting wetlands. To do this, at first import of satellite data in picture format into the QGIS program (.img or.tiff) was done. Then, the total number of samples was divided by utilizing into 80 % for training and 20 % for testing. According to Mandale and Jadhawar (2015), this model produces results based on patterns seen in the input data [29]. Therefore, it is acknowledged that the expansion of built-up areas and agricultural land are the main factors determining the future occurrence of wetland regions [30]. The study also considers the impact of the soil's capacity to retain water and its geomorphological characteristics on the forecasting process. However, these were not deemed important enough to be included in the current research area. As a result, in this context, built-up and agricultural land was considered to be the primary governing criteria. The study concludes that the ANN model can be used to predict future occurrences of wet regions. First, for each particular year, the NDVI and the NDBI are used to designate agricultural land and built-up land, respectively, using equations (5) and (6), respectively.

$$NDBI = \frac{p\text{NIR} - p\text{MIR}}{p\text{NIR} + p\text{MIR}} \quad \text{(Equation 5)}$$

$$NDVI = \frac{p\text{NIR} - p\text{GREEN}}{p\text{NIR} + p\text{GREEN}} \quad \text{(Equation 6)}$$

where, R stands for the Red band, MIR for Mid Infra-Red, and NIR for Near Infra-Red. Land use appropriateness conditioning factors, such as NDVI and NDBI, were derived for 2022 and 2015 to employ in the forecast. The ANN model was then used to condition the integrating parameters. A built-in approach for gathering training datasets and testing datasets is included with the QGIS MOLUSCE plug-in. Based on the training datasets, a land use appropriateness model was developed using the ANN model. These suitability models were then merged with a map showing the change in land use between 1995 and 2005 between 2005 and 2015.

The study used a 10-pixel neighborhood for prediction using the CA model, initially defined over a ten-year iteration. There were several measures used to forecast the years 2030 and 2040. To forecast 2030, a preliminary land use transition map was created between 2005 and 2015. The land use suitability model was then created using ANN utilizing the 2015 suitability conditioning factors. Wetlands were predicted for 2030 using this method.

2.5. Determination of the ESV

The ecosystem service (ES) coefficients were divided into eleven service types based on the important services they provide, such as gas management, water control, climate regulation, water regulation. habitat, food production, raw material supply, soil formation and preservation, genetic sources, pollination, recreation and culture (Table 2) [31]. As land use patterns change, their values also change. By summing together all of the numbers for different services, the coefficient value for each type of land is determined. The values of the ES coefficient for each LULC category of the land tested are presented in Table 2.

The capacity of an ecosystem to provide ES is equivalent to the economic value of the typical grain yield of agricultural land per hectare per year [33,34]. To estimate the ESVs of the various land use classes in the research region, several unit values were used in this study. Additionally, this study explicitly used the Benefit Transfer Method (BTM) of [35]. The BTM transfers the equivalent value coefficient from one site to other environmentally and socioeconomically comparable locations based on geographic homogeneity. Equivalent biomes used to determine the ES coefficient value are summarized in Table 3.

The overall ESVs of a certain land use type was calculated using LULC calculations for the base years as a substitute. Using the unit values from Costanza et al. (2014) and Xie et al. (2003) [31], [32], the value coefficient of each ecosystem service function has been changed for the DAP area. To calculate the ESVs for a particular land-use type, the area was multiplied by the most recent value coefficients for each ecosystem service function (ha). Ecosystem Service Values were determined following equation (7).

$$\mathrm{ESVa} = \mathrm{Aa} * \ \mathrm{VCa} \qquad \text{(Equation 7)}$$

In equation (7), ESVa is the equivalent square value of land use type "a," Aa is the type "a" area in hectares, and VCa is the type "a" value coefficient expressed in US dollars per hectare per year.

2.6. Mathematical determination of sensitivity coefficients

The Coefficient of Sensitivity (CS) was used to determine the percentage change in ESV for a particular percentage change of an input (Equation (8)). I is the land use category, while z and cal are the adjusted and original values, respectively. It establishes the percentage change in ESV for a particular percentage change in value coefficient (VC). The ESV is inelastic and the ESVs are robust regarding the search region if the CS value is less than one. The ESV dependence on the ES Value Coefficient (VC) is measured by the coefficient of sensitivity (CS), which also ensures that the coefficients employed are appropriate for the research region [36].

$$CS = \frac{(ESVz - ESVcal)/ESVcal}{(\mathrm{Vz} - \mathrm{Vcal})/\mathrm{Vcal}} \qquad \text{(Equation 8)}$$

A flowchart of the methodology is presented in Fig. 2.

3. Results

3.1. Inventories of wetlands

Wetland inventories were determined by combining LULC maps of pre-monsoon and post-monsoon periods. The study revealed low-lying wetlands in the central area of the DAP and high wetlands outside it. The maximum number of wetlands was 527.4 km^2 in 1995 and the lowest in 2022 (Table 4 and Fig. 3). Temporary wetlands have decreased by 25.06 % over the past 20 years, while other land uses have increased by 15 0.5 % and permanent wetlands decreased by 45.9 %.

Furthermore, Fig. 3 depicts other land usage increased steadily and wetlands declined gradually over the periods. Temporary wetlands decreased by 25.06 % in the past 20 years, from 1995 to 2015, but there was a steady increase of about 1.63 % from 2015 to 2022. On the other hand, other land uses increased by 15.5 % in the past 27 years from 1995 to 2022, while permanent wetlands

Table 2
Ecosystem service value coefficient for different functions (In $/hectare/year).

Ecosystem Functions	Forest	Agriculture	Water	Wetland	Settlement	Total
Gas regulations (GR)	4	0	0	0	0	4
Water regulation (WR)	3	0	7514	1789	16	9322
Soil formation (SF)	14	532	0	0	0	546
Habitat regulation (HR)	619	0	0	12452	0	13071
Raw material (RM)	152	219	0	416	0	787
Climate regulation (CR)	711	411	0	200	905	2227
Water supply (WS)	143	400	1808	959	0	3310
Pollination (PO)	9	22	0	0	0	31
Food production (FP)	270	2323	106	952	0	3651
Cultural (CU)	1	0	0	636	0	637
Genetic resources (GER)	448	1042	0	243	0	1733
Total	2374	4949	9428	17647	921	35319

Source: [31,35].

Table 3
Equivalent biomes used to determine the ES coefficient value.

Land Use	Equivalent biome	Ecosystem service coefficient (US$ ha-1 per year)
Agriculture	Crop-land	4949
Forest	Mangrove	2374
Settlement	Urban	921
Aquaculture	Wetland	17647
Water	Rivers	3990

Source: [31,35].

