

Research Article

Ecology

Mapping, Monitoring, and Valuing: A Comprehensive Analysis of Ecosystem Services Provided by Dhaka's Green Spaces and Water Bodies

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Abstract

Dhaka, home to more than 22.4 million residents, delivers a wide spectrum of ecosystem services through its green spaces and water bodies, yet these systems are being converted to built-up land at an accelerating rate. This study maps, monitors, and values those services using primary and secondary data. Primary data came from a field-based observation protocol, transect assessment, a questionnaire survey of visitors and adjacent residents, key informant interviews, and geospatial recording. Secondary data came from published land cover, remote sensing, water quality, and valuation studies. Surface water fell from 11.82 percent of the city area in 1990 to 5.16 percent in 2021. Water bodies declined by 32.57 percent and lowlands by 52.58 percent between 1960 and 2008, while rivers and canals contracted by 64.55 percent between 1978 and 2009. Built-up land expanded by 188.35 percent between 1990 and 2020, driving a 59.55 percent decline in ecosystem service value, a loss of 85 million US dollars. Residual green and blue spaces still perform critical cooling, air purification, drainage, recharge, and cultural functions, but supply is spatially unequal and institutionally unprotected.

Keywords: Dhaka, Urban ecosystem services, Green spaces, Water bodies, Ecosystem service valuation, Land use change, Urban wetlands, Environmental governance, Bangladesh

Introduction

Cities in the Global South are expanding faster than their ecological infrastructure can be planned or replaced. Urban green and blue spaces, including parks, urban forests, roadside plantings, rooftop and homestead gardens, lakes, ponds, canals, rivers, and floodplain wetlands, provide services fundamental to urban habitability: local climate regulation, air purification, stormwater retention, groundwater recharge, food production, recreation, and biodiversity support (Abdullah et al., 2022). In densely built cities these are infrastructure in the functional sense rather than aesthetic amenities, since they reduce heat stress, absorb pollutants, and support physical and psychological well-being (Xu, 2026).

Dhaka illustrates the challenge acutely. The city lies on the Buriganga River and covers 1463.60 square kilometers at the district scale, with its core subject to continuous densification (Zinia & McShane, 2018). Average annual maximum and minimum temperatures are 34.5 degrees Celsius and 11.5 degrees Celsius, with average annual rainfall of 1,931 millimeters. The city faces extreme heat, severe air pollution, recurrent flooding, and progressive groundwater depletion, each a symptom of ecological deficit rather than isolated environmental failure.

The empirical record of that deficit is substantial. Built-up land in the Dhaka metropolitan area expanded by 188.35 percent between 1990 and 2020, at an average annual growth rate of approximately 6.28 percent, mainly through conversion of agricultural land,

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Received Dates: Oct 02, 2026;

Accepted Date: Oct 09, 2026;

Published Date: Oct 10, 2026:

water bodies, and vegetated land. Total ecosystem service value fell by 59.55 percent, from 142.72 million US dollars in 1990 to 57.72 million US dollars in 2020, a reduction of 85 million US dollars (Rahman & Szabó, 2021). Across five major Bangladeshi cities, a combined monetary loss of 628.58 million US dollars was attributed to the degradation of green and blue spaces over thirty years, concentrated in Dhaka and Chattogram.

Green cover is sparse by international standards. Dhaka has just 8.5 percent tree-covered land, while a functional city is generally considered to need at least 20 percent green space (Rahman & Zhang, 2018). More recent estimates are lower, with only 8 percent tree-covered land and approximately 2 percent healthy green space in 2020 (Sorker et al., 2023). Ward-level analysis measured total green space coverage of 2.24 percent and a maximum per capita green space of 0.003207 square meters in the best-served ward (Nahin et al., 2023).

Water bodies show a parallel trajectory. Water bodies declined by 32.57 percent and lowlands by 52.58 percent between 1960 and 2008, with more than 49 percent of the total wetland area lost (Islam et al., 2014). Between 1978 and 2009, rivers and canals in the metropolitan area contracted by 64.55 percent, and wetlands and water bodies together occupied only about 21 percent of the metropolitan area in 2009 against approximately 52 percent in 1978 (Habiba et al., 2011). Satellite monitoring shows surface water falling from 11.82 percent of the city area in 1990 to 10.77 percent in 2000, 9.36 percent in 2010, and 5.16 percent in 2021 (Hossain et al., 2023). In a household survey, 59.4 percent of respondents reported drainage congestion and waterlogging as the principal consequence of wetland loss, 30.8 percent identified loss of groundwater recharge capacity, and 5.9 percent identified loss of water reservoirs.

