

Developing Equivalent Weight Coefficients for Ecosystem Service Valuation in Dhaka City, Bangladesh

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Abstract: Understanding and quantifying ecosystem services in urban landscapes is vital for achieving sustainable environmental management. Dhaka, one of the fastest growing megacities in South Asia, has undergone drastic transformations in its land use and land cover, which has severely altered ecosystem structure and function. This study introduces a modified framework for developing and applying Equivalent Weight Coefficients (EWCs) to estimate ecosystem service values (ESVs) at a regional scale. Using multi-temporal remote sensing data and spatial modeling, regional EWC adjustments were made based on biophysical variables such as Normalized Difference Vegetation Index (NDVI), Fractional vegetation cover (FVC), Net primary productivity (NPP), Rainfall, and Crop yield. After incorporating biophysical parameters, the total ecosystem service values (ESVs) increased across all land cover types. The most significant percentage increases occurred in bare land (38%) and built-up areas (38%), followed by forest and vegetation (35.56%), agricultural land (25.46%), and waterbodies (19.28%). Although the proportional rise in bare land and built-up categories appears large, these categories contribute minimally to total ESV, while the major ecological gain in absolute value was from waterbodies ($+7,001.64 \times 10^6$ US\$), confirming their dominant contribution to Dhaka's ecosystem functions. The methodological framework developed in this study is scalable and can be applied to other tropical megacities facing similar urbanization pressures, improving global efforts to harmonize development with ecosystem conservation.

Keywords: Ecosystem service value (ESV), Ecosystem service value coefficient (EWC), Biophysical Parameter, Regional scale, NPP, FVC, MNDWI, NDVI, Rainfall, Crop Yield

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1. Introduction

Ecosystem service valuation (ESV) offers a vital quantitative framework for understanding the economic significance of natural systems in promoting urban sustainability (Xie et al., 2017a). Ecosystems function as both natural resources and assets, forming the foundation for human survival and development (Braat & de Groot, 2012). Through continuous ecological processes, ecosystems generate a wide range of ecological goods and services that shape and sustain the environmental conditions essential for humans, animals, and plants (MA, 2005).

Although ecosystems contribute to human well-being through ecological, socio-cultural, and economic dimensions, assigning monetary values to ecosystem services is an effective means of raising awareness and communicating their relative importance to policymakers. Monetary valuation also facilitates more efficient allocation of limited financial resources by identifying areas where conservation and restoration yield the greatest economic and ecological returns at the lowest cost (Crossman & Bryan, 2009).

However, existing socioeconomic accounting systems often fail to fully incorporate ESV due to challenges in estimating values for non-market ecosystem components. Despite numerous studies on ecosystem service valuation (Costanza et al., 1997; Shi, 2024; XIE Gao-di, 2008), accurately identifying, quantifying, and monetizing ESV. There is still no universally accepted, comprehensive, and scientifically robust framework for ESV assessment and accounting (Zhang et al., 2017).

The equivalent factor method proposed by (Xie et al., 2008, 2010) assumes that each unit area of an ecosystem acts as a functional unit providing ecological services and products. When the monetary value of various ecosystem services per unit land area is established, the total ESV for specific ecosystems and regions can be estimated based on the area coverage of each ecosystem type.

Using this approach, several studies have quantified changes in ecosystem service values in Bangladesh through the equivalent factor method, a unit value-based approach (Akber et al., 2018; Hoque et al., 2020; Morshed et al., 2022; Ziaul Hoque et al., 2022; Zinia & McShane, 2018). Nevertheless, a gap persists in assessing ecosystem services for Dhaka city using region-specific parameters. Ecosystems of the same type may yield different service values depending on local climatic and environmental conditions (Zhao et al., 2021). The equivalent factors developed by Costanza et al. (1997) and de Groot et al. (2012) were designed for global-scale evaluations, later refined by Xie et al. (2015, 2017) for China and by (Sannigrahi et al., 2019) for India to reflect regional characteristics.

To address this gap, the present study employs regional parameters and develops a localized equivalent coefficient to estimate Dhaka's ecosystem service value (ESV).