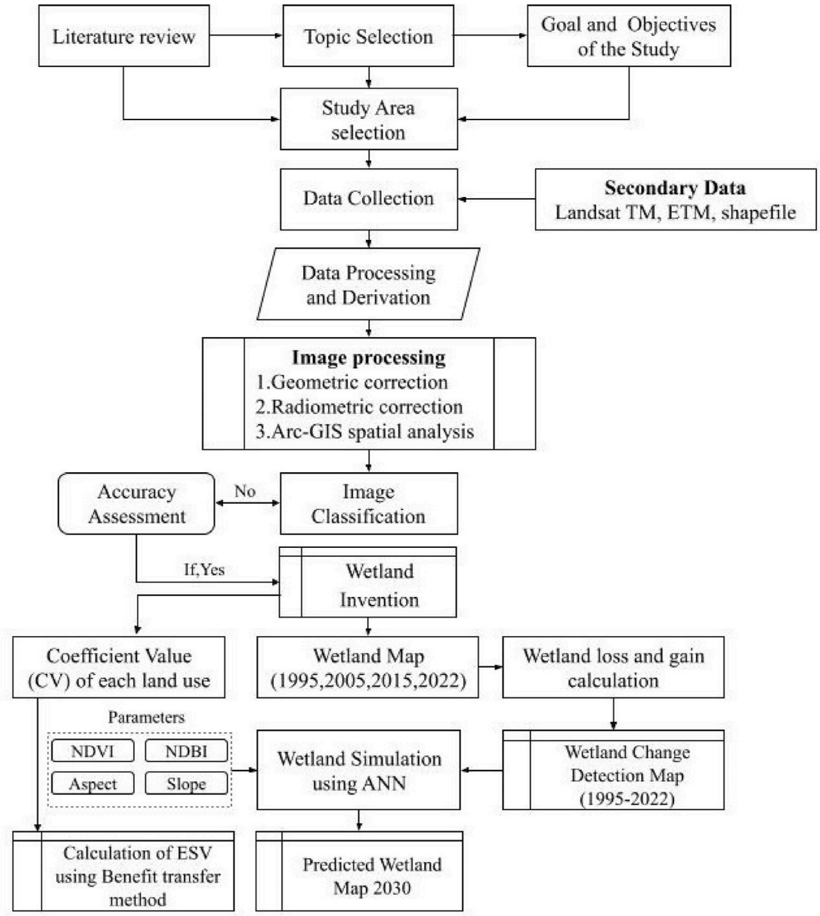

Fig. 2. Flowchart of the mythology.

decreased by 45.9 % in the past 27 years.

3.2. Temporal changes of temporary & permanent wetlands

Table 5 and Fig. 4 show the changes in temporary and permanent wetlands from 1995 to 2022. Temporary wetlands decreased from

Table 4
Area of Wetlands in DAP area during 1995 and 2022.

Land Cover Types	Year Wise Area in Sq. Km			
	1995	2005	2015	2022
Temporary Wetland	379.3	361.5	284.5	306.3
Permanent Wetland	148.0	98.2	94.9	80.2
Other	1001.6	1012.0	1097.6	1142.5

379.344 km^2 in 1995 to 361.44 km^2 in 2005, and increased slightly in 2022. The areas permanent wet conditions decreased slightly in 2015 and 2022.

3.3. DAP region-wise Wetland Condition from 1995 to 2022

From 1995 to 2022, wetlands in the DAP area were highest in the central Dhaka region (110.10 km^2) and lowest in the southwest region (53.34 km^2) (Table 6 & Fig. 5). However, in 2022, the North region had the highest number (89.64 km^2) and the lowest (44.60 km^2). The distribution of wetlands has declined the most in the central region.

3.4. Transition of wetland during the period 1995 to 2022

The text focuses on the transition of wetland land cover classes from 1995 to 2022, analyzing primary transitions, gain, loss and persistence for each land cover type (Fig. 6). Also, Table 7 depicts the change in land cover between 1995 and 2022.

The study reveals the transition of land cover classes from 1995 to 2022, with 223.12 km^2 of permanent wetlands remaining unchanged, 185.08 km^2 of areas converted to temporary wetlands, 257.37 km^2 of others, 110.14 km^2 in permanent wetlands, 677.54 km^2. of unchanged temporary wetlands, 917.94 km^2 of temporary wetlands converted to others, 27.21 km^2 of permanent wetlands and 3964.59 km^2 of other land covers.

3.5. Future prediction

Simulated and actual wetlands for 2022 and 2030 show significant wetland loss, with smaller patches transforming more quickly than larger central regions (Figs. 7 and 8). The size of the simulated temporary wetlands decreased by 12 %, while the calculated permanent wetlands increased by 71.23 km^2.

3.6. Validation of prediction model using receiver operating curve (ROC) and kappa coefficient

The derived metrics show an overall accuracy of 0.90, a Kappa coefficient of 0.88, and an AUC of 0.89 under ROC (Table 8). Fig. 9 depicts the ROC curve for the wetland area. These findings, along with the accompanying ROC curve, demonstrate that the model is highly valid. Given that the simulated models for 2022 are very accurate and reliable, it is reasonable to believe that the models for 2030 will be similarly valid, ensuring consistent and predictable future predictions.

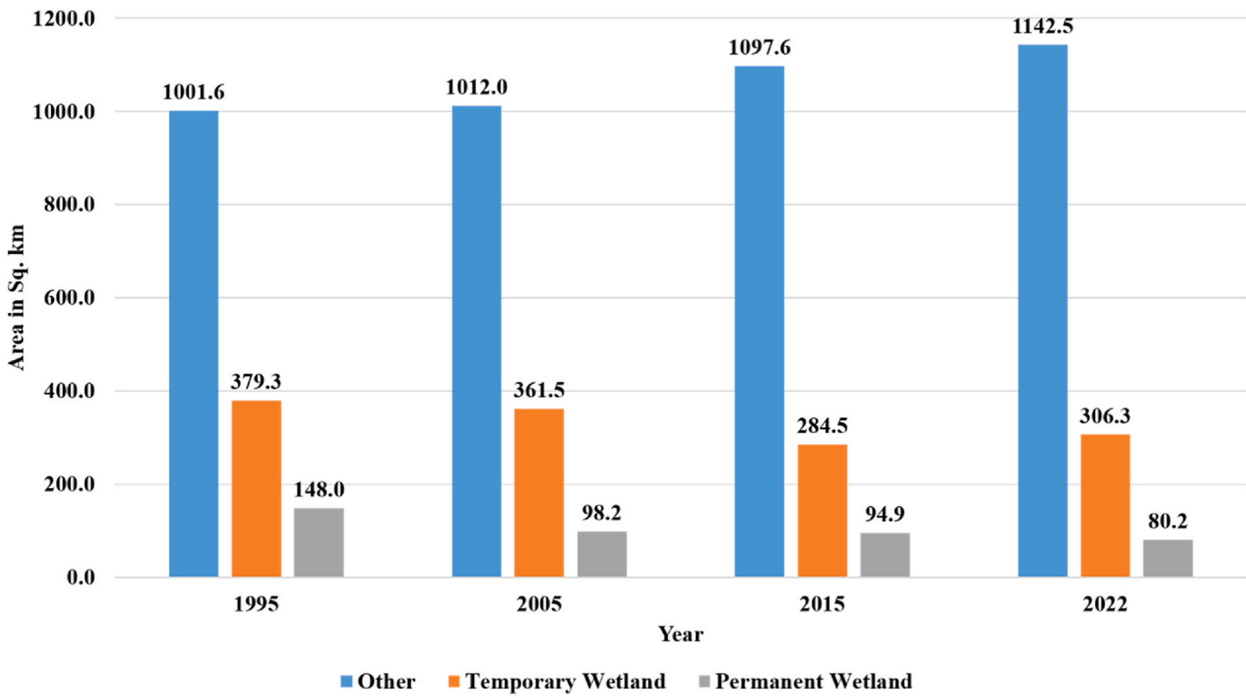

Fig. 3. Area of Wetlands in DAP area (1995–2022).