Valuation work remains partial. One assessment of provisioning services from rooftop gardens, parks, and a jheel estimated a total gross value of 5.34 million Bangladeshi Taka, equivalent to 68,465 US dollars for 2016, with 72 percent originating from rooftop gardens (Zinia & McShane, 2018). Recreational valuation of the National Botanical Garden estimated willingness to pay of 0.955 US dollars using the travel cost method, with an annual consumer surplus of 593,634.5 US dollars, and a contingent valuation estimate of 0.225 US dollars with a revenue maximizing entrance fee of 0.376 US dollars (Tahzeeda et al., 2018). For the Bhawal Sal forest, a contingent valuation study of 418 visitors estimated average willingness to pay of 188.99 Taka, equivalent to 1.72 US dollars, at least nine times the prevailing fee (Forhad et al., 2025). This study responds to the gap these studies leave by combining primary and secondary data to map extent and change, monitor service condition, and value the services Dhaka's green and blue spaces supply.

Literature Review

The urban ecosystem services framework

The ecosystem services framework treats nature as capital generating flows of benefits. In urban settings these flows are grouped into provisioning services such as food and fresh water, regulating services such as climate regulation, air purification, and water retention, cultural services such as recreation, aesthetics, and sense of place, and supporting services such as habitat provision (Abdullah et al., 2022). Green and blue spaces are jointly recognized as the principal generators of these services in built environments. Delivery is spatially contingent: the capacity of green space to regulate temperature varies with patch

size, configuration, and vegetation structure, so benefits differ across a city rather than being uniform (Li et al., 2022). Pollutant removal and carbon sequestration likewise depend on biomass, species composition, and surrounding impervious surface. The health dimension is also established. Air pollution is responsible for approximately 4.2 million premature deaths annually, was identified as the fourth most significant risk factor for mortality and disease globally, and accounted for 12 percent of fatalities in children under five (Salman et al., 2023). Urban vegetation mitigates both heat and pollution pathways.

Green and blue space dynamics in Dhaka

Multi-temporal analysis covering 1991 to 2021 across five Bangladeshi cities found declining green and blue space produced a combined monetary loss of 628.58 million US dollars, highest in Dhaka and Chattogram because of the intensity of anthropogenic activity. A thirty-year analysis of the Dhaka metropolitan area attributed a 59.55 percent decline in ecosystem service value to built-up expansion and identified water bodies as the single greatest contributor to remaining value; the elasticity result, indicating that a 1 percent transition in land use produces approximately a 0.33 percent change in total value, quantifies the system's sensitivity to further conversion (Rahman & Szabó, 2021). Water bodies declined from 2952.02 hectares in 1960 to 1990.71 hectares in 2008, while lowlands declined from 13527.58 hectares to 6414.57 hectares (Islam et al., 2014). Lowlands in the south-western corner toward Mirpur, Mohammadpur, and Pallabi Cantonment were filled for development, parts of the Gulshan and Dhanmondi lakes were reduced, and some channels in Motijheel are no longer identifiable. A remote sensing analysis found approximately 29 square kilometers of rivers and canals and 130.17 square kilometers of wetlands in 1978, against only 10.28 square kilometers and 53.6 square kilometers in 2009 (Habiba et al., 2011). The drainage system historically consisted of 43 major canals, many no longer existing. Approximately 95 percent of Dhaka's water supply is drawn from underground sources, and average annual groundwater decline within the city during 1995 to 1999 ranged from 1.02 to 2.46 meters (Hassan & Zahid, 2011).

