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Monitoring Changes in Ecosystem Service Valuation of Arial Beel, Bangladesh

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ABSTRACT: Wetlands are an important part of the environment that maintains the ecological balance and provide critical ecosystem services. They are an integral part of the life and livelihood of the rural communities and are essential for biodiversity conservation. The aim of this study is to quantify the temporal change of Ecosystem Service Value (ESV) in Arial Beel, Munshiganj, Bangladesh, from 2000 to 2025. For this, Landsat 9, 8 OLI/TIRS, and Landsat 5 TM imagery were used for Land Use and Land Cover (LULC) mapping. Then the ESV was calculated, and a sensitivity analysis was conducted to check the robustness of the ESV coefficients. This study found that, over the 25 years, cropland and urban settlement of the study area almost doubled at the cost of its Beel area (wetland) and water bodies (Rivers and Streams). This resulted in a decrease in the ESV of the study area by 2.29 million USD per year. Moreover, nine ecosystem service functions were assessed in this study, among which eight showed a decreasing trend over time in the study area. Lastly, the results of the sensitivity analysis indicated that the ESV coefficients used in the study were inelastic and reliable. This study will provide a clear understanding of the ecosystem services condition of the Arial Beel and foster recognition of the need for wetland conservation to sustain its ecosystem services.

Keywords: Land Use and Land Cover; Ecosystem Service Value; Sensitivity Analysis; Freshwater Ecosystem; Wetland; Bangladesh

INTRODUCTION

In the contemporary world, rapid industrialization and urbanization are leading to a drastic and unplanned change in Land Use in both rural and urban areas (Yirsaw et al., 2017). These changes bring various consequences, and the loss of ecosystem services is one of them (Sun et al., 2018). Ecosystem services are the functions of the biotic and abiotic features of different ecosystems that play a crucial role in the betterment of human life directly or indirectly (Costanza et al., 1997; Hoque et al., 2022). Not only do they have monetary values, but they also provide regulating, provisioning, supporting, and cultural ecosystem services (Feng et al., 2012; Zhan, 2015; Hoque et al., 2022). The human-induced land use change is resulting in the decline of various ecosystems, such as forests (Sharma et al., 2019), wetlands (Lahon et al., 2023), and highlands (Tolessa et al., 2016), among others. This reduction deprives humans of various non-material services, such as recreation (Sun et al., 2018), the regulation of water and climate, soil formation, and the control of erosion (Zhao et al., 2019; Sahle et al., 2018; Hu et al., 2020). That's why ecosystem services should be a matter of concern, even though these services are not seen in bare eye.

Wetlands in Bangladesh occupy 50% of the country's land surface, which is about 7-8 million hectares (Khan, 1993). Among these, 90% are part of freshwater ecosystems, which are largely dependent on the three major river systems: the Ganges, Brahmaputra, and Meghna (Gopal, 1995). Freshwater ecosystems play a crucial role in the livelihoods of people in riverine countries, such as Bangladesh, especially for rural populations (Bhatta et al., 2015; Coates et al., 2013). Moreover, it provides various regulating, provisioning, supporting, and cultural services worldwide (Dodds et al., 2013) and contains a rich biodiversity (Kundzewicz, 2003). But the ecosystem services of the wetlands of Bangladesh are degrading day by day due to increasing population pressure and rural poverty (ADB, 2021; Rahman & Islam, 2005), poor infrastructural development, and lack of management (Byomkesh et al., 2008), and lastly, climate change (Mehvar et al., 2019). Therefore, for the well-being of rural people in Bangladesh, it is crucial to understand the ecosystem services provided by wetlands and implement effective management strategies for their conservation. Several studies have been conducted in Bangladesh on the

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ecosystem services of wetlands, particularly those in coastal areas. Mehvar et al. (2019) assessed the impact of climate change on the ecosystem services of coastal wetlands in Bangladesh and attempted to project the changes until 2100. Hossain et al. (2013) developed a framework that integrated ecosystem services and climate change adaptation into development programs in Bangladesh. Huq et al. (2020) highlighted the dependency of rural people in Southern Bangladesh on the ecosystem services provided by the coastal wetlands. Al-Amin et al. (2021) assessed the use and value of freshwater wetlands (locally known as *haors)* to the local community and their willingness to participate in the conservation of these wetlands. Islam (2010) highlighted the importance of threats to wetlands in Bangladesh and emphasized the need for sustainable management and protection of these wetlands.

Quantifying the change in Ecosystem Service Value (ESV) is a beneficial task for decision-makers, as it will help in environmental protection and the wise use of resources (Li et al., 2019; Farley, 2008; Song and Deng, 2015). Shave has made various attempts to quantify Ecosystem Service Value. De Groot (1987) argued about the undervaluation of the environment in the economic system and suggested the term "environmental function" to reflect their values. Bingham et al. (1995) attempted to improve the methods of valuing ecosystem services using a multidisciplinary approach. Costanza et al. (1997) quantified the ecosystem service value per hectare per year of 17 ecosystem functions and for 16 core biomes, which was later updated by Costanza et al. (2014). The value coefficient of ecosystem functions is widely used in various studies for different ecosystems (Akber et al., 2018; Hoque et al., 2022). GIS and remote sensing play a pivotal role in assessing changes in Ecosystem Service Value (ESV) in response to changes in Land Use and Land Cover (LULC). It is highly beneficial for LULC mapping and area calculation by class (Hossen et al., 2025; Natarajan et al., 2016; Liu et al., 2020), which is the primary work for assessing changes in ESV. Several studies have used GIS and Remote sensing for such work. Li et al. (2019) evaluated the change in Ecosystem Service Value due to rapid land use change in Central Asia using GIS and remote sensing. Lahon et al. (2023) employed geospatial techniques to assess LULC-associated ESV changes in the Brahmaputra Valley, India. Chow (2015) employed GIS methodologies to assess the direct utilization of mangrove plantations by local communities in coastal Bangladesh and the economic value of these uses. Moreover, Huq et al. (2019) also used geospatial techniques to highlight the interaction between ESV and LULC in a temporal context. The objectives of this study are to: (1) evaluate the change in time of Land Use and Land Cover (LULC); (2) examine the change in Ecosystem Service Value (ESV) in Arial Beel, Munshiganj, being one of the extremely affected wetlands in Bangladesh (The Daily Star, 2023). These research results will help policymakers understand the timeframe for change in Arial Beel, raise awareness among the public, and inform policy improvements for the conservation of this wetland. Additionally, it will contribute to Bangladesh's attainment of Sustainable Development Goal (SDG) 6 - 'Clean Water and Sanitation', SDG 13-'Climate Action', SDG 14-'Life Below Water' and SDG 15- 'Life on Land' through sustainable agriculture, climate actions, biodiversity conservation and sustainable management of the flora and fauna associated with this wetland (Ramsar Convention, 2018; UN 2025).