Accordingly, the specific objectives of this study are to:

1. Identify and analyze suitable biophysical parameters influencing regional variations in ecosystem services;
2. Calibrate global ecosystem service values using regional biophysical parameters; and

3. Develop an equivalent weight coefficient for high density Dhaka city by applying biophysical parameters.

2. Materials and Methods

2.1 Study Area

Dhaka city, one of the most rapidly urbanizing metropolises in South Asia, has experienced massive ecological transformations driven by land use change, population pressure, and industrialization (Bhuiyan et al., 2024). Despite extensive global research on ESV, region-specific coefficients remain underdeveloped for tropical urban environments. This study aims to address this gap by formulating equivalent weight coefficients customized for Dhaka, thereby reflecting its distinct ecological dynamics and climatic variability.

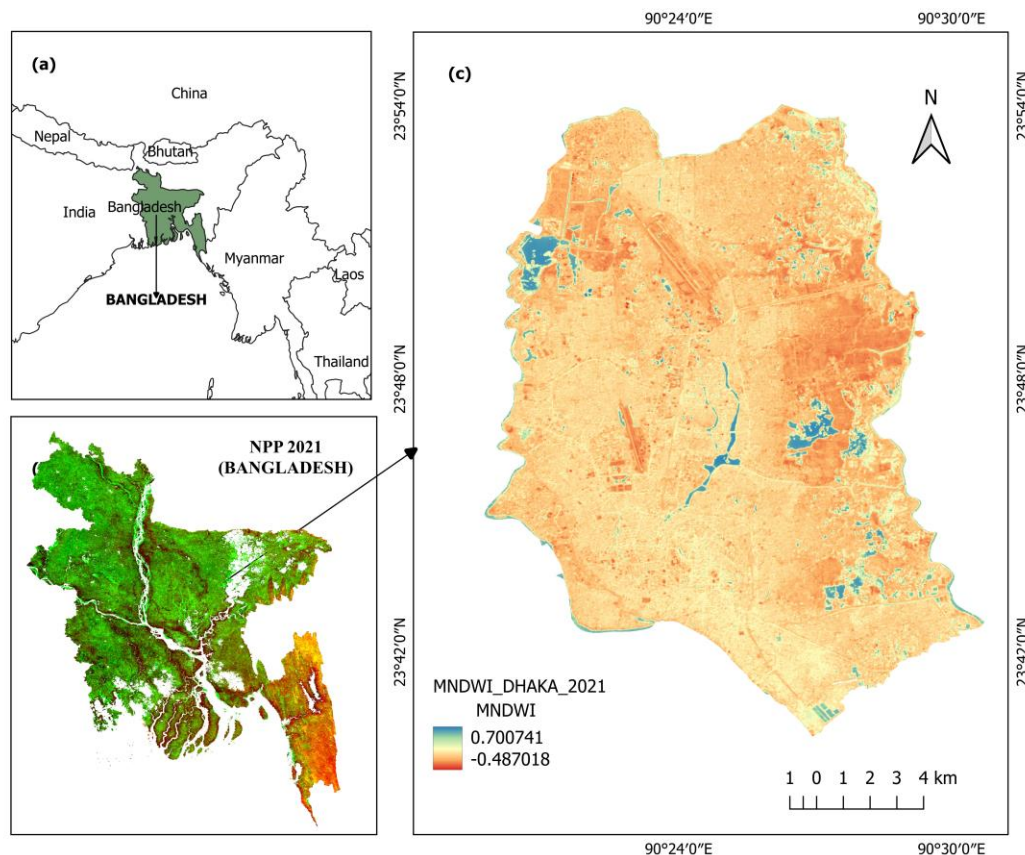


Fig. 1. Study area (a) location of Bangladesh, (b) Bangladesh Net Primary Productivity (NPP), 2021 and (c) Modified Normalized Difference Water Index (MNDWI) of Dhaka 2021.

2.2 Data Sources and criteria for data selection

Data on the monetary value of ecosystem services were sourced from a number of existing databases including: Ecosystem Service Value Database (ESVD) (Braat & de Groot, 2012; Brander et al., 2024; Stenger et al., 2009), as well as other relevant studies (Table: 1) with

data on ecosystem service values (Costanza et al., 1997; De Groot et al., 2002; Brander et al., 2006).