Regulating services: Climate and air quality

Land surface temperature analysis found built-up area in Dhaka increased by 67 percent between 1993 and 2020, largely replacing lowland, followed by vegetation, bare soil, and water bodies, with temperatures ranging from 23.26 to 39.94 degrees Celsius in 1993, 23.69 to 43.35 degrees Celsius in 2007, and 24.44 to 44.58 degrees Celsius in 2020 (Imran et al., 2021). The rising floor and ceiling of the temperature range indicate narrowing thermal relief (Ahmed et al., 2013; Li et al., 2022). On air quality, between 2012 and 2018 water bodies declined by 2 percent and vegetation by 5.3 percent while construction and bare land increased by 4 percent and 3.4 percent; the spatial correlation between PM_{2.5} and vegetation was negative at 0.212 and between PM_{2.5} and water bodies negative at 0.028 (Zarin & Esraz-Ul-Zannat, 2023). Projected annual average PM_{2.5} for 2024 was 188 to 312 micrograms per cubic meter, and air pollution alone accounts for 17.6 percent of mortality and disability risk in Dhaka. Work on roadside greenery found carbon dioxide accounts for more than ninety percent of the city's air pollution burden, with denser vegetation absorbing more vehicular carbon dioxide (Neema & Jahan, 2014).

Provisioning and recreational valuation

Provisioning valuation in Dhaka found about 35 percent of surveyed household-maintained rooftop gardens, almost 70 percent belonging to property owners, with mixed gardens at

36 percent and fruit gardens at 32 percent of gardens (Zinia & McShane, 2018). Estimates of willingness to pay at comparable sites are consistently above prevailing charges: 1.72 US dollars at Bhawal against a fee at least nine times lower (Forhad et al., 2025), and 0.955 US dollars at the National Botanical Garden (Tahzeeda et al., 2018). International comparators corroborate measurable demand, with aggregate willingness to pay for one Brazilian park estimated between 550,547.94 and 1,445,188.35 US dollars from 338 households (Brandli et al., 2014), an Indonesian park study estimating 4,877 rupiah (Idris et al., 2021), and a Brazilian ecological park finding 58 percent of respondents willing to pay (Silva et al., 2020).

Cultural and supporting services

A survey of 405 residents found widespread dissatisfaction with green space quantity, with recreation the most preferred cultural service category (Sultana et al., 2022). Perceptions varied by income, with higher income respondents valuing cultural heritage and lower income respondents valuing recreation, and women generating high demand but facing access constraints from insecurity and traffic congestion (Sultana & Selim, 2021). Work at Ramna Park confirmed significant cultural service provision and diverse values even in ordinary surroundings (Jahan et al., 2024), while research in low-income countries underscores the weight of cultural services for mental health (Nawrath et al., 2021), and European evidence cautions against generalizing gender effects across contexts (Fischer et al., 2018). Biodiversity provides an integrating indicator: 83 bird species were recorded across seasons in a subtropical urban landscape, with 63 in winter, and resident bird richness declines with increasing imperviousness across both the Global North and South while abundance rises with habitat heterogeneity (Shome et al., 2023; Sultana et al., 2020, 2023). Only about 8 percent tree cover remains in Dhaka, against less than 15 percent vegetation in Bangalore and approximately 5 percent green cover in Kolkata; some Dhaka bird species are now locally extinct and others critically endangered (Ahsan & Nayeem, 2016).

River water quality

Assessment of the Turag, Balu, and Buriganga found poor water quality with very low dissolved oxygen, high organic loading, and pathogens exceeding national standards, with ammonia levels sufficiently high that river water and sediments can be presumed anaerobic, releasing metals and methane and hydrogen sulfide (Rampley et al., 2019). Turag monitoring recorded pH of 6.6 to 7.98, conductivity of 160 to 1107 microsiemens per centimeter, dissolved oxygen of 0.11 to 6.8 milligrams per liter, biological oxygen demand of 10 to 180, and chemical oxygen demand of 21 to 220, with most parameters exceeding permissible limits (Rahman, 2012). Dry season monitoring found the highest biological oxygen demand of 46 milligrams per liter at the Turag, against 18 at the Buriganga, 4 at the Dhaleshwari, 8 at the Balu, 42 at Tongi Khal, and 30 at the Shitalakhya, against a WHO guideline dissolved oxygen value of 6 and an ideal of 14.6 milligrams per liter (Islam, 2023). The Buriganga and Turag receive industrial wastewater and discharge from textile and leather processing, and despite a 2017 directive requiring tannery relocation to Savar, only about one third had shifted at the time of reporting (Hossain et al., 2021).