MATERIALS AND METHODS

Study Area

The study area of this research is the Arial Beel, which spans 36,313.92 hectares in Dohar, Lohaganj, Nawabganj, Sreenagar, and Serajdiganj upazila in Munshiganj district, as well as a small portion in Keraniganj upazila in Dhaka district, Bangladesh. The geographical Location of Arial Beel is 23°32′ N to 23°48′ N latitude and 90° 08′ E to 90° 27′ E longitudes. Occupying a portion of the low-lying basin between the Ganges floodplain and the young Brahmaputra floodplain (Siddique et al., 2019), most of the area of this wetland is in lowland (BARC, 2005). The Beel lies between the Ganges and the Dhaleshwari River, and the Ichamoti River flows through it, providing a significant source of runoff during the monsoon (Siddique et al., 2019). Moreover, this Beel is home to more than 500 species of flora, 260 species of fish, and 400 species of vertebrates (Siddique, 2011). And in the dry season, it provides vegetables, rice, and corn (National Tourism Organization, 2025). This wetland is important not only for agriculture and water resources, but also for reducing floodwater regulation in its surrounding areas. However, due to population growth and Land Use change, this wetland is degrading day by day. The study area is predominantly agricultural, with a concentration of land use in the center and southern parts of the area. It also has a significant portion of rural and urban settlements scattered on the western and eastern sides. The pesticides used in agricultural land are harming aquatic plants and animals in the area (Siddique, 2011). Moreover, the increase in settlements in the Beel area is causing various issues, such as the loss of water bodies, drainage problems, and the loss of vegetation, ultimately leading to the degradation of Ecosystem Service Values (ESV).

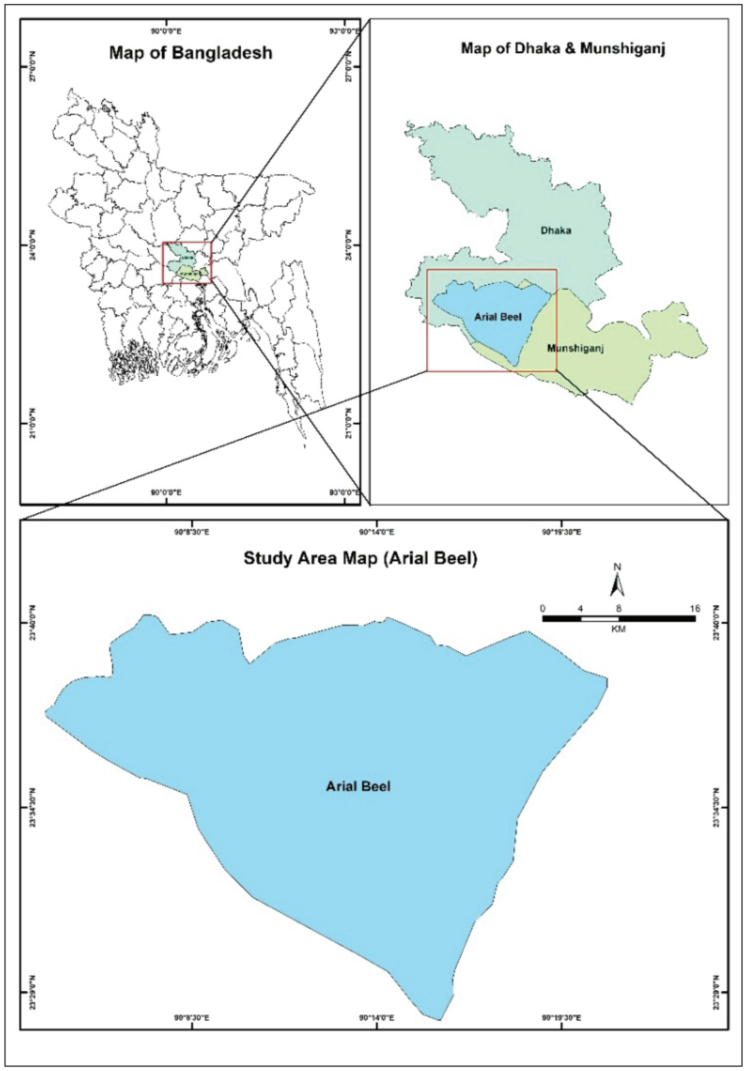

Figure 1: Study Area Map Presenting the Geographical Location of Arial Beel

Data Acquisition

Landsat satellites provide 30m resolution data, which is easily accessible and used in various studies for image classification (Seyam et al., 2023; Kikon et al., 2023; Naim & Al Kafy, 2021; Hoque et al., 2022). Landsat 5 TM, Landsat 8 OLI/TIRS, and Landsat 9 OLI/TIRS Satellite imagery were used in this study, acquired from USGS Earth Explorer (https://earthexplorer.usgs.gov/). The images were collected at an interval of 5 years for detailed analysis of LULC change. To classify the year 2025, images were acquired from Landsat 9 on 16 February 2025. As the Landsat 9 was launched in 2021 (NASA, 2022), images were acquired from the Landsat 8 OLI/TIRS Satellite for the dates 27 December 2020 and 30 December 2015. For the years 2010, 2005, and 2000, images were acquired from the Landsat 5 TM satellite as Landsat 8 was launched in 2013 (NASA, 2023). The images were acquired during the same seasons (October to February – Dry Season) to get images with low cloud cover. Although the dates of image acquisition vary slightly, they represent the same seasonal condition with minimal variation. The WRS path of the images is 137, and the row is 044.

Table 1: Information of the Data (Landsat 5, Landsat 8, and Landsat 9) Used in this Study

Product	Mission	Date Acquired	WRS Path	WRS Row	Bands Used
LT05_L2SP_137044_20001220_20200906_02_T1	Landsat 5	2000/12/20	137	044	B1, B2, B3, B4, B5
LT05_L2SP_137044_20051015_20200901_02_T1	Landsat 5	2005/10/15	137	044	B1, B2, B3, B4, B5
LT05_L2SP_137044_20100215_20200825_02_T1	Landsat 5	2010/02/15	137	044	B1, B2, B3, B4, B5
LC08_L2SP_137044_20151230_20200908_02_T1	Landsat 8	2015/12/30	137	044	B2, B3, B4, B5, B6, B7
LC08_L2SP_137044_20201227_20210310_02_T1	Landsat 8	2020/12/27	137	044	B2, B3, B4, B5, B6, B7
LC09_L2SP_137044_20250216_20250219_02_T1	Landsat 9	2025/02/16	137	044	B2, B3, B4, B5, B6, B7

Land Use and Land Cover (LULC) Mapping

The acquired images were preprocessed using ArcMap 10.8 before classification. For Landsat 5, five bands (B1, B2, B3, B4, and B5) were stacked, and for Landsat 8 and Landsat 9, six bands (B2, B3, B4, B5, B6, and B7) were stacked together to make a composite band. The NIR and SWIR bands were also utilized in this study to create a false-color composition of the images, which provides a more accurate representation of features such as urban areas and agriculture (Butler, 2019). Then the composite images were extracted using the vector shapefile of the study area. To enhance the visibility of the images, radiometric correction and geometric correction may be required for some images (Seyam et al., 2023); however, as this study uses Level-2 Surface Reflectance Products from USGS, which are already corrected, these images don't require them.