Table 1. Ecosystem service value estimation methods

Ecosystem service value aggregation (Kubiszewski et al., 2013a,b), Costanza et al. (2014).			
S	Aggregation method	Assumptions/approach	Examples
1	Basic value transfer	Assumes values constant over ecosystem types	Costanza et al. (1997), Liu et al. (2010a,b)
2	Expert modified value transfer	Adjusts values for local ecosystem conditions using expert opinion surveys	Batker et al. (2008)
3	Statistical value transfer	Builds statistical model of spatial and other dependencies	de Groot et al. (2012)
4	Spatially explicit functional modeling	Builds spatially explicit statistical or dynamic systems models incorporating valuation	Boumans et al. (2002), Costanza et al. (2008), Nelson et al. (2009)

All potential data on values were screened to ensure they contain suitable and sufficient information regarding the multiple dimensions for the analysis.

2.3 Value standardization

The standard equivalent factor, used as a baseline for evaluating ecosystem services, represents the ecological value generated by the natural components of an ecosystem per unit area of land. Establishing this factor is one of the two essential steps in applying the equivalent value method. However, because there is no universally accepted approach or quantitative framework for valuing ecosystem services, determining a truly objective standard equivalent factor remains challenging (Costanza et al., 1997). At regional or provincial scales, the global equivalent coefficient often introduces significant bias and uncertainty in ecosystem service valuation. This limitation arises from the inherent landscape complexity and spatial heterogeneity of ecosystems, which cause the generalized coefficients to inadequately reflect the actual economic values of specific ecosystems.

Number of studies have incorporated different environmental and biophysical parameters to refine the value coefficients of ecosystem services. For example, precipitation levels and their spatial distribution have been shown to positively influence water supply and

regulation services. Similarly, biomass, net primary productivity (NPP), and normalized difference vegetation index (NDVI) exhibited strong positive relationships with gas regulation (GR), climate regulation (CR), disturbance regulation (DR), habitat provision, biodiversity conservation, and soil formation and retention services (Deng et al., 2021; Figuepron et al., 2013; Fu et al., 2016; Peng et al., 2021a; Xie et al., 2017a; Zhang et al., 2017).

Furthermore, several researchers reported a significant and positive association between biomass-NDVI and various ecosystem functions (Fei et al., 2018; Pandey et al., 2019; Zeng et al., 2020), offering critical evidence and direction for adjusting the coefficient values. In the present study, the equivalent coefficients corresponding to different reference periods were modified using factors such as NPP, NDVI, crop yield, precipitation, Fractional Vegetation Cover (FVC), and the NPP/NDVI ratio.

Temporal crop yield data were sourced from the Bangladesh Bureau of Statistics under the Statistics and Informatics Division (SID), Ministry of Planning, Government of the People's Republic of Bangladesh (<http://www.bbs.gov.bd/>). Rainfall information was obtained from the Bangladesh Agricultural Research Council (BARC) (<http://www.barc.gov.bd/>) and the Bangladesh Meteorological Department (<https://www.bmd.gov.bd/>). Annual NPP data used for spatiotemporal analysis were derived from the NASA LP DAAC USGS EROS Center (<https://lpdaac.usgs.gov/products/mod17a3hgv006/>; Running and Zhao, 2019).

The NDVI and FVC were calculated using the following equations:

$$\begin{aligned} \text{NDVI} &= (\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED}) \\ \text{FVC} &= (\text{NDVI} - \text{NDVI}_{\min}) / (\text{NDVI}_{\max} - \text{NDVI}_{\min}) \end{aligned} \quad (1)$$

2.4 Establishment of the equivalent coefficients table

Using the correction factors, the equivalent value coefficients of each ecosystem service (ES) for the reference year was modified according to the following equations:

$$\begin{aligned} F_{ij} &= B_j \times F_{n1} \\ F_{ij} &= P_j \times F_{n2} \\ F_{ij} &= V_j \times F_{n3} \\ F_{ij} &= Y_j \times F_{n4} \end{aligned} \quad (2)$$

Here, F_{ij} denotes the equivalent value coefficient per unit area for ecosystem service i in region j ; B_j represents the spatial and temporal correction factor for biomass (based on NPP and NDVI) in region j ; P_j denotes the precipitation-based correction factor; V_j refers to the spatial and temporal correction factor for Fractional Vegetation Cover (FVC); and Y_j represents the correction factor for crop yield.