Governance constraints

Policy instruments exist but are weakly implemented. Bangladesh became a Ramsar signatory in 1992, and national direction comes from the National Water Management Plan of

2004, the Bangladesh Climate Change Strategy and Action Plan of 2009, and the Bangladesh Delta Plan 2100, yet directives are not trickled down into municipal plans and climate change is not mainstreamed in urban spatial planning (Ahmed et al., 2018). Although the Dhaka Metropolitan Development Plan for 1995 to 2015 contains policies on conservation of flood plains and detention areas and the Water Body Conservation Act strengthened the legal basis for wetland protection, rapid wetland loss demonstrates institutional failure, with barriers from weak coordination and external forces (Jahan et al., 2008). Legal analysis of nature-based solutions concludes that enforcement failure and late consultation present serious impediments (Govind & Alam, 2022), and assessment of greening in the Dhaka North City Corporation notes that policies are often well elaborated but inadequately implemented owing to vested interests (Shammi et al., 2023). Comparative research on the East Kolkata Wetlands identifies enforcement gaps and regulatory inconsistency (Yadav et al., 2025), while wetland hydrology research shows aquifer vulnerability where surface water and groundwater interaction is unregulated (Sikdar & Sahu, 2009).

Research Gap

Existing work on Dhaka is rich but fragmented. Land use change studies quantify area and monetary value but do not assess how residual green and blue spaces are used, perceived, or managed on the ground. Valuation studies produce site-specific estimates but are not connected to the spatial distribution of service supply, so it is not known which parts of the city are service-rich and which are service-poor. Governance research explains why policies fail but does not link institutional failure to measurable service loss. No established monitoring framework for Dhaka combines remotely sensed extent indicators, field-observed condition indicators, social data on demand and use, and monetary value estimates into a single system. Water bodies, identified as the greatest contributor to remaining service value, have rarely been studied at the level of individual blue spaces and their adjacent communities. Evidence is also unevenly distributed across periods and boundaries, limiting comparability. Finally, social differentiation in service demand, documented by cultural services research, is rarely linked to the physical distribution of green and blue space, so the population groups bearing the largest service deficit remain unidentified.

Research Objectives

The overarching aim is to map, monitor, and value the ecosystem services provided by Dhaka's green spaces and water bodies, and to translate the findings into an operational monitoring framework for urban planning. The specific objectives are:

1. To map the spatial extent, distribution, and temporal change of green spaces and water bodies in the Dhaka metropolitan area from 1960 to 2021.
2. To assess, through field observation and transect survey, the condition and functional performance of provisioning, regulating, cultural, and supporting services at selected sites.
3. To examine, through a questionnaire survey of visitors and adjacent residents, use patterns, perceived benefits, perceived problems, and stated management preferences.
4. To document, through key informant interviews, the institutional and governance factors constraining protection of green and blue infrastructure.
5. To estimate the monetary value of key service streams using market price valuation and stated preference methods.

6. To quantify the loss of ecosystem service value associated with land use and land cover change over three decades.
7. To identify the spatial and social distribution of service supply and demand and the areas and groups experiencing the greatest deficit.
8. To develop an integrated monitoring framework and draw policy recommendations for mainstreaming ecosystem service values into planning and investment.

Hypothesis

To guide this study, two hypotheses were tested:

- H₁: Rapid expansion of built-up land cover across the Dhaka metropolitan area over the past three decades has caused a statistically significant, non-linear decline in regulating and blue space ecosystem service values.
- H₂: The public's willingness to pay (WTP) for urban green and blue space conservation significantly exceeds current institutional entrance fees and municipal maintenance expenditures, indicating an uncaptured economic demand for ecological preservation.

Methodology

Research Design

The study used a mixed methods design combining primary and secondary data in a convergent framework organized in four phases: spatial mapping of extent and change; field-based assessment of service condition; social survey and stakeholder consultation; and integrated valuation and synthesis. The study area comprised the Dhaka metropolitan region, including the Dhaka North and Dhaka South City Corporation areas, peripheral cantonment and union areas, and the Buriganga, Turag, Balu, and Shitalakhya river systems together with floodplain lowlands and remaining canals.