Table 5
Changes in temporary & permanent Wetland.

Land Cover Types	Year Wise Area change in Sq. Km		
	1995–2005	2005–2015	2015–2022
Temporary Wetland	−17.8	−77	21.8
Permanent Wetland	−49.8	−3.3	−14.7
Other	10.4	85.6	44.6
Sign	(−) Decrease, (+) Increase		

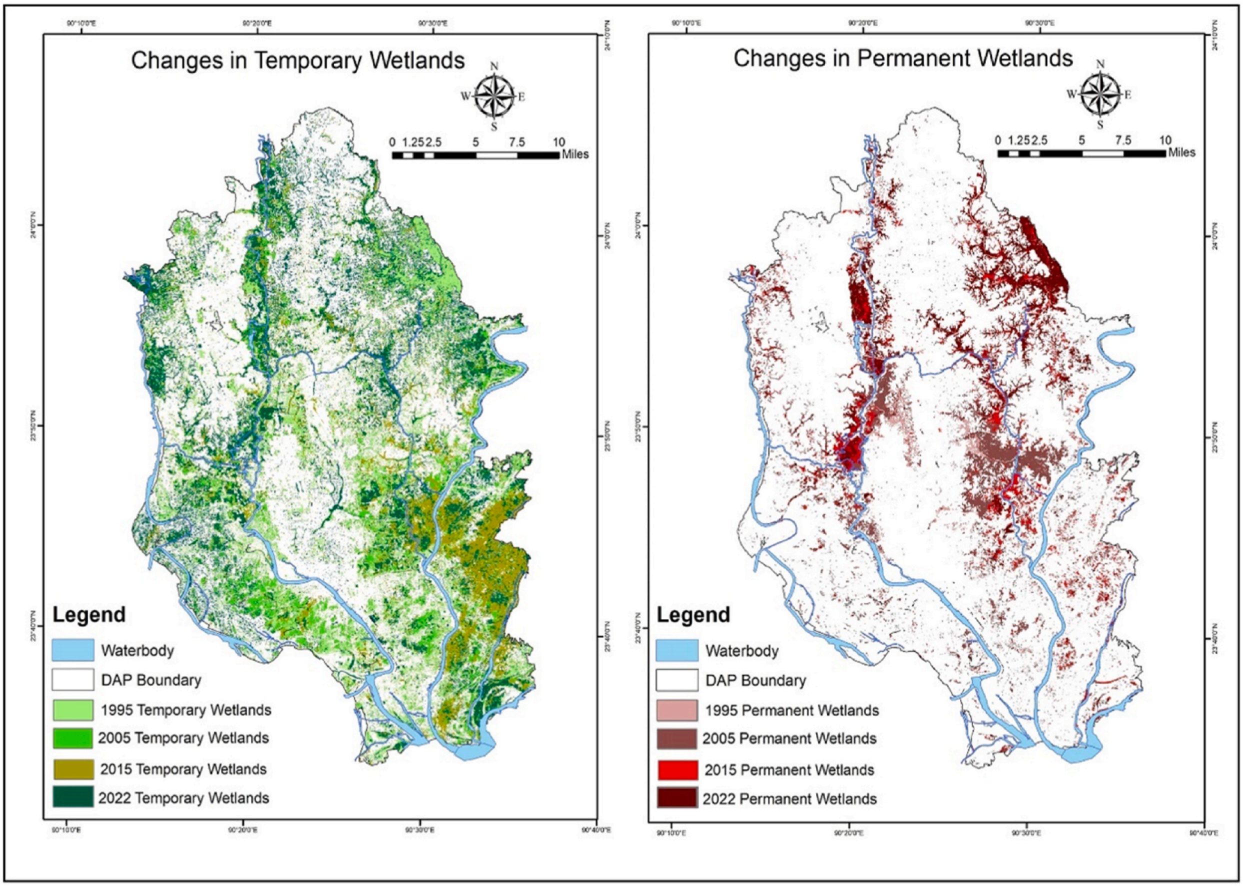

Fig. 4. Changes in temporary & permanent Wetland from 1995 to 2022.

Table 6
DAP region-wise wetland conversion during 1995 and 2022.

DAP Region	Area (sq. km)	
	1995	2022
Dhaka Central Region	110.10	44.60
Eastern Region	96.15	61.95
Northern region	98.47	89.64
Southern Region	77.35	75.43
South Western Region	53.34	45.30
Western Region	80.17	65.81