The coefficients F_{n1} , F_{n2} , F_{n3} , and F_{n4} correspond to specific ecosystem service categories:

- F_{n1} : Gas regulation, climate regulation, disturbance regulation, waste treatment, pollination, biological control, habitat, raw material, production, genetic

resources, recreational, and cultural services.

- F_{n2} : Water supply, and water regulation services.
- F_{n3} : Erosion control and soil formation services.
- F_{n4} : Food production services.

The estimation of the correction factors (B_j , P_j , V_j and Y_j) at both regional and national levels was based on the spatial and temporal patterns of NPP, NDVI, biomass, and rainfall, as expressed in the following equations:

$$B_i = \left(\frac{NDVI_i}{NDVI_j} + \frac{NPP_i}{NPP_j} \right)$$

$$P_i = \left(\frac{R_i}{R_j} \right)$$

$$V_i = \left(\frac{FVC_i}{FVC_j} \right)$$

$$Y_i = \left(\frac{Y_i}{Y_j} \right) \quad (3)$$

Here, R and Y represent rainfall and crop yield, respectively, while i and j indicate the factor distributions at the study region and national scales. The detailed equivalent coefficient values (F_{n1} , F_{n2} , F_{n3} , and F_{n4}).

2.5 Classification of ecosystem and ecosystem services

In this study, we used the framework of Costanza et al. (1997) to assess the economic value of 17 ecosystem services for 16 biomes (Table 2), based on published studies and some original calculations.

Table 2. Global equivalent biomes and their functions

Supporting	NC	Nutrient Cycling
	Po	Pollination
	Ha	Habitat/Refugia
	SF	Soil Formation
Regulating	GR	Gas Regulation
	CR	Climate Regulation
	DR	Disturbance regulation
	WT	Waste Treatment
	BC	Biological Control
	WR	Water Regulation
	EC	Erosion Control
Provisioning	RM	Raw Materials
	GR	Genetic Resources
	WS	Water Supply
	Fp	Food Production
Cultural	Re	Recreation
	Cu	Cultural

However, a growing body of research has revealed that ES functions are controlled by many ecological mechanisms and processes, which are intimately tied to regional ecological circumstances (Xie et al., 2017b). This study developed the correction factors (Table 5) to update the regional coefficient value in this study region. We measured the ESVs of five ecosystems (Table 3) in Dhaka using the updated unit values.

Table 3 Land use categories equivalents for biomes identified in the literature (Costanza et al., 1997, 2014; de Groot et al., 2012).

Land Cover Types	Description
Waterbody	Rivers, lakes, ponds, canals, wetlands, and low-lying water areas.
Forest and Vegetation	Forests, trees, natural vegetation, gardens, parks, and recreational green spaces.
Built-up Area	Urban areas including residential, commercial, industrial zones, mixed-use areas, settlements, roads, and other artificial structures.
Agricultural Land	Cropland and fallow lands.
Bare Land	Sandy areas, exposed soil, and newly developed or transformed land for construction or housing projects.

The total ESVs were calculated as follows:

$$ESV_K = \sum_{f=1}^{17} (A_K \times F_{ij}) \quad (4)$$

$$ESV_f = \sum_k^6 (A_K \times F_{ij}) \quad (5)$$

$$ESV = \sum_{f=1}^{17} \sum_{k=1}^6 (A_K \times F_{ij}) \quad (6)$$

Where, ESV_K , ESV_f , and ESV is the ecosystem service value (US\$ $ha^{-1}yr^{-1}$) of ecosystem type k , and ecosystem service f , total ecosystem service value, F_{ij} is the updated equivalent value coefficient of ecosystem service f and ecosystem types k , A_K is the area (ha) of ecosystem type k (Costanza et al., 2017; He et al., 2021; Makwinja et al., 2021; Peng et al., 2021b; Sannigrahi et al., 2018).

3. Results

3.1 Land use land cover classification according to the global biomes

We Classified the sentinel 2A satellite imagery for the year 2021 for Land use Land cover (LULC) Classification using Random Forest (RF) Classifier in Google Earth Engine.