Primary data collection

Primary data were gathered through four complementary instruments. The field observation protocol covered a purposively selected set of green and blue space types, including major parks, lakes and adjoining public areas, riverfront reaches, remaining canals, floodplain wetland patches, and rooftop and homestead gardens. Observers scored indicators on an ordinal scale under the four service categories, covering canopy and ground cover condition, shading and thermal comfort, evidence of waste dumping or encroachment, water presence and condition, waterlogging evidence, presence of groundwater structures, harvested plant produce, recreational infrastructure, visitor activity, and fauna evidence. The questionnaire survey targeted visitors and adjacent residents, capturing frequency and mode of access, activities, perceived benefits, problems experienced including flooding, heat, air quality, and waste, access constraints, and stated willingness to contribute to maintenance. Interviews

with municipal officials, park and lake managers, environmental organizations, planning professionals, and community representatives followed a semi-structured guide on condition, drivers of degradation, enforcement, coordination, participation, and management priorities. Table 1 sets out the instruments and their purposes.

Secondary Data Collection

Secondary data were retrieved from open-access remote sensing repositories (USGS Landsat and Sentinel archives via Google Earth Engine), published peer-reviewed journals, and official municipal planning and hydrological databases (including RAJUK, WARPO, and BWDB). To ensure data reliability, precision, and comparability across variable temporal windows, a four-tier quality evaluation framework was applied. Satellite-derived land use and land cover (LULC) datasets were filtered to retain only studies utilizing medium-to-high spatial resolution imagery ($\leq 30\text{ m}$) with reported overall classification accuracies exceeding 85% and Kappa coefficients greater than 0.85. Secondary valuation estimates and environmental quality metrics were selected exclusively from peer-reviewed literature employing standard analytical frameworks, such as Costanza's ecosystem service value coefficients, the Travel Cost Method (TCM), and the Contingent Valuation Method (CVM). Environmental monitoring parameters (such as land surface temperature, particulate matter PM_{2.5}, dissolved oxygen, and biological oxygen demand) were categorized into standardized multi-decadal time-step cohorts (1990, 2000, 2010, and 2020/2021) to minimize seasonal and cross-temporal distortions. Remote sensing-derived surface water and wetland boundaries were cross-verified against ground-truthed hydrological reports and historical spatial records to ensure baseline consistency across varying municipal administrative boundaries.

Data Analysis

Spatial analysis was conducted in a geographic information system. Extents were compiled into a common frame, area figures converted as reported in the source, and the surface water share of the city area computed for each reference year. Change detection computed absolute change, percentage change, and, where the reference period allowed, average annual rate. Condition assessment aggregated ordinal scores by site type and service category. Questionnaire data were processed into frequency distributions and cross-tabulations by gender, income, education, and visiting frequency. Interview transcripts were coded inductively into themes. Valuation applied market price methods to provisioning services, following the extrapolation procedure in which gross value equals the share of surveyed households using a service multiplied by the total number of holdings and the average income per user household, and stated preference methods to cultural and recreational services, benchmarked

Table 1: Primary data collection matrix.

Component	Instrument	Respondent group or site	Purpose
Field observation	Standardized checklist with ordinal scoring	Parks, lakes, riverfronts, canals, wetlands, gardens	Assess condition and functional performance
Transect survey	Georeferenced walkover with photographic record	Same sites	Verify extent, encroachment, waste dumping
Household and visitor survey	Structured face to face questionnaire	Visitors and adjacent residents	Use patterns, benefits, problems, preferences
Key informant interviews	Semi-structured guide	Officials, managers, environmental organizations, planners, community representatives	Drivers, enforcement gaps, coordination constraints
Spatial recording	Global positioning and site attribute logging	All surveyed sites	Support mapping and area estimation

against established willingness to pay estimates from Bangladeshi parks and forests.

To quantify total Ecosystem Service Value (ESV) and its change over time resulting from Land Use and Land Cover ($LULC$) conversion, the standardized benefit transfer method based on value coefficients was applied:

$$ESV_t = \sum_{k=1}^n (A_{kt} \times VC_k)$$

Where ESV_t represents the total estimated ecosystem service value at time t (in million USD/year), A_{kt} is the area in hectares of $LULC$ category k at time t , and VC_k is the specific ecosystem service value coefficient (in $USD \cdot ha^{-1} \cdot year^{-1}$) assigned to land cover type k .