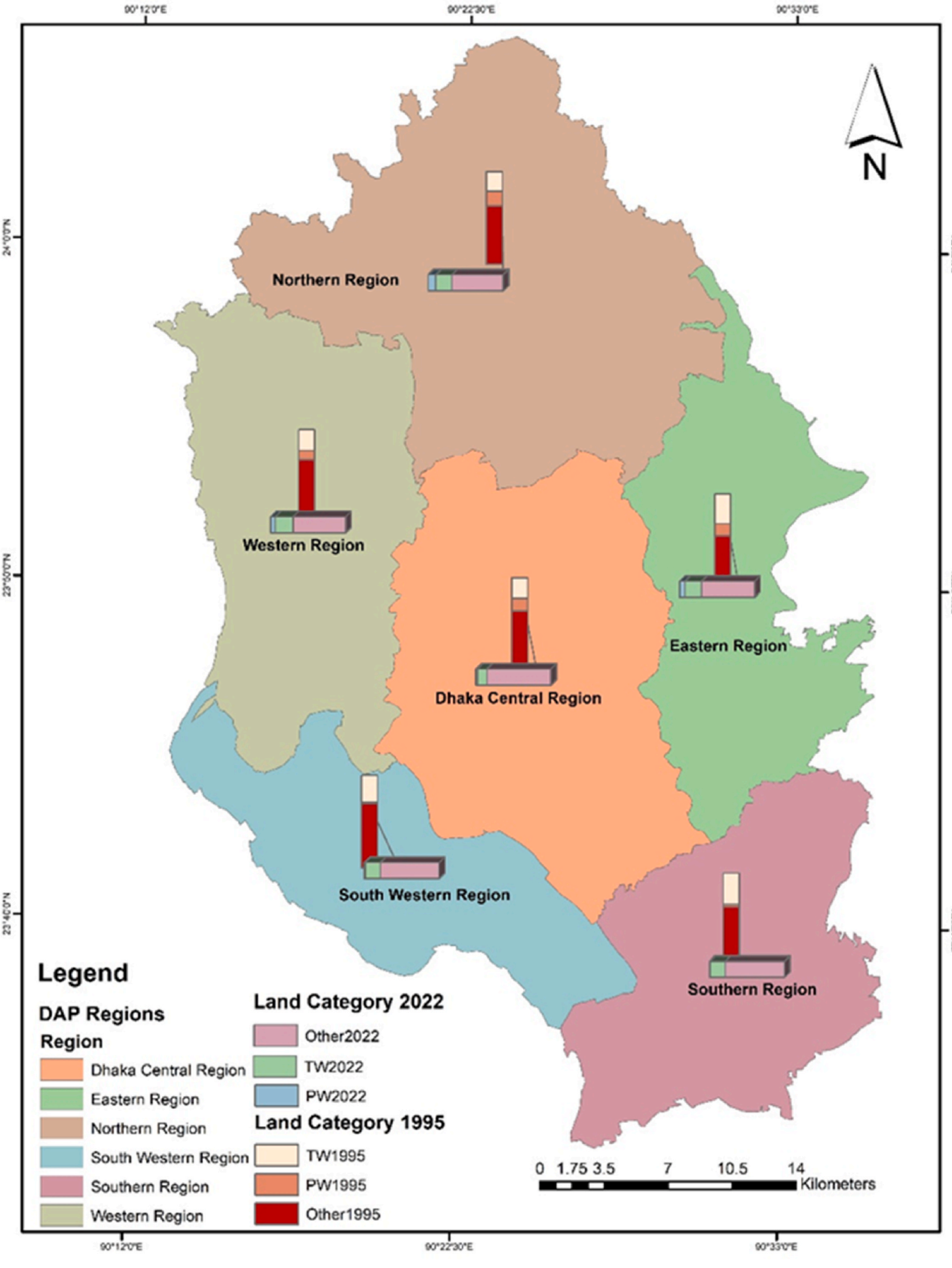

Fig. 5. Region wise Wetland Condition in Sq. Km (1995–2022).

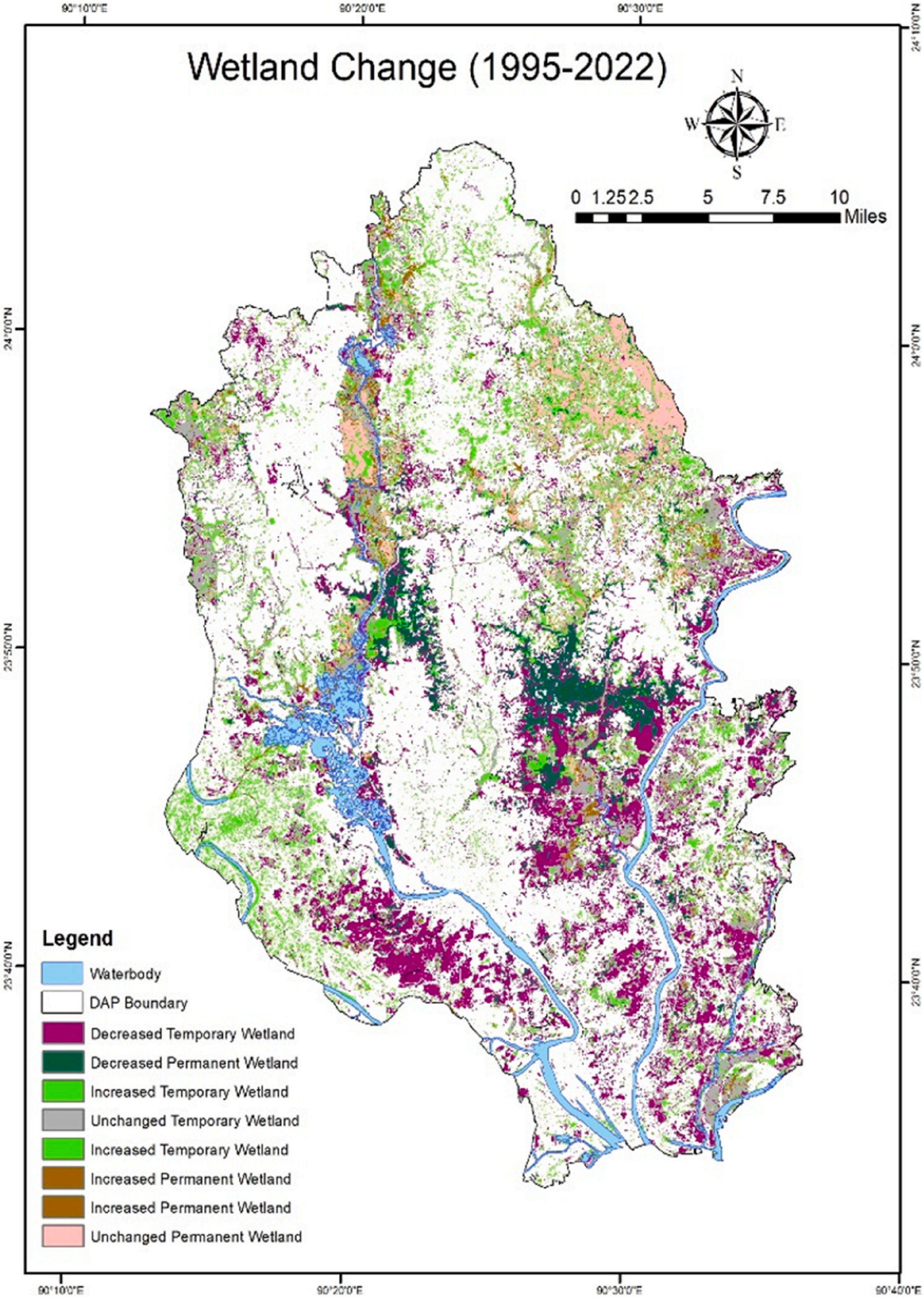

Fig. 6. Transition of Wetland from 1995 to 2022.

Table 7
Transition of Wetland classes of DAP area during 1995 and 2022.

Land Cover Types	Land Cover Change from 1995 to 2022				
	Permanent Wetland	Temporary Wetland	Other	Loss	Gain
Permanent Wetland	223.12	110.14	27.21	442.45	257.37
Temporary Wetland	185.08	677.54	514.54	917.94	699.62
Other	257.37	917.94	3964.59	529.023	1175.31

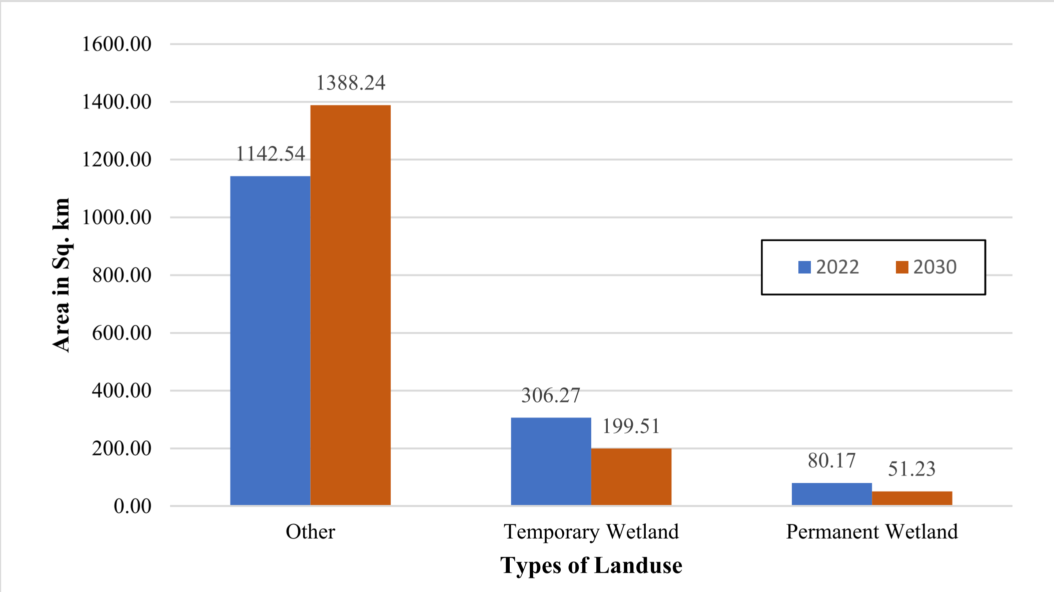

Fig. 7. Present & Future Land Cover Condition in Study Area (Sq. km).