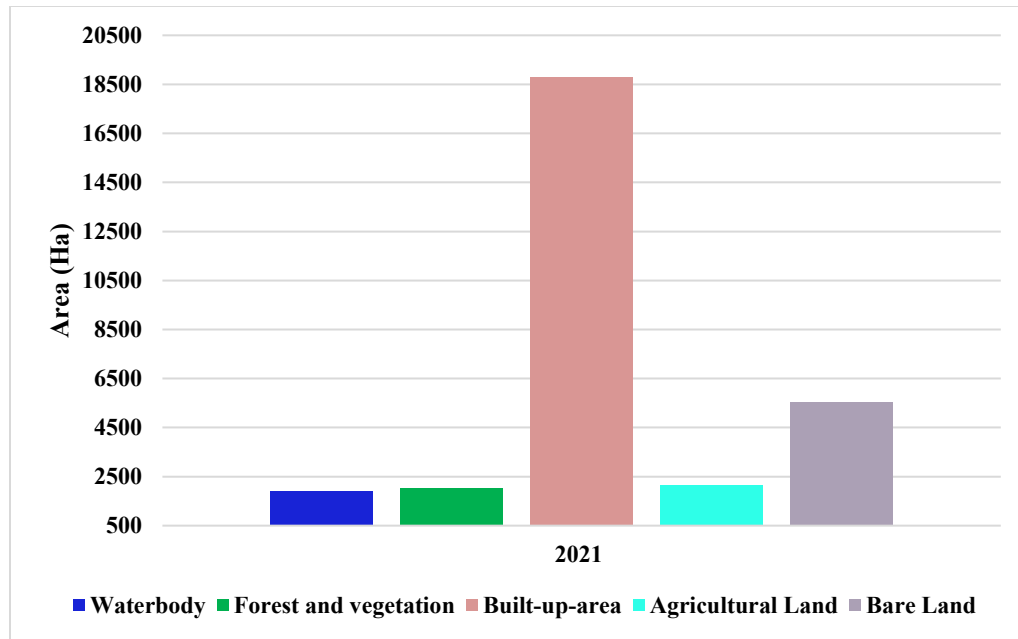


Fig.2. Land Use Land Cover Classification

The overall accuracy was 92.32 %. Built-up area is the dominant land use type in the study region, contributing 60.99% to the total geographical area, followed by bare land (17.41%), Agricultural land (8.16%), Waterbody (6.47%), and Forest and Vegetation (06.27%) (Fig.). Waterbody and agricultural land ecosystems are the most important and ecologically and biologically diverse ecosystems in the study region.