After completing preprocessing, the images were classified using ArcMap 10.8. In this study, the Maximum Likelihood Supervised Classification Method was employed based on the spectral reflection differences across various features (Gadrani et al., 2018; Hossen et al., 2025). For this, at least 100 training samples (polygons) were taken for each class using the Classification Toolbar in ArcMap 10.8. The samples were distributed all over the study area, and they were selected with the help of Google Earth Pro. At last, the signature file containing the training samples was used to perform the classification. Five Land Use classes were identified in this study. Those are: Crop Land, Beel Area, Urban Settlement, Rivers and Streams, and Rural Settlements with Tree Cover (Table 2). After supervised classification, the area of each land cover is calculated in hectares, and LULC change was analyzed.

$$Percentage\ of\ Area\ Change = \frac{A_f - A_i}{A_i} \times 100$$

The equation above is used to analyze the change of LULC in this study. Here, A_i and A_f are the initial area and the final area, respectively. The difference between Ai and A_f is the total LULC area gain or loss from one time to another.

Table 2: Land Use and Land Classification Scheme Used in This Study

Land Use Class Name		Description
1.	Crop Land	Cultivated or uncultivated agricultural lands
2.	Beel Area	A low-lying area having static water in the monsoon, but it dries up in the dry season.
3.	Urban Settle-ments	Roads, buildings, industries, brick fields, and other areas with heavy concrete-built structures
4.	Rivers and Streams	Waterbodies that hold water the whole year
5.	Rural Settle-ments with Tree Cover	Primarily a mixture of vegetation and rural settlements, including katcha or semi-pucca houses, cowsheds, and other structures.

Accuracy Assessment

Accuracy assessment is critical to ensure the validity of image classification (Alqurashi & Kumar, 2013). In this study, an accuracy assessment was conducted for each LULC Map by generating 300 stratified random points, which were different from the training samples and were selected independently, using ArcMap 10.8. The points were validated using Google Earth Pro, as it facilitates the validation of historical images. The historical images were used as closely as possible to the dates of the corresponding classified images. At last, a confusion error matrix was used to calculate the overall accuracy, producer's accuracy, user's accuracy, and kappa statistics for each LULC Map. The overall accuracy of the LULC classification ranges from 84.39% to 91.42%, and the kappa statistics range from 0.79 to 0.88, which indicates that the LULC classifications conducted in this study are suitable for further analysis (Ursu et al., 2025).

Table 3: Accuracy Assessment Result of Image Classification in This Study

Classification	Overall Accuracy	Kappa Statistics
LULC 2000	84.39%	0.79
LULC 2005	86.96%	0.83
LULC 2010	87.00%	0.83
LULC 2015	85.00%	0.81
LULC 2020	90.37%	0.86
LULC 2025	91.42%	0.88

Ecosystem Service Value (ESV) Calculation

The ecosystem services and the value coefficient of ESV for each land use class have been determined through a thorough literature review, where studies were reviewed in both global and local scales. As the specific Ecosystem Value Coefficient of each LULC class of Arial Beel is not available, various studies were investigated, keeping in mind the ecological similarities. Several authors have taken this approach in their studies, where the exact value of the ESV coefficient for a particular ecosystem is not available (Peng et al., 2021; Hoque et al., 2022; Akber et al., 2018; Chow, 2015; Huq et al., 2019).

Various studies have used the value coefficient of ESV per unit area in their studies. Gao-di et al. (2002) evaluated the ESV through a literature review and expert opinion, which was later followed by D. Song et al. (2025) for assessing the ESV of ten land use classes in China. However, the work of Costanza et al. (1997) is a pioneer in this field, where the ESV coefficient was applied to 16 major land biomes and 17 different ecosystem services worldwide using the Benefit Transfer Method (BTM). This study was later followed by various scholars (Xie et al., 2017; Luan & Liu, 2022; Tan et al., 2020; Shao et al., 2020). In the context of Bangladesh, Hoque et al. (2022) used such an ESV value coefficient for seven land use classes for the coastal areas of Bangladesh. A case study on urban ecosystems conducted by Rahman and Szabó (2021) assessed ESV for five land-use classes. Moreover, numerous studies have been conducted in Bangladesh using the ESV Coefficient to assess various ecosystem services (Huq et al., 2019; Akber et al., 2018; Chow, 2015; Hoque et al., 2020; Morshed et al., 2022). After reviewing all the literature, the ESV Coefficients for nine ecosystem service functions were determined for the LULC types in this study (Table 4).

Table 4: ESV Coefficient for Different LULC Classes in Arial Beel in USD $ha^{-1}year^{-1}$

Ecosystem Service Functions	ESV Coefficient in USD ($ha^{-1}year^{-1}$)				
	Crop Land	Settlement	Tree Cover	Rivers and Streams	Beel Area
Climate Regulation	426	0	533	533	488
Water Regulation	958	0	1277	2555	5606
Culture and Recreation	261	392	261	457	2211
Soil Formation and Retention	141	0	141	141	141
Food Production	922	0	357	603	614
Raw Materials	317	0	211	423	425
Waste Treatment	1103	0	1103	2206	3015
Extreme Event Management	78	78	78	233	233
Biodiversity Protection	333	0	499	499	948
Total	4539	470	4460	7650	13681

The ESV was calculated for each LULC type by multiplying the area of each class by the total value coefficient. Service-wise ESV was calculated by multiplying the area by the ESV of each ecosystem service.

$$Ecosystem\ Service\ Value_t = \sum A_{lt} \times C_l$$

Here, "A" is the Area (Hectares) of a particular LULC type, and "C" refers to the ESV Coefficient (USD $ha^{-1}year^{-1}$) for each LULC type. "l" refers to a specific LULC type, and "t" refers to a particular year.