3.7. Ecosystem service value changing with the variations of ecosystem functions

This study ranked eleven ecosystem functions based on their contribution to the value of ecosystem services (Table 9). Housing regulation and food production come first, followed by climate regulation, water supply, waste management, soil formation, preservation of biodiversity, gas regulation, materials raw materials, leisure and culture, and food. Habitat control and waste treatment were the largest contributors. Gas regulation, soil creation, habitat regulation, food production and pollination have remained constant.

3.8. Ecosystem service value changing in different years

The value of DAP ecosystem services declined between 1995 and 2022 due to the loss of wetlands, agricultural land and forests (Table 9). This was offset by an increase in settlement value. From 2022 to 2030, the value of all ecosystem services decreased by more than 64.46 billion, mainly due to the decrease in wetlands, agriculture and forests.

3.9. Ecosystem services sensitivity

The study used Equation (8) to calculate the change in total ecosystem service values (ESV) and sensitivity coefficient (CS) due to a 50 % change in ESV coefficient values (Table 10). The results showed that the ESVs was essentially inelastic, with the wetland class having the highest sensitivity coefficient. Agricultural land use declined between 1995 and 2030 (see Table 11).

4. Discussion

Wetlands play an important role in the lives of millions of disadvantaged people across the world by offering viable livelihoods, while wetlands are considered important components of biodiversity on a local, regional, and national scale [37]. They provide flood and erosion control, as well as economic and social benefits to the surrounding communities [38]. Changing patterns of urban areas are causing considerable changes in the city's land cover, making wetland conservation and mitigation an unavoidable approach for Bangladesh's future [39,40]. This paper assesses the changes in wetlands and predicts the subsequent changes in associated ecosystem

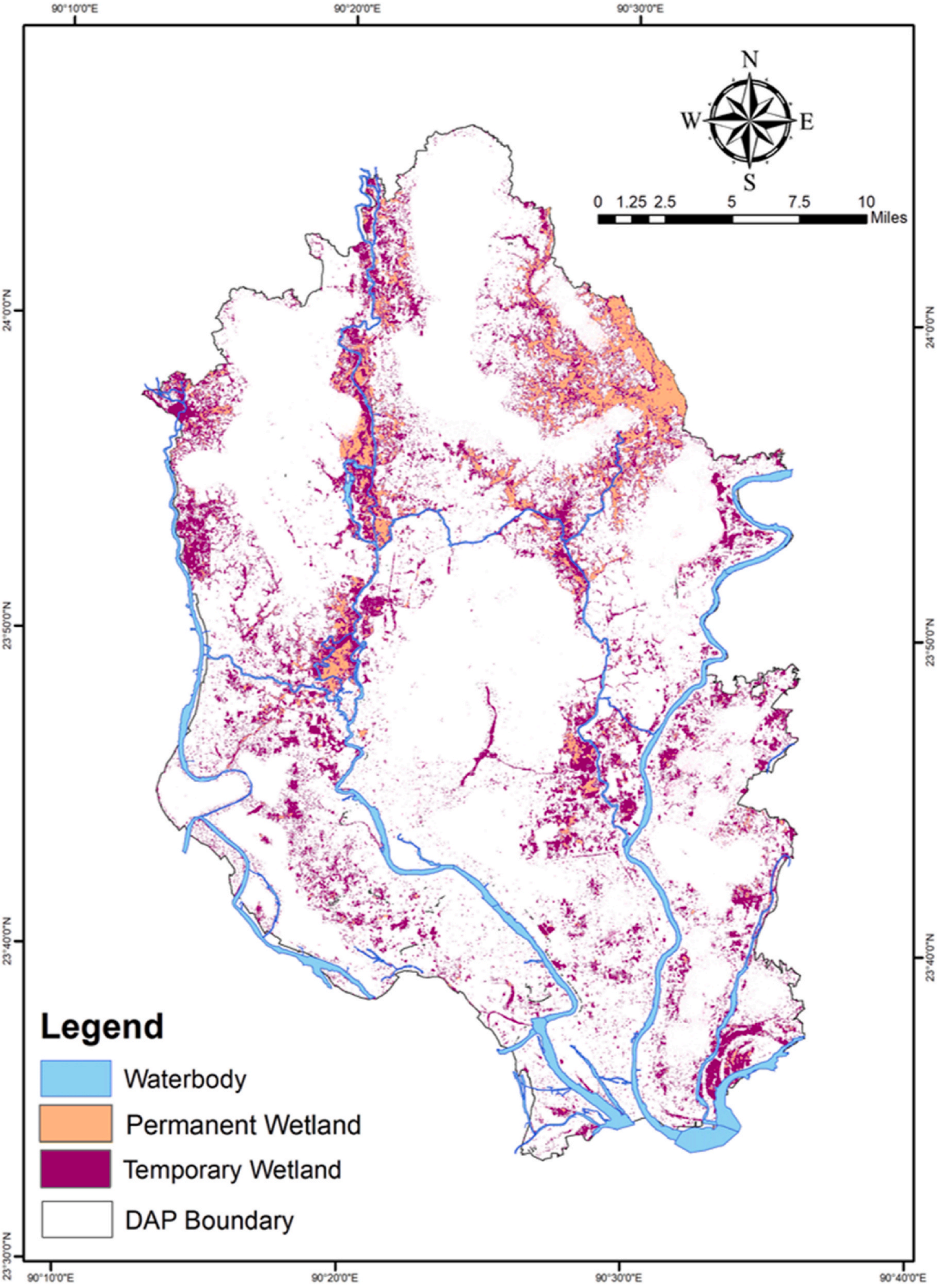

Fig. 8. Future Waterbody & Wetland condition of 2030.

Table 8
Overall accuracy, Kappa coefficient and AUC under ROC.