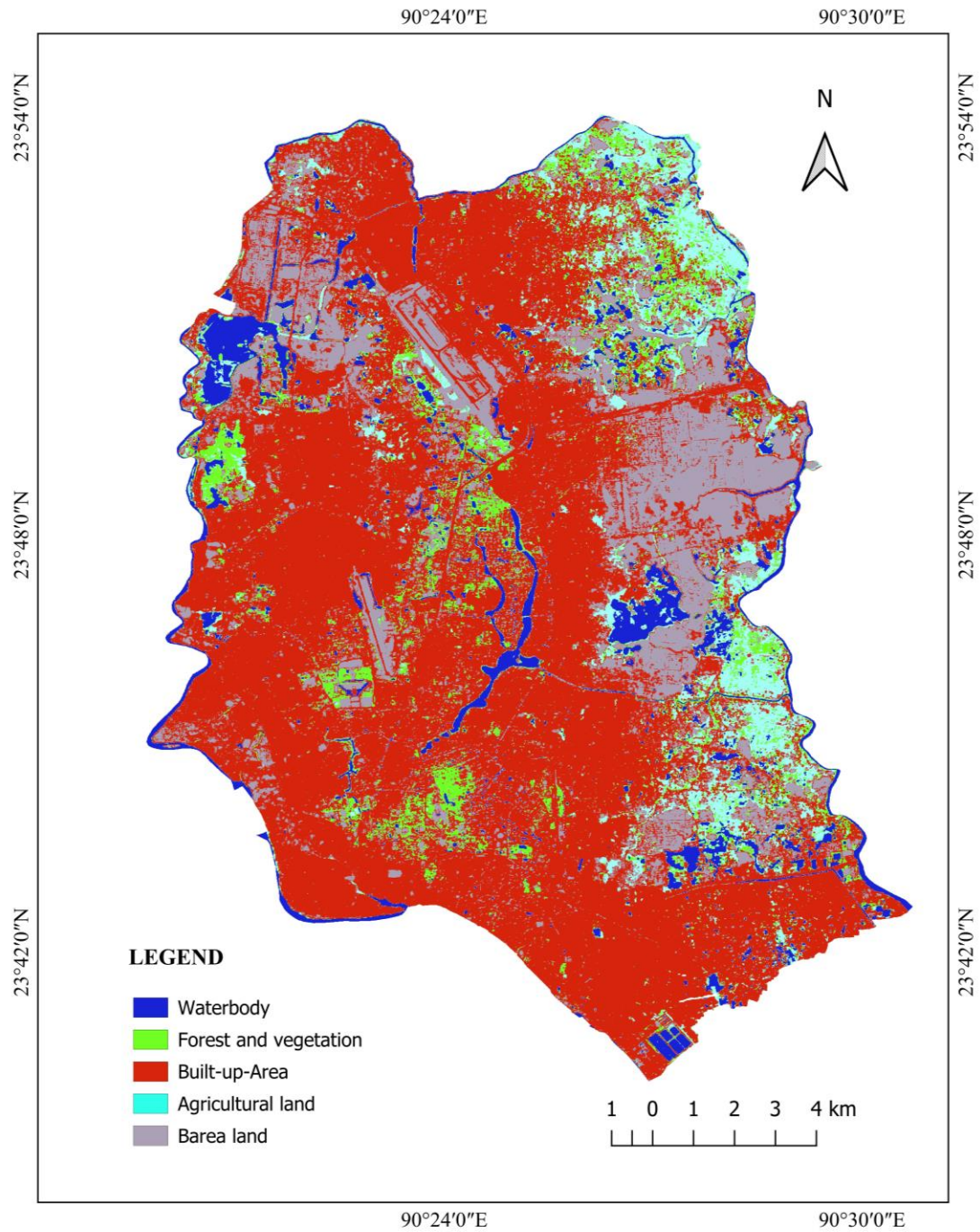


Fig.3. (a) LULC maps of the study area (2021), Area (ha) of the major land classes

3.2 Standard Value of Ecosystem Services of Dhaka City

The equivalent weight coefficient for each of these ecosystem services collected from extensive literature survey. This adjustment was made using the U.S. Department of Labor's Consumer Price Index (CPI) Inflation Calculator (https://www.bls.gov/data/inflation_calculator.htm).

Table 4. Equivalent weight coefficient for ecosystem service valuation before applying biophysical parameters

SI			Ecosystem functions	Waterbody	Forest and vegetation	Agricultural Land	Bare Land	Built-up-Area
1	GR	F _{n1}	Gas Regulation	0	25.67	237.21	0.11	0.00
2	CR	F _{n1}	Climate Regulation	870.28	3645.21	319.57	0.00	64.20
3	DR	F _{n1}	Disturbance regulation	5325.14	117.70	0.00	0.00	0.00
8	NC	F _{n1}	Nutrient Cycling	3054.92	5.35	0.00	0.00	0.00
9	WT	F _{n1}	Waste Treatment	5710.36	10.70	457.94	0.00	0.00
10	Po	F _{n1}	Pollination	0.00	53.50	0.00	0.00	0.00
11	BC	F _{n1}	Biological Control	1690.64	19.62	336.04	0.00	0.00
12	Ha	F _{n1}	Habitat/Refugia	627.21	0.00	0.00	0.00	0.00
14	RM	F _{n1}	Raw Materials	757.94	149.80	128.48	0.00	0.00
15	GR	F _{n1}	Genetic Resources	2082.99	41.01	0.00	0.00	0.00
16	Re	F _{n1}	Recreation	7805.82	1546.18	0.00	0.00	0.00
17	Cu	F _{n1}	Cultural	2304.12	7.00	0.00	0.00	401.26
4	WR	F _{n2}	Water Regulation	2605.99	31.75	167.28	0.00	0.00
5	WS	F _{n2}	Water Supply	6592.61	402.19	0.00	0.00	0.00
6	EC	F _{n3}	Erosion Control	2156.17	12.40	0.00	0.00	0.00
7	SF	F _{n3}	Soil Formation	0.00	2.98	224.60	0.00	0.00
13	Fp	F _{n4}	Food Production	1730.66	480.74	444.04	0.00	0.00