Sensitivity Analysis of ESV Coefficients

The ecosystem service value coefficient of this study faced the scarcity of exact data on particular land use, which is why proxies of different biomes are used for various land use classes (Hoque et al., 2022), e.g., the ESV coefficients of Inland wetlands from De Groot et al. (2012) are used as a proxy for the ESV of Beel Area as Arial Beel is also a freshwater wetland and is situated inland. However, it may cause uncertainty in the result due to variations in local conditions. That's why a sensitivity analysis was conducted using the elasticity concept (Hoque et al., 2022), which is the percentage change in total ESV of the study area divided by the percentage change in ESV Coefficient for ±50% change in the Value Coefficient for each land use (Mansfield, 1972). In this study, the sensitivity of all the ESV Coefficients is assessed to test their robustness (Kreuter et al., 2001; Hoque et al., 2022).

$$CS = \frac{(ESV_m - ESV_i)/ESV_i}{(C_m - C_i)/C_i}$$

This formula is used to assess the Sensitivity of ESC Coefficient (CS). Here, ESV is the total Ecosystem Service Value of the study area, and C is the ESV Coefficient for each LULC Type. "m" and "i" stand for modified value and initial value, respectively. If the value of CS (Coefficient Sensitivity) is less than 1, then the ESV coefficients are robust, which means the ESV of that land use will not change drastically if the ESV Coefficients are changed by ±50%. But if the CS is greater than 1, then the ESV coefficients are elastic, which means a small change in the ESV coefficient will bring about a drastic change in the ESV of that LULC class (Hoque et al., 2022; Kreuter et al., 2001; Gashaw et al., 2018; Li et al., 2007).

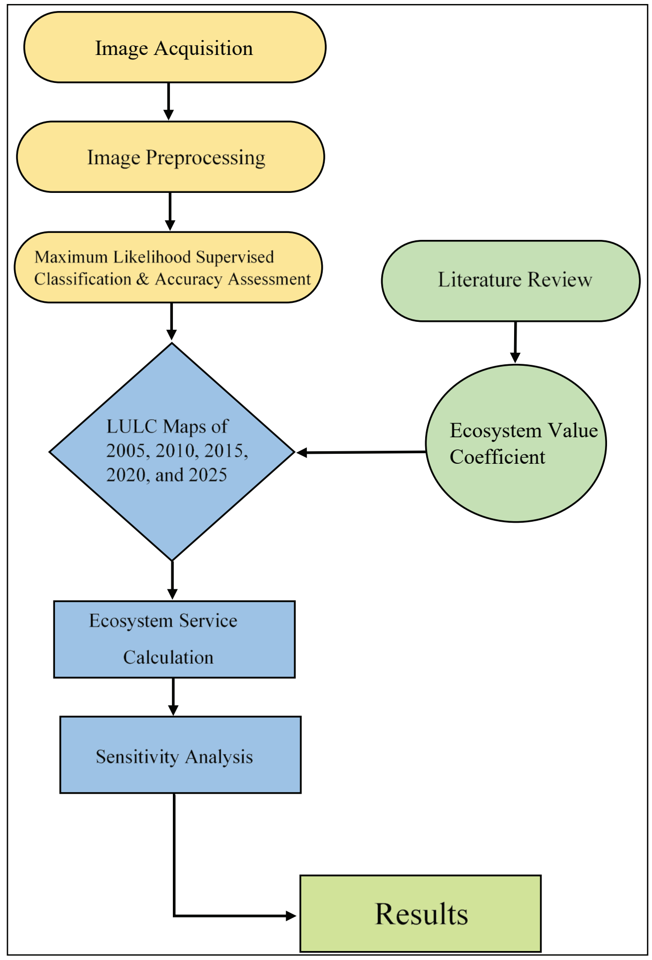

Figure 3: Graphical Representation of the Methods Used in the Study

RESULTS

Dynamics of LULC in Arial Beel

The land use and land cover (LULC) dynamics illustrate the changing trend of different LULC classes in the study area from 2000 to 2025. Over the past 25 years, the Beel area has been halved, resulting in a loss of 5,650.65 hectares, which has reduced the Beel area from 29.87% of the total area in 2000 to 14.31% of the total area in 2025. Although the reduction was initially very gradual, from 2000 to 2005, and later it accelerated in the time period during 2005 to 2025, with an overall reduction of 49.93%. On the contrary, agricultural land has increased by approximately 58.29% over the 25 years, rising from 10,306.6 hectares (28.38% of the total area) in 2000 to 16,314.5 hectares (44.93% of the total area) in 2025.