Predicted Year	For Wetland Area		
	Accuracy (%)		
	Overall	Kappa	ROC
2022	0.90	0.88	0.89

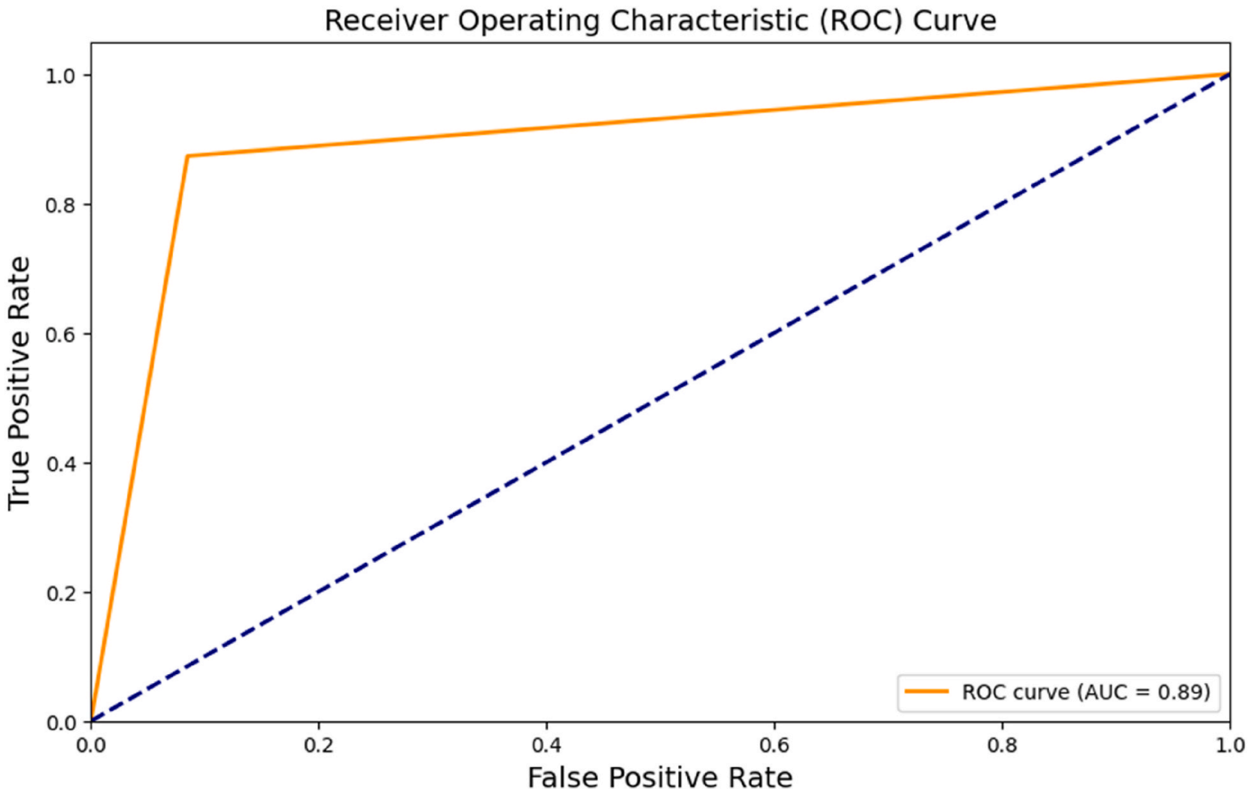

Fig. 9. Sensitivity analysis using ROC.

service values (ESVs).

Between 1995 and 2022, the RAJUK DAP region has experienced a significant decline in wetland values and ESV, while expansion of urban areas is one of the major root causes. The study found a 19.26 % decrease in temporary wetlands and a 45.83 % reduction in permanent wetlands, with further declines expected by 2030. Increased urbanization over the past two decades has led to a significant conversion of LULC in the region. Besides, a study conducted by Sharah, R. (2011), described that over 30 years, wetlands in Dhaka have contracted by 76.67 %, leading to significant soil erosion and this erosion has impacted the city's drainage system and contributed to waterlogging issues [41]. Also, over the last three decades, the marginal area of Dhaka city developed so fast by converting agricultural land and wetlands into residential, commercial, industrial areas, etc. [42].

Furthermore, the southern part of Dhaka experienced the smallest decline in temporary wetlands, at 3.05 %, while the central region faced the largest decrease, at 24.5 %. In central Dhaka, permanent wetlands declined by approximately 24.5 %, and in the southwestern region, they decreased by about 1.05 % during the same period. According to prediction analysis using ANN, wetlands are expected to be less developed, and there will be more open space by 2030. Compared to 2022, by 2030, there will be a 21.57 % increase in other land uses and a 38.23 % and 26.25 % decrease in temporary and permanent wetlands, respectively. The degradation of wetlands in the RAJUK DAP area of Bangladesh has also resulted in several problems. For example, wetland degradation in Dhaka heightens the risk of flooding by diminishing the land's ability to absorb water, while this issue is exacerbated by the city's rapid development and population growth [43]. Here, as a capital city of Bangladesh, Dhaka is considered as main area to manage livelihoods, education, residential, and health facilities, while this city is the prime destination for internal migrants [44]. This increasing population requires all kinds of necessities for life and livelihood, which led to a high rate of urbanization and damage of wetlands and associated floodplain areas [45].

Moreover, using LULC data and a modified ecosystem value coefficient, it was observed that due to increased settlement utilization,

Table 9
Tendency of ecosystem Functions.

Ecosystem Functions	1995			2022			Tendency
	ESV (US$ ha-1 per year)	%	Rank	ESV (US$ ha-1 per year)	%	Rank	
Gas regulations (GR)	0.15	0.012	11	0.07	0.008	11	—
Water regulation (WR)	115.72	9.07	3	91.22	9.79	4	⬇
Soil formation (SF)	23.09	1.81	9	12.52	1.34	9	—
Habitat regulation (HR)	680.65	53.35	1	492.3	52.85	1	—
Raw material (RM)	37.11	2.9	7	23.85	2.56	8	⬇
Climate regulation (CR)	72.18	5.66	6	95.42	10.24	3	⬆
Water supply (WS)	78.11	6.12	4	53.87	5.78	5	⬇
Pollination (PO)	1.28	0.1	10	0.67	0.07	10	—
Food production (FP)	159.41	12.49	2	10.25	10.26	2	—
Cultural (CU)	33.58	2.63	8	95.51	2.64	7	⬆
Genetic resources (GER)	74.33	5.82	5	41.46	4.45	6	⬇

Table 10
Ecosystem service value from 1995 to 2030.

Land Use		Water	Wetland	Settlement	Forest	Agriculture	Total
ESV (Billion)	1995	11.13	930.42	16.96	91.94	209.74	1260.19
	2022	11.08	681.95	66.60	42.60	114.15	916.38
	2030	10.81	634.11	72.37	38.31	96.32	851.92
1995–2022	Billion	−0.05	−248.47	49.64	−49.34	−95.59	−343.81
	%	−0.45	−26.71	74.53	−53.67	−45.58	−51.86
	%/yr	−0.02	−0.99	2.76	−1.99	−1.69	−1.92
2022–2030	Billion	−0.27	−47.84	5.77	−4.29	−17.83	−64.46
	%	−2.44	−7.02	8.66	−10.07	−15.62	−26.48
	%/yr	−0.30	−0.88	1.08	−1.26	−1.95	−3.31

Table 11
Ecosystem service sensitivity.