3.3 Correction factors for revising the standard valuation of ecosystem services

We calibrated per-unit value coefficients for each of the five land-use/land-cover (LULC) categories. The value of a specific ecosystem service per unit area can be estimated by multiplying its corresponding equivalent coefficient by standard factors (Xie et al., 2017b).

Table 5. Biophysical parameters for calibrating ecosystem service coefficients

Year	Yield	NPP	NDVI	Rainfall	FVC	NPP & NDVI
2021	1.86	0.74	0.63	0.91	0.64	0.69

3.4 Equivalent weight co-efficient for ecosystem service evaluation in Dhaka city

Regional parameters such as NDVI, NPP, FVC, rainfall, and crop yield play a crucial role

in accurately estimating ecosystem service values (ESVs) by reflecting the spatial and temporal variations in ecosystem productivity and functioning. The Normalized Difference Vegetation Index (NDVI) and Net Primary Productivity (NPP) serve as indicators of vegetation health and biomass production, which are directly linked to services like carbon sequestration, climate regulation, and habitat maintenance. Fractional Vegetation Cover (FVC) represents the extent of vegetation cover, influencing soil protection, erosion control, and water regulation. Rainfall determines water availability and regulates hydrological services such as water supply, purification, and flood control. Similarly, crop yield provides a measure of provisioning services, particularly food and raw material production. By incorporating these regional biophysical parameters, the valuation of ecosystem services becomes more realistic and region-specific, capturing ecological dynamics that global or generalized coefficients often overlook.

Table 6. Equivalent weight coefficient for ecosystem service valuation after applying biophysical parameters

SI			Ecosystem Functions	Waterbody	Forest and vegetation	Agricultural Land	Bare Land	Built-up-Area
1	GR	Fn1	Gas Regulation	0	25.66	237.20	0.11	0
2	CR	Fn1	Climate Regulation	870.28	3645.21	319.56	0	64.19
3	DR	Fn1	Disturbance regulation	5325.14	117.70	0	0	0
8	NC	Fn1	Nutrient Cycling	3054.91	5.35	0	0	0
9	WT	Fn1	Waste Treatment	5710.35	10.69	457.93	0	0
10	Po	Fn1	Pollination	0	53.50	0	0	0
11	BC	Fn1	Biological Control	1690.63	19.62	336.04	0	0
12	Ha	Fn1	Habitat/Refugia	627.21	0	0	0	0
14	RM	Fn1	Raw Materials	757.93	149.79	128.47	0	0
15	GR	Fn1	Genetic Resources	2082.98	41.01	0	0	0
16	Re	Fn1	Recreation	7805.81	1546.17	0	0	0
17	Cu	Fn1	Cultural	2304.11	6.99	0	0	401.26
4	WR	Fn2	Water Regulation	2605.99	31.74	167.27	0	0
5	WS	Fn2	Water Supply	6592.61	402.19	0	0	0
6	EC	Fn3	Erosion Control	2156.17	12.40	0	0	0
7	SF	Fn3	Soil Formation	0	2.98	224.60	0	0
13	Fp	Fn4	Food Production	1730.65	480.73	444.03	0	0

3.5 Calibrated and non-calibrated ecosystem service value coefficients

After incorporating biophysical parameters, the total ecosystem service values (ESVs) increased across all land-cover types. The most significant percentage increases occurred in bare land (38%) and built-up areas (38%), followed by forest and vegetation (35.56%), agricultural land (25.46%), and waterbodies (19.28%). Although the proportional rise in bare land and built-up categories appears large, these categories contribute minimally to

total ESV, while the major ecological gain in absolute value was from waterbodies ($+7,001.64 \times 10^6$ US\$), confirming their dominant contribution to Dhaka's ecosystem functions.