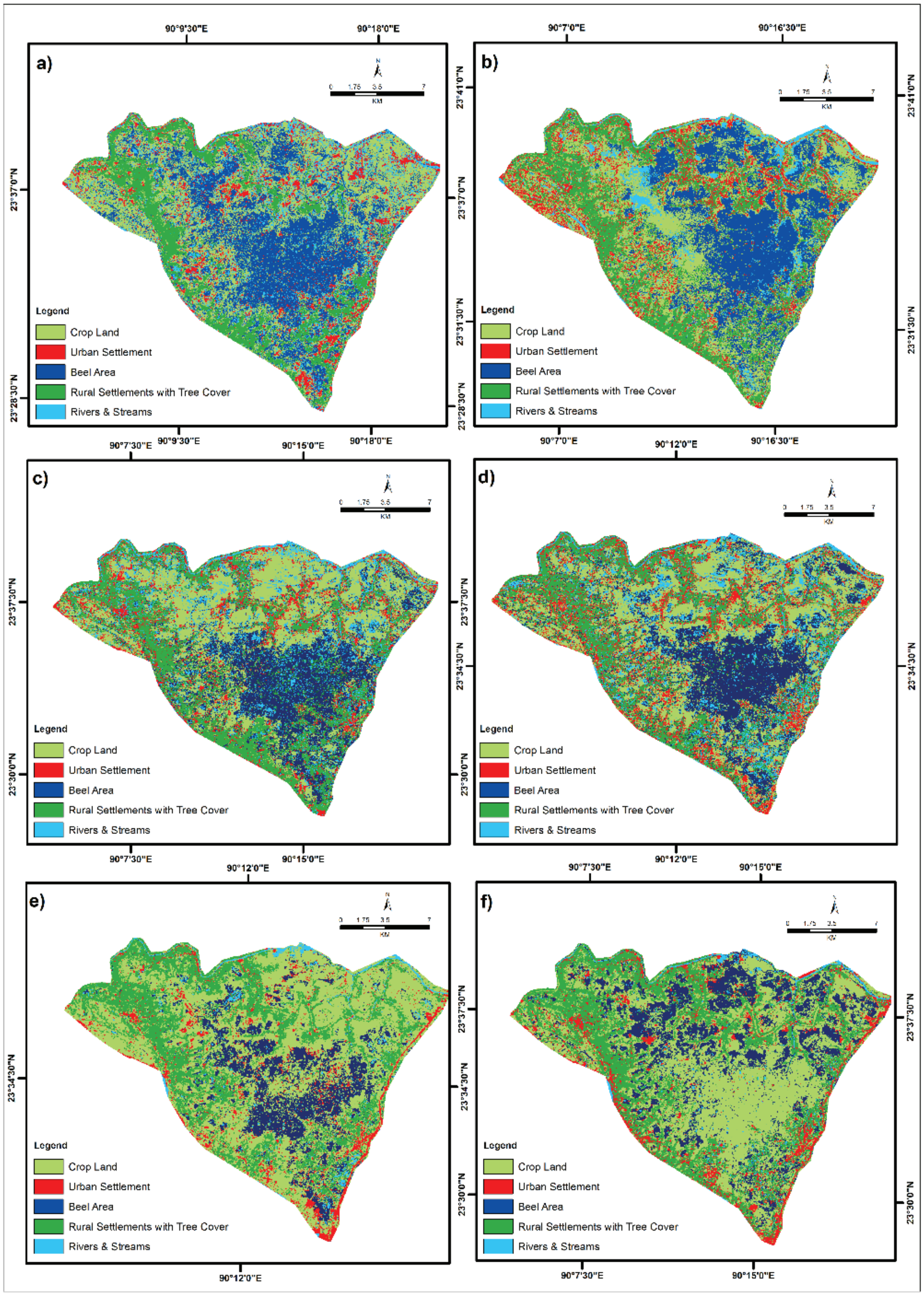

Figure 2: Land Use and Land Cover (LULC) Map of Arial Beel of the Year (a) 2000, (b) 2005, (c) 2010, (d) 2015, (e) 2020 and (f) 2025

Table 5: Area Calculation (in Hectares) of LULC Classes of Arial Beel

		Crop Land	Urban Settlement	Beel Area	Rural Settlement with Tree Cover	Rivers and Streams
2000	**Area**	10306.6	2095.48	10848.5	7060.78	4002.59
	%	28.38	5.77	29.87	19.44	11.02
2005	**Area**	11198.7	2971.74	10380.04	7228.34	4535.1
	%	30.84	8.18	28.58	19.91	12.49
2010	**Area**	11629.71	3162.09	8192.25	8666.61	4663.26
	%	32.03	8.71	22.56	23.87	12.84
2015	**Area**	12885.95	3693.78	7827.03	7635.06	4272.1
	%	35.48	10.17	21.55	21.03	11.76
2020	**Area**	14163.7	3756.6	6443.34	8775.83	3174.45
	%	39	10.34	17.74	24.17	8.74
2025	**Area**	16314.5	4789.8	5197.82	7208.71	2803.09
	%	44.93	13.19	14.31	19.85	7.72

Additionally, a gradual change in urban settlement is observed, increasing from 5.77 percent of the total area in 2000 to 13.19 percent in 2025, representing a substantial upward trend at a rate of 128.57%. This trend indicates the influence of urbanization and growing population density in the area, as well as the expansion of settlement areas, which contributed to the decline of the Beel area alongside the increasing trend in agricultural land area. Moreover, these changes in LULC also resulted in a significant reduction in the area of water bodies (rivers, streams & ponds) by 29.97% from 4002.59 hectares in 2000 to 2803.09 hectares in 2025. The tree cover, along with rural settlement in the Arial Beel, showed moderate variation overall from 2000 (7060.78 hectares) to 2025 (7208.71 hectares). Still, between 2000 and 2020, there was a gradual increasing trend, and the trend reversed in the past five years (Fig. 3).

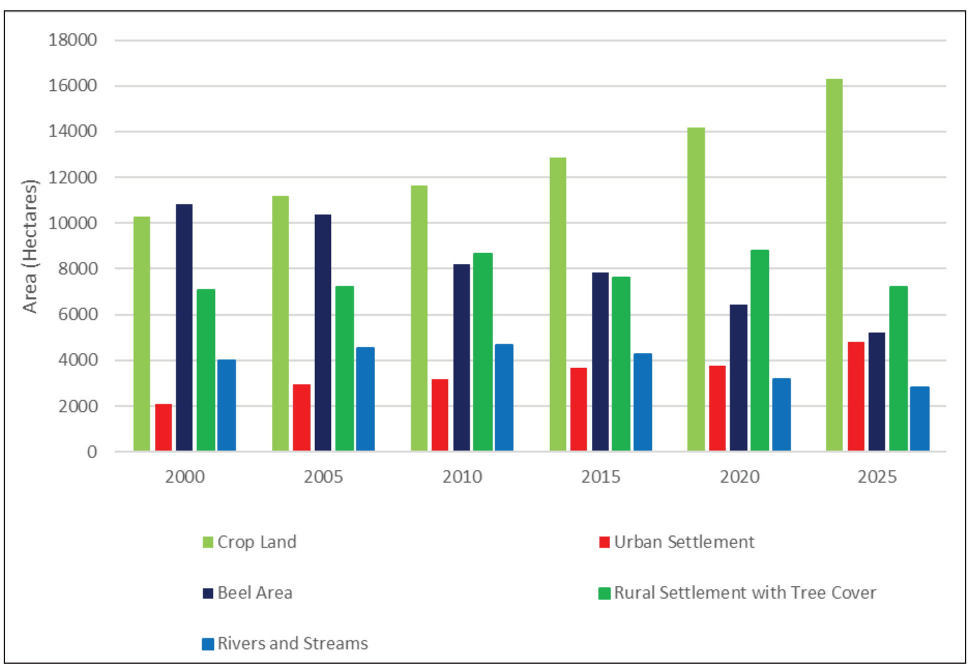

Figure 4: Bar Chart Illustrating the LULC Changes in the Study Area

Temporal Dynamics of Ecosystem Service Value (ESV)

The initial ESV value in 2000 was 258.29 million USD, which experienced a 1.12% increase by 2005, and the value rose to 261.17 million USD. But in the later years, the ESV value gradually decreased. From 2005 to 2010, the ESV drastically declined by 7.85% to 240.68 million USD, despite a noticeable upward trend before. The ESV change was -2.76% from 2010 to 2015, -7.01% from 2015 to 2020, and -7.64% from 2020 to 2025. After a net deduction of 57.55 million USD (22.17%) over 25 years, the ESV declined to 201.01 million USD in 2025.

The largest portion of ESV in the study area is contributed by the Beel Area (57.46% of the total ESV), which experienced a decrease of 52.09% and fell to 71.11 million USD in 2025. The ESV of rivers and streams exhibits an increasing trend followed by a decreasing trend. It was 30.62 million USD in 2000, which experienced an increase of 16.5% (35.67 million USD in 2010) from 2000 to 2010. Later, it decreased by 29.98% (from 21.44 million USD in 2025) over the next 15 years, resulting in a net decrease in ESV for this LULC type.