Land Use Types	1995		2022		2030	
	%	CS	%	CS	%	CS
Agriculture	8.32	0.17	33.34	0.67	5.65	0.11
Forest	3.65	0.07	34.48	0.69	2.24	0.04
Settlement	0.67	0.01	46.59	0.93	4.24	0.08
Wetland	36.92	0.74	47.61	0.95	37.21	0.74
Water	0.44	0.01	38.14	0.76	0.63	0.01

Here, CS=Coefficient of sensitivity.

the ESV of the entire study region decreased by around 344.041 trillion US dollars between 1955 and 2022. Significant land usage changes occurred between 1995 and 2022, leading to considerable changes in ESV values. The total ESV of wetlands dropped by about 26.72 % during this period, primarily due to conversion to habitation and agricultural use. The ESV of settlements increased by a maximum of 74.53 %, as nearly 20.21 % of the ESV value of wetlands were converted to settlements. On the other hand, a study conducted by (Sarkar and Maji, 2022), the loss of wetlands in city area has resulted in a significant decline in biodiversity, primarily due to urbanization, while approximately 49 % of wetland areas were lost between 1960 and 2008, impacting natural habitats significantly [46]. Also, emerging challenges due to climate change impacts will worsen these scenarios [47], while Kibria & Yousuf Haroon, (2017) described that changes in wetlands driven by climate change in Bangladesh hold the potential to significantly impact the lives of Dhaka residents, disrupting key sectors such as fishing, farming, tourism, and aquaculture, while this could lead to economic challenges [48].

For the long-term and balanced maintenance of ecosystems, the research recommends establishing a comprehensive land use plan and implementing improved LULC management techniques to curb the encroachment of construction activities on wetlands, farms, and other natural areas. While future land management could be enhanced through the ESV scenario, greater attention from politicians and political groups is essential. In this study, the calculation of ESV considered a total of eleven ecosystem functions. The ESV scenario emerges as a promising option for managing future lands, particularly in terms of enhancing environmental conditions, addressing food supply shortages, promoting sustainable use of natural resources, and fostering livable communities. To prevent the encroachment of residential, industrial, and commercial construction on wetlands, farms, and other natural areas, it is imperative to develop an adequate land use plan. Additionally, decision-makers should explore alternate conservation initiatives and implement improved LULC management strategies for the long-term and balanced preservation of ecosystems.

5. Conclusion and recommendations

The study highlights the significant impact of ecosystems on wetlands in the RAJUK DAP area, where land cover and land use have changed rapidly. This has led to deterioration in water quality, affecting downstream wetlands and groundwater. To improve environmental conditions, sustainable use of natural resources and food supply, the ESV scenario could be a better option. However, this requires increased attention from government organizations and legislators. To preserve ecosystems, an appropriate land use plan must be created to prevent land from encroaching on forests, farms, and wetlands. Restoration of damaged water bodies and appropriate conservation and management measures are essential. Recommendations include implementing existing regulatory frameworks, restoring degraded wetlands, promoting sustainable livelihoods, and implementing watershed management practices to conserve wetlands. Further study can be conducted to assess the changing aspects of ecosystem services along with the changing pattern of climatic components, and assessment of the national-level regulatory frameworks can be conducted too.

Data availability statement

Data will be made available on reasonable request.

CRediT authorship contribution statement

Mohd Fardeen Khan: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Md Kamrul Islam:** Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization. **Md Arif Chowdhury:** Writing – review & editing, Writing – original draft.

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.

References

[1] W.J. Mitsch, B. Bernal, M.E. Hernandez, Ecosystem services of wetlands, International Journal of Biodiversity Science, Ecosystem Services & Management 11 (1) (2015) 1–4. Taylor & Francis.
[2] W.V. Reid, et al., Ecosystems and Human Well-Being-Synthesis: A Report of the Millennium Ecosystem Assessment, Island Press, 2005.
[3] J. Langemeyer, E. Gómez-Baggethun, D. Haase, S. Scheuer, T. Elmqvist, Bridging the gap between ecosystem service assessments and land-use planning through Multi-Criteria Decision Analysis (MCDA), Environ. Sci. Pol. 62 (2016) 45–56.
[4] D. Haase, et al., A quantitative review of urban ecosystem service assessments: concepts, models, and implementation, Ambio 43 (2014) 413–433.
[5] Y. Chen, H. Lu, J. Li, J. Xia, Effects of land use cover change on carbon emissions and ecosystem services in Chengyu urban agglomeration, China, Stoch. Environ. Res. Risk Assess. 34 (8) (2020) 1197–1215.
[6] H. Desta, B. Lemma, A. Fetene, Aspects of climate change and its associated impacts on wetland ecosystem functions: a review, J. Am. Sci. 8 (10) (2012) 582–596.
[7] Q. Cheng, L. Zhou, T. Wang, Assessment of ecosystem services value in Linghekou wetland based on landscape change, Environ. Sustain. Indic. 15 (Sep. 2022) 100195, https://doi.org/10.1016/j.indic.2022.100195.
[8] C. Montoya-Tangarife, F. De La Barrera, A. Salazar, L. Inostroza, Monitoring the effects of land cover change on the supply of ecosystem services in an urban region: a study of Santiago-Valparaíso, Chile, PLoS One 12 (11) (2017) e0188117.
[9] M.A.E. AbdelRahman, An overview of land degradation, desertification and sustainable land management using GIS and remote sensing applications, Rendiconti Lincei. Sci. Fis. Nat. 34 (3) (2023) 767–808.
[10] M.A.E. AbdelRahman, M.M. Metwaly, Digital soil characteristics mapping for aiding site-specific management practices in the West Nile Delta, Egypt, Discov. Sustain. 4 (1) (Nov. 2023) 47, https://doi.org/10.1007/s43621-023-00162-6.
[11] V. Camacho-Valdez, A. Ruiz-Luna, A. Ghermandi, P.A.L.D. Nunes, Valuation of ecosystem services provided by coastal wetlands in northwest Mexico, Ocean Coast Manag. 78 (Jun. 2013) 1–11, https://doi.org/10.1016/j.ocecoaman.2013.02.017.
[12] S.N. Islam, S. Reinstädtler, A. Gnauck, Degraded coastal wetland ecosystems in the Ganges-Brahmaputra Rivers Delta region of Bangladesh, Coast. Wetl. Alter. Remediat. (2017) 187–213.
[13] Baid U., et al., The rsna-asnr-miccai brats 2021 benchmark on brain tumor segmentation and radiogenomic classification, arXiv Prepr. arXiv2107.02314 2 (2021) 1–19.
[14] A.S.M.M. Kamal, S. Midorikawa, GIS-based geomorphological mapping using remote sensing data and supplementary geoinformation: a case study of the Dhaka city area, Bangladesh, Int. J. Appl. Earth Obs. Geoinf. 6 (2) (2004) 111–125.