Table 7. Difference between estimating ESV with and without regional factors

Land Cover Type	Total ESV (Without Parameters)	Total ESV (With Parameters)	Absolute Change ($\times 10^6$ US\$)	Percent Change (%)
Waterbody	36 313.21	43 314.85	+7 001.64	19.28%
Forest and Vegetation	4 833.09	6 551.81	+1 718.72	35.56%
Agricultural Land	1 845.40	2 315.15	469.75	25.46%
Bare Land	0.08	0.11	0.03	38.00%
Built-up Area	337.29	465.46	128.17	38.00%

After incorporating biophysical parameters, the total ecosystem service values (ESVs) increased across all land-cover types. The most significant percentage increases occurred in bare land (38%) and built-up areas (38%), followed by forest and vegetation (35.56%), agricultural land (25.46%), and waterbodies (19.28%). Although the proportional rise in bare land and built-up categories appears large, these categories contribute minimally to total ESV, while the major ecological gain in absolute value was from waterbodies ($+7,001.64 \times 10^6$ US\$), confirming their dominant contribution to Dhaka's ecosystem functions.

3.6 Estimating regional ecosystem service values using adjusted coefficient

A combination of remote sensing and statistical methods was used to derive land cover data and biophysical variables. Satellite imagery from sentinel missions was analyzed using the Random Forest algorithm within Google Earth Engine. Ecosystem categories were classified into vegetation, agricultural land, water bodies, bare soil, and built-up areas. To regionalize the equivalent coefficients, correction factors including NDVI, NPP, precipitation, crop yield, and fractional vegetation cover (FVC) were computed. These variables were then incorporated into a recalibration model to derive Dhaka-specific equivalent weights for 17 ecosystem functions.

Table 8. Ecosystem service values (ESVs) across different ecosystem service functions in year 2021

Ecosystem service value ($\times 10^6$ USD)		
Ecosystem service functions		
Supporting	NC	5.87
	Po	0.18
	Ha	1.44
	SF	0.5
Regulating	GR	1.14
	CR	10.99
	DR	10.46
	WT	11.96
	BC	4
	WR	5.42
	EC	4.16
	RM	2.03
Provisioning	GR	4.08
	WS	13.47
	Fp	5.25
Cultural	Re	18.13
	Cu	11.97

4. Discussion

Integrating regional biophysical variable; NDVI, NPP, FVC, rainfall, and crop yield substantially improved the precision and ecological relevance of the ESV estimation. These parameters represent vegetation health, biomass productivity, vegetation cover, hydrological variability, and provisioning capacity, respectively. By accounting for spatial and temporal heterogeneity, the revised coefficients corrected the bias of global averages, which often overlook local ecological dynamics. The enhancement of ESVs following parameter adjustment indicates that Dhaka's ecosystems possess higher functional capacity than initially estimated using static global coefficients. This refined approach reveals that vegetation and water systems contribute disproportionately to regulating and supporting services such as carbon sequestration, climate regulation, and water supply. Incorporating such parameters not only strengthens the reliability of ecosystem valuation but also provides a robust, data-driven foundation for urban sustainability planning, ecological restoration, and resource management in rapidly urbanizing tropical cities.

5. Conclusion

This study demonstrates the significant advantages of incorporating regional biophysical parameters into ecosystem service valuation in rapidly urbanizing environments such as

Dhaka. By integrating NDVI, NPP, rainfall, fractional vegetation cover (FVC), and crop yield into the valuation framework, the recalibrated Equivalent Weight Coefficients (EWCs) more accurately represented the ecological capacity of each land cover class. Statistical comparison showed noticeable increases in ecosystem service values across all land covers when these parameters were applied particularly for forests (+35.56%), agricultural lands (+25.46%), and waterbodies (+19.28%), which play crucial roles in regulating and supporting urban ecosystem functions. Although built-up and bare land exhibited the highest percentage increase (38%), their absolute contributions remain minimal, reinforcing the importance of conserving the city's natural ecosystems. The methodological framework developed in this study is scalable and can be applied to other tropical megacities facing similar urbanization pressures, improving global efforts to harmonize development with ecosystem conservation.

Declaration of competing interest

The authors declare that they have no competing interests.

Data availability

Data will be made available on request.

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