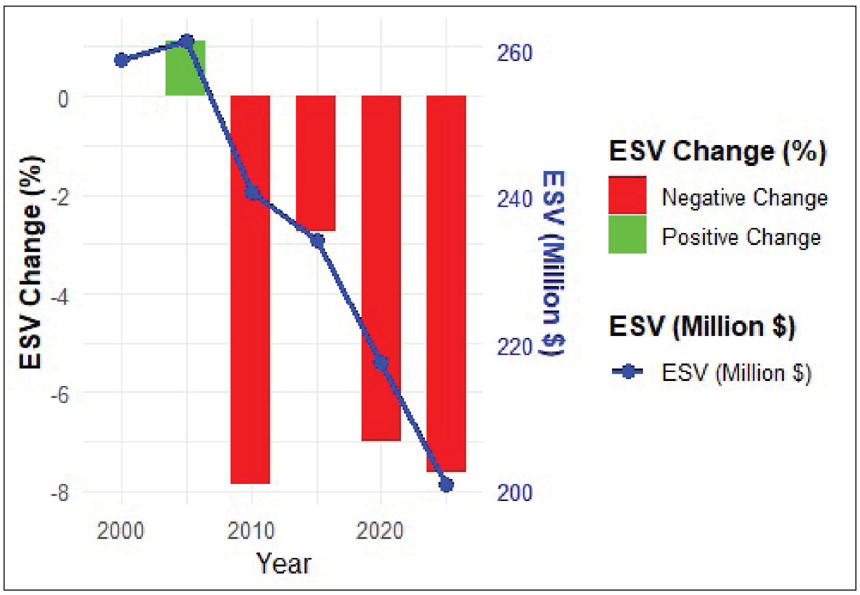

Figure 5: Change in Ecosystem Service Value (ESV) from 2000 to 2025

Table 6: Temporal Valuation of Ecosystem Services of Each LULC Type

		Cropland	Urban Settlement	Beel Area	Rural Settlement with Tree Cover	Rivers and Streams	Total
2000	ESV (In Million USD)	46.78	0.98	148.42	31.49	30.62	258.29
	In %	18.11%	0.38%	57.46%	12.19%	11.85%	-------
2005	ESV (In Million USD)	50.83	1.4	142.01	32.24	34.69	261.17
	In %	19.46%	0.53%	54.37%	12.34%	13.28%	-------
2010	ESV (In Million USD)	52.79	1.49	112.08	38.65	35.67	240.68
	In %	21.93%	0.62%	46.57%	16.06%	14.82%	-------

2015	**ESV (In Million USD)**	58.49	1.74	107.08	34.05	32.68	234.04
	In %	25%	0.74%	45.75%	14.55%	13.96%	-------
2020	**ESV (In Million USD)**	64.29	1.77	88.15	39.14	24.28	217.63
	In %	29.54%	0.81%	40.51%	17.98%	11.16%	-------
2025	**ESV (In Million USD)**	74.05	2.25	71.11	32.15	21.44	201.01
	In %	36.84%	1.12%	35.38%	15.99%	10.67%	-------

The crop land in the study area increased over the years, resulting in a gradual increase in its ecosystem service value (Fig. 5). In 2000, the amount was 46.78 million USD, which rose to 74.05 million USD by 2025. From 2000 to 2025, a negative association has been observed between the Beel area and the change in crop land area. This indicates that a significant portion of the Beel area may have been converted to crop land in these 25 years. Due to urbanization, the Arial Beel area also witnessed a substantial increase in urban settlement at a rate of 129.59% from 2000 to 2025, and the ESV value increased from 0.98 million USD to 2.25 million USD in this time period. Although it faced a drastic change, it contributes to a very minimal portion of the total ESV of the Arial Beel. The net change in the ESV of rural settlements with tree cover appears to be minimal, with some fluctuations over the 25 years. The tree cover associated ESV was 31.49 million USD (12.19% of total ESV) in 2000, and increased to 39.14 million USD (17.98% of total ESV) in 2020 due to an increasing rate of 24.29% from 2000 to 2020, and in 2025 it reduced to 32.15 million USD (15.99% of total ESV) at a rate of -17.85% from 2020 to 2025 (Table 6).

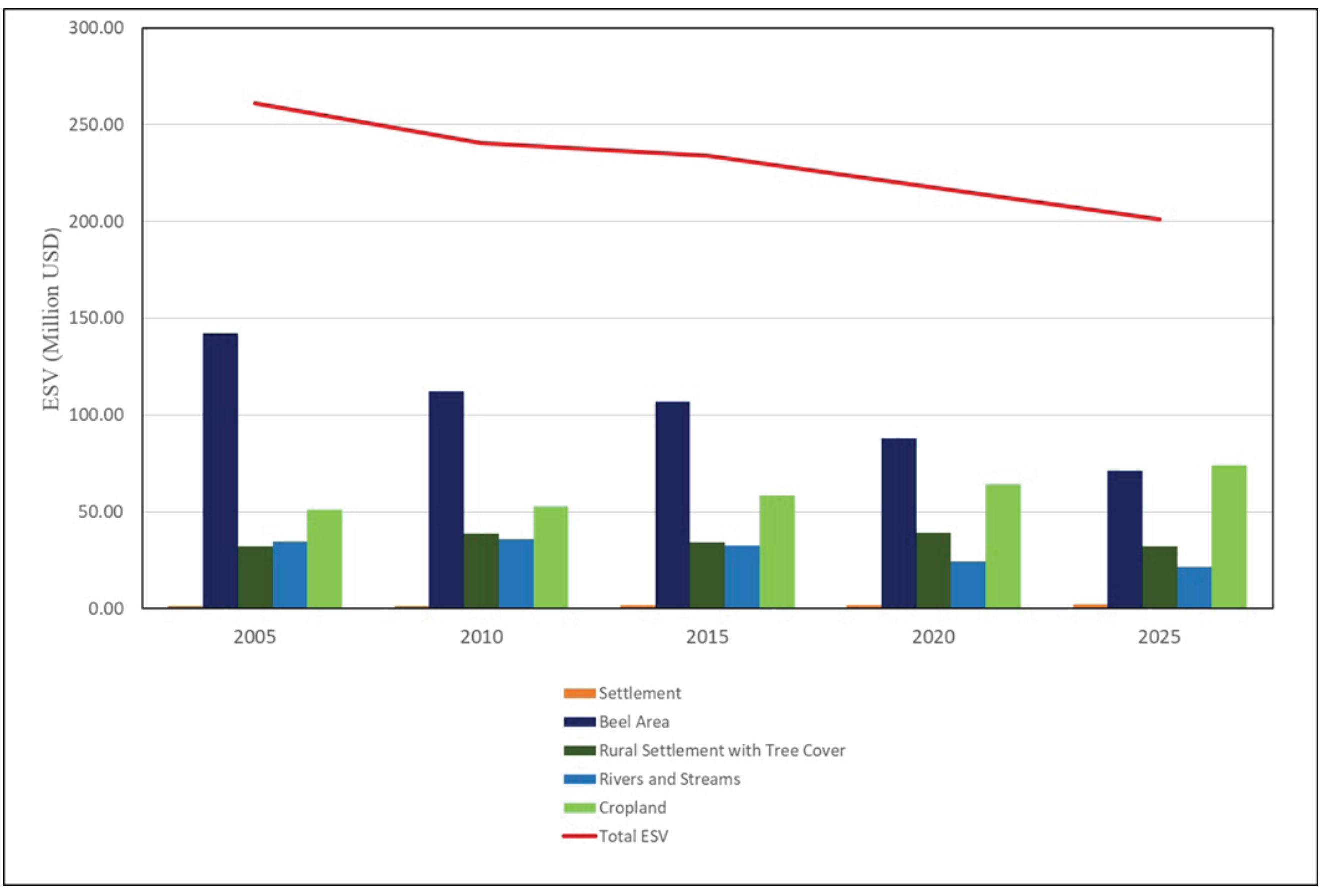

Figure 6: Bar Diagram Illustrating the ESV Dynamics of Each LULC Type in the Study Area