[15] D. Vlahov, Urbanization, urbanicity, and health, J. Urban Heal. Bull. New York Acad. Med. 79 (90001) (Dec. 2002) 1S–12, https://doi.org/10.1093/jurban/79.suppl_1.S1.
[16] R. Ahammad, N. Stacey, T.C.H. Sunderland, Use and perceived importance of forest ecosystem services in rural livelihoods of Chittagong Hill Tracts, Bangladesh, Ecosyst. Serv. 35 (2019) 87–98.
[17] S. Sannigrahi, et al., Responses of ecosystem services to natural and anthropogenic forcings: a spatial regression based assessment in the world's largest mangrove ecosystem, Sci. Total Environ. 715 (2020) 137004.
[18] M.A. Chowdhury, S. Nowreen, N.J. Tarin, M.R. Hasan, R.U. Zzaman, N.I. Amatullah, WASH and MHM experiences of disabled females living in Dhaka slums of Bangladesh, J. Water, Sanit. Hyg. Dev. 12 (10) (Oct. 2022) 683–697, https://doi.org/10.2166/washdev.2022.060.
[19] D.T. Jerin, et al., An overview of progress towards implementation of solid waste management policies in Dhaka, Bangladesh, Heliyon 8 (2) (2022) e08918.
[20] A. Khan, et al., Processes controlling the extent of groundwater pollution with chromium from tanneries in the Hazaribagh area, Dhaka, Bangladesh, Sci. Total Environ. 710 (2020) 136213.
[21] S. Talukder, Appraisal of Detailed Area Plan and Development of a Revised Conceptual Plan for Dhaka City, 2019.
[22] H.M. Arifeen, et al., Determine the land-use land-cover changes, urban expansion and their driving factors for sustainable development in Gazipur Bangladesh, Atmosphere 12 (10) (2021) 1353.
[23] M.M. Morshed, G. Rahman, Detailed area plan (DAP): why it does not work? World T. Plan. Day (2013) 42–47.
[24] S.K. McFEETERS, The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features, Int. J. Rem. Sens. 17 (7) (May 1996) 1425–1432, https://doi.org/10.1080/01431169608948714.
[25] D. Tien Bui, B. Pradhan, O. Lofman, I. Revhaug, Landslide susceptibility assessment in Vietnam using support vector machines, decision tree, and naïve bayes models, Math. Probl Eng. 2012 (2012) 1–26, https://doi.org/10.1155/2012/974638.
[26] J. Hiestermann, N. Rivers-Moore, Predictive modelling of wetland occurrence in KwaZulu-Natal, South Africa, South Afr. J. Sci. 111 (7–8) (2015) 1–10.
[27] H.R. Pourghasemi, B. Pradhan, C. Gokceoglu, M. Mohammadi, H.R. Moradi, Application of weights-of-evidence and certainty factor models and their comparison in landslide susceptibility mapping at Haraz watershed, Iran, Arabian J. Geosci. 6 (7) (Jul. 2013) 2351–2365, https://doi.org/10.1007/s12517-012-0532-7.
[28] S. Pal, S. Talukdar, Application of frequency ratio and logistic regression models for assessing physical wetland vulnerability in Punarbhaba river basin of Indo-Bangladesh, Hum. Ecol. Risk Assess. 24 (5) (Jul. 2018) 1291–1311, https://doi.org/10.1080/10807039.2017.1411781.
[29] M.A. Mandale, B.A. Jadhawar, Weather forecast prediction: a Data Mining application, Int. J. Eng. Res. Gen. Sci. 3 (2) (2015) 1279–1284.
[30] S. Pal, S. Talukdar, Impact of missing flow on active inundation areas and transformation of parafluvial wetlands in Punarbhaba–Tangon river basin of Indo-Bangladesh, Geocarto Int. 34 (10) (Aug. 2019) 1055–1074, https://doi.org/10.1080/10106049.2018.1469676.
[31] R. Costanza, et al., Changes in the global value of ecosystem services, Global Environ. Change 26 (2014) 152–158.
[32] G. Xie, C.-X. Lu, Y.-F. Leng, D.U. Zheng, S. Li, Ecological assets valuation of the Tibetan Plateau, J. Nat. Resour. 18 (2) (2003) 189–196.
[33] M. Dardonville, B. Legrand, H. Clivot, C. Bernardin, C. Bockstaller, O. Therond, Assessment of ecosystem services and natural capital dynamics in agroecosystems, Ecosyst. Serv. 54 (2022) 101415.
[34] T. Jogun, A. Lukić, M. Gašparović, Simulation model of land cover changes in a post-socialist peripheral rural area: Požega-Slavonia County, Croatia, Hrvat. Geogr. Glas. Geogr. Bull. 81 (1) (Jun. 2019) 31–59, https://doi.org/10.21861/HGG.2019.81.01.02.
[35] R. Costanza, et al., The value of the world# s ecosystem services and natural capital, Ecol. Econ. 25 (1) (1998) 3–15.
[36] X. Wang, et al., miR-214 targets ATF4 to inhibit bone formation, Nat. Med. 19 (1) (Jan. 2013) 93–100, https://doi.org/10.1038/nm.3026.
[37] J.K. Parikh, H. Datye, Sustainable Management of Wetlands: Biodiversity and beyond, Sage, 2003.
[38] E.B. Barbier, Wetlands as natural assets, Hydrol. Sci. J. 56 (8) (2011) 1360–1373.
[39] N. Rashid, J.A.M.M. Alam, M.A. Chowdhury, S.L.U. Islam, Impact of landuse change and urbanization on urban heat island effect in Narayanganj city, Bangladesh: a remote sensing-based estimation, Environ. Challenges 8 (2022) 100571.
[40] R.S. Leya, S.K. Bala, I.H. Newton, M.A. Chowdhury, S.M. Haque, Water security assessment of a peri-urban area: a study in Singair Upazila of Manikganj district of Bangladesh, Environ. Dev. Sustain. 24 (12) (Dec. 2022) 14106–14129, https://doi.org/10.1007/s10668-021-02023-6.
[41] R. Sharah, Impact of Climate Change on Drainage Cost in Selected Zone of Dhaka, 2019.
[42] M. Hassan, J. Southworth, Analyzing land cover change and urban growth trajectories of the mega-urban region of Dhaka using remotely sensed data and an ensemble classifier, Sustainability 10 (2) (Dec. 2017) 10, https://doi.org/10.3390/su10010010.
[43] A.M. Dewan, M.H. Kabir, K. Nahar, M.Z. Rahman, Urbanisation and environmental degradation in Dhaka metropolitan area of Bangladesh, Int. J. Environ. Sustain Dev. 11 (2) (2012) 118, https://doi.org/10.1504/IJESD.2012.049178.
[44] S. Hossain, Migration, urbanization and poverty in Dhaka, Bangladesh, J. Asiat. Soc. Bangladesh (Sci.) 58 (2) (2013) 369–382 [Online]. Available: http://www.asiaticsociety.org.bd/journal/10ShahadatHossain.pdf.
[45] M. Moniruzzaman, et al., Decadal urban land use/land cover changes and its impact on surface runoff potential for the Dhaka City and surroundings using remote sensing, Rem. Sens. 13 (1) (2020) 83.
[46] D. Sarkar, N. Maji, Status and threats of wetland change in land use pattern and planning: impact of land use patterns and urbanization, in: Handbook of Research on Monitoring and Evaluating the Ecological Health of Wetlands, IGI Global, 2022, pp. 106–127.
[47] M.A. Chowdhury, M.K. Hasan, S.L.U. Islam, Climate change adaptation in Bangladesh: current practices, challenges and the way forward, J. Clim. Chang. Heal. 6 (May 2022) 100108, https://doi.org/10.1016/j.joclim.2021.100108.
[48] G. Kibria, A.K. Yousuf Haroon, Climate change impacts on wetlands of Bangladesh, its biodiversity and ecology, and actions and programs to reduce risks, Wetl. Sci. Perspect. From South Asia (2017) 189–204.