Analysis of the Ecosystem Service Functions in the Study Area

Changes in the LULC have brought about a drastic change in the functions of ecosystem services. Except for the food production function, the ESV of all other functions has decreased at varying rates over the 25 years. The ESV of food production function experienced a gradual rise from 21.10 million USD in 2000, with a percentage share of 8.2%, to 22.50 million USD (11.2%) in 2025, increasing at a rate of 6.63%. It is due to the drastic increase in crop lands in that area, as the ESV coefficient for food production is the greatest for cropland. Moreover, the decline of waterbodies (Rivers and Streams) and wetlands (Beel areas) has significantly impacted the water regulation, waste treatment, and biodiversity protection functions in the study area. The water regulation function had the largest ESV value among all functions, at 89.93 million USD (34.8% of total ESV) in 2000. This later decreased by 32.01% and fell to 61.14 million USD (30.4% of total ESV). The ESV of Waste treatment function was 60.69 million USD, with a percentage share of 23.5% in 2000. Though the value experienced an initial increasing trend from 2000 to 2005, it degraded to 47.8 million USD in 2025 at a rate of -21.24% over the last 25 years. For the biodiversity protection function, the ESV was 19.4 million USD, with a percentage share of 7.4%, in 2000. It was reduced to 15.36 million USD (7.6% of total ESV) in 2025, with a reduction rate of 20.16%.

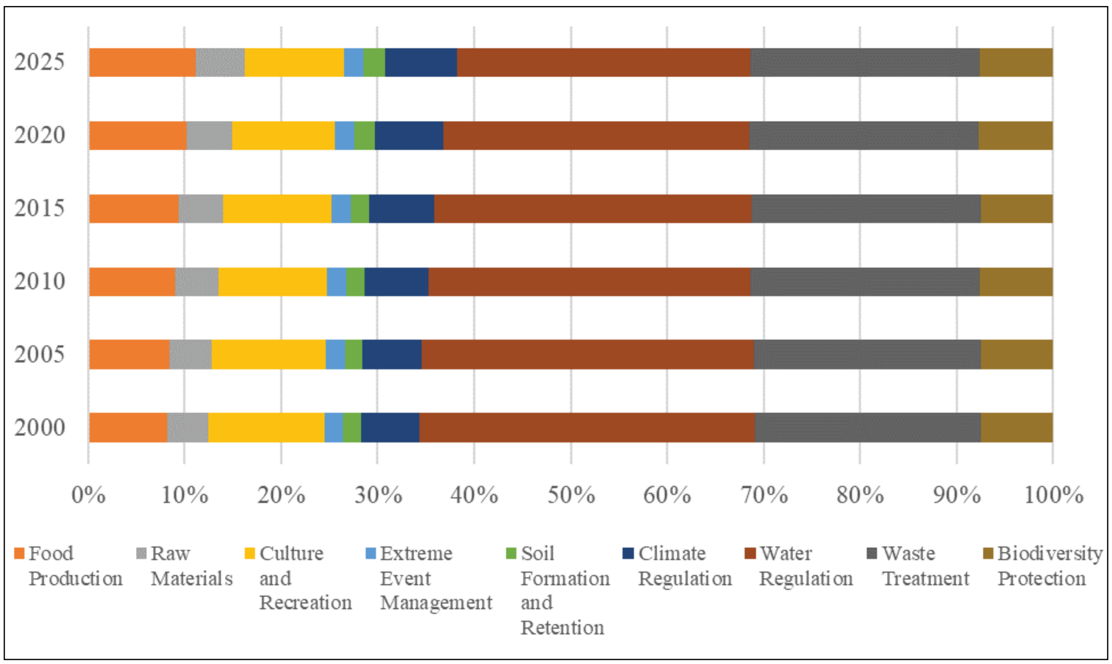

Figure 7: Change in the ESV of Each Ecosystem Service Function from 2000 to 2025

The ESV value for the raw material function also experienced a slight increase, from 11.06 million USD in 2000 to 11.41 million USD in 2005. However, it eventually experienced a decreasing trend in the remaining years, ultimately reaching 10.09 million USD by 2025. The gradual decrease in waterbodies and wetland areas is mostly responsible for this. ESV of extreme event management, soil formation, and retention experienced a slight decline over the 25 years. The ESV of extreme event management decreased by 91,000 (approximately 0.91 million USD), and for soil formation and retention, the change is approximately 37,000 (roughly 0.37 million USD). Wetlands are an integral part of the lives of local communities, and they carry a significant cultural heritage (Islam, 2010). This is also associated with ecosystem services. Thus, due to the decrease in the Beel Area in Arial Beel, the ESV of the Culture & Recreation function decreased by 10.38 million USD during these 25 years. Lastly, the climate regulation function exhibits two contrasting trends: an upward trend from 2000 to 2010 at a rate of 3.08%, and a downward trend from 2010 to 2025 at a rate of -7.72%. The ESV of climate regulation was 15.58 million USD, 16.06 million USD, and 14.82 million USD in the years 2000, 2010, and 2025, respectively.

Table 7: ESV of each Ecosystem Service Function from 2000 to 2025

		Food Production	Raw Materials	Culture and Recreation	Extreme Event Management	Soil Formation and Retention	Climate Regulation	Water Regulation	Waste Treatment	Biodiversity Protection
2000	**ESV (In Million USD)**	21.10	11.06	31.17	4.98	4.82	15.58	89.93	89.93	19.24
	in %	8.2%	4.3%	12.1%	1.9%	1.9%	6.0%	34.8%	34.8%	7.4%
2005	**ESV (In Million USD)**	22.01	11.41	31	5.14	4.7	16.11	89.74	89.74	19.44
	in %	8.4%	4.4%	11.9%	2.0%	1.8%	6.2%	34.4%	34.4%	7.4%
2010	**ESV (In Million USD)**	21.66	10.97	26.78	4.83	4.67	16.06	80.05	80.05	18.29
	in %	9.0%	4.6%	11.1%	2.0%	1.9%	6.7%	33.3%	33.3%	7.6%
2015	**ESV (In Million USD)**	22.00	10.83	26.06	4.71	4.6	15.66	76.89	76.89	17.65
	in %	9.4%	4.6%	11.1%	2.0%	2.0%	6.7%	32.9%	32.9%	7.5%
2020	**ESV (In Million USD)**	22.06	10.42	23.16	4.32	4.59	15.55	69	69	16.79
	in %	10.1%	4.8%	10.6%	2.0%	2.1%	7.1%	31.7%	31.7%	7.7%
2025	**ESV (In Million USD)**	22.50	10.09	20.79	4.07	4.45	14.82	61.14	61.14	15.36
	in %	11.2%	5.0%	10.3%	2.0%	2.2%	7.4%	30.4%	30.4%	7.6%

Analysis of Coefficient Sensitivity

The results of the sensitivity analysis of the value coefficient of ecosystem services are represented in Table 8. The CS for all LULC types ranged from 0.001 to 0.57, indicating that the ESV of the study area is inelastic in terms of the ESV coefficient. However, the CS of the urban settlement is the lowest, ranging from 0.003 to 0.01 over the 25-year timespan. This makes the value coefficient of urban settlement the most robust one in this study. Moreover, the CS of cropland, *Beel* area, rivers and streams, and rural settlement with tree cover ranges from 0.18 to 0.37, 0.57 to 0.35, 0.12 to 0.11, and 0.12 to 0.16, respectively. This illustrates that the ESV calculated in this study is reliable, and there will be no significant change in the ESV of the study area for a ±50 % change in the value coefficient of any LULC type.

Table 8: Sensitivity of the Coefficient Used in the Study

		Crop Land ± 50%	Urban Settle-ment ± 50%	Beel Area ± 50%	Rural Settlement with Tree Cover ± 50%	Rivers and Streams ± 50%
	Percentage	± 9.06%	± 0.19%	± 28.73%	± 6.1%	± 5.93%
2000	**CS**	0.18	0.003	0.57	0.12	0.12
	Percentage	± 9.73%	± 0.27%	± 27.19%	± 6.17%	± 6.67%
2005	**CS**	0.19	0.005	0.54	0.12	0.13
	Percentage	± 10.97%	± 0.31%	± 23.28%	± 8.03%	± 7.41%
2010	**CS**	0.22	0.006	0.47	0.16	0.15
	Percentage	± 12.5%	± 0.37%	± 22.88%	± 7.27%	± 6.98%
2015	**CS**	0.25	0.007	0.46	0.15	0.14

	Percentage	± 14.77%	± 0.41%	± 20.25%	± 8.99%	± 5.58%
2020	**CS**	0.3	0.008	0.41	0.18	0.11
	Percentage	± 18.42%	± 0.56%	± 17.69%	± 8%	± 5.33%
2025	**CS**	0.37	0.01	0.35	0.16	0.11

DISCUSSION

Over the timeframe of the study, Arial Beel witnessed a significant shift from its wetland areas and waterbodies to croplands and urban settlements. Cropland increased more than 1.5 times its starting year, whereas urban settlement increased more than two times. On the other hand, the Beel area and waterbodies (rivers and streams) have almost halved in these 25 years. So, a shift from natural landscape to artificial landscape has been observed in the study area, which has many adverse impacts in terms of ecosystem services. The growth of croplands may have given rise to the food production function of the ecosystem, but it has heavily impacted the fisheries of the wetland. The majority of the local community in this area is largely dependent on the wetland for fisheries (Hossain & Mohammad, 2009). But the use of pesticides in the croplands is having a very harmful impact on the fish species, especially catfish (Hossain & Mohammad, 2009). Moreover, Hossain and Mohammad (2009) also found that the pesticides used in the agricultural land have a high impact on fish resources, but it has a low impact on rat species, which eventually poses a threat to the crops. Therefore, the conversion of natural landscapes into croplands may increase food production, but it reduces other ecosystem services. Moreover, all the ecosystem service functions assessed in this study have experienced a decreasing trend. Thestudy area has experienced significant urbanization in recent years. The construction of the 6-lane Dhaka Madaripur Highway, which is not more than 5km from the study area, may have an impact on this urbanization (Morshed et al., 2024). Such a shift from the Beel area or vegetation to urban settlements has resulted in reduced ecosystem services. As a result, the local communities of that area are facing adverse impacts such as flood risk (Siddique et al., 2019), loss of fisheries (Roy et al., 2022), extreme events, loss of raw materials, climate impacts, and so on. So, this study emphasizes the conservation of the natural landscape of Arial Beel in order to sustain its ecosystem services for the betterment of the local community and the future generation. This study faced the limitation of high-resolution, easily accessible historical images, which could have been beneficial for more accurate results. Moreover, the lack of cloud-free data in the same months may cause a minor variation in some land use classes, particularly for waterbodies, agricultural land, and beel area, which was not entirely excluded. However, the results of this study can be considered reliable and accurate as it covers a long time range of data in the same season, and the overall accuracy of the classification is also high. But site-specific Ecosystem Value Coefficients, considering the local conditions, would have been more helpful in this study. The strength of this study lies in its wetland-specific focus, integrating GIS and ecosystem services, and filling a regional gap in Bangladesh. Furthermore, it provides a comprehensive picture of the changing nature of LULC in wetland areas and associated wetland degradation in Bangladesh.

CONCLUSION

This study assessed the change in ecosystem service value of the Arial Beel in relation to its changing Land Use and Land Cover (LULC) from the year 2000 to 2025. The study found that the urban settlement and cropland of the area have increased by 128% and 58%, respectively, resulting in a decrease of Beel Area and waterbodies at a rate of 52% and 30%. As a result of this LULC change, the Ecosystem Service Value (ESV) of Arial Beel decreased from 258.29 million USD in 2000 to 201.01 million USD in 2025. Moreover, the study area experienced a decrease in all of its ecosystem service functions except for food production. Beel Areas are the most influential LULC types in terms of Ecosystem Service Value. So, the drastic decrease in the Beel area has resulted in overall ESV loss in the study area. On the other hand, urban settlement is the least influential one. That's why a minor increase is observed in the ESV of the study area. Moreover, a sensitivity analysis has also been performed to assess the elasticity of the value coefficients of ecosystem services used in this study. The results ranged from 0.003 to 0.57 under all circumstances. This indicates that the coefficients used in this study are inelastic and reliable. This study will give an insight into the degrading condition of the

Arial Beel, which is a region of major environmental concern in Bangladesh, to policymakers and encourage them to come forward to make policies to conserve the wetland. So, further studies should be conducted for the sustainable management of ecosystem services of Arial Beel for the betterment of the local communities and both flora and fauna.

DECLARATION OF INTEREST STATEMENT

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

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