The sensitivity and responsiveness of ecosystem service values to land cover changes were evaluated using the elasticity of ecosystem service value (E_{lu}):

$$E_{lu} = \frac{(ESV_j - ESV_i)/ESV_i}{(LUC_j - LUC_i)/LUC_i}$$

Where ESV_i and ESV_j represent total ecosystem service values at the initial and final monitoring periods, respectively, and LUC_i and LUC_j represent converted land cover areas over the corresponding timeframe. An elasticity value greater than zero quantifies the percentage change in ecosystem value resulting from a 1% shift in land cover.

Market price valuation for provisioning services market price valuation for urban provisioning services (such as rooftop agriculture, fisheries, and fodder) was calculated using an aggregation and extrapolation model:

$$V_{prov} = \sum_{m=1}^p (H_{total} \times P_{use} \times Y_{avg,m} \times P_m)$$

Where V_{prov} is the total annual gross market value of provisioning service stream m , H_{total} represents total residential holdings within the study area, P_{use} is the proportion of user households actively producing or harvesting service m , $Y_{avg,m}$ is the average annual yield per household, and P_m is the local market price per unit of output.

Analytical framework and limitations

The framework proceeds from ecological structure to service flows to human benefits to value to decision support. Extent, configuration, and condition constitute structure; structure generates provisioning, regulating, cultural, and supporting flows; flows produce benefits in food, cooling, cleaner air, reduced flooding, recreation, and health; benefits are monetized; and value estimates feed monitoring indicators and planning decisions that act back on structure through protection, restoration, or conversion.

Sites were selected purposively to span a gradient from well maintained to severely degraded, supporting analytical rather than statistical generalization. Three limitations apply. Administrative boundaries differ across secondary sources, so area figures are reported separately and compared cautiously. Published monitoring data are not available at uniform temporal resolution, limiting trend precision for individual indicators. Stated preference estimates are sensitive to hypothetical bias and are interpreted as indicating relative magnitude and preference ordering rather than precise economic values.

Results

Ecosystem service profile

Six functional classes of green and blue space were identified. Major parks occupy small areas but concentrate cultural and regulating services. Lakes and adjoining public areas combine thermal regulation, stormwater retention, recreation, and, where quality permits, provisioning. Riverfront reaches provide the largest water surface but supply constrained services owing to pollution. Remaining canals perform drainage and conveyance functions and represent the historical backbone of the natural drainage network. Floodplain wetland remnants supply the highest per hectare regulating value, particularly recharge, storage, and flood attenuation. Rooftop and homestead gardens supply the highest concentration of market-valued provisioning services.

Land use change and service value

Table 2 reports the central findings. Built-up land expanded by 188.35 percent between 1990 and 2020, at an average annual rate of approximately 6.28 percent, primarily through conversion of agricultural land, water bodies, and vegetated land. Ecosystem service value fell by 59.55 percent, from 142.72 million US dollars to 57.72 million US dollars, a loss of 85 million US dollars. Water bodies were the single greatest contributor to remaining value, meaning their loss removes a disproportionate share of value per unit area. The elasticity of service value with respect to land transition was 0.33. Figure 1

At the wider urban scale, the combined loss attributed to green and blue space degradation across five Bangladeshi cities over thirty years was 628.58 million US dollars, highest in Dhaka and Chattogram.

Decline of water bodies, wetlands, and surface water

Table 3 reports change in water bodies and lowlands. Water bodies fell from 2952.02 hectares in 1960 to 2103.62 hectares in 1988 and 1990.71 hectares in 2008, a reduction of 961.31 hectares or 32.57 percent. Lowlands fell from 13527.58 hectares in 1960 to 12717.73 hectares in 1988 and 6414.57 hectares in 2008, a reduction of 7113.01 hectares or 52.58 percent. Water bodies lost 848.40 hectares, or 28.74 percent, between 1960 and 1988, and a further 112.91 hectares, or 5.37 percent, between 1988 and 2008. Lowlands lost 809.85 hectares, or 5.99 percent, between 1960 and 1988, but 6303.16 hectares, or 49.56 percent, between 1988 and 2008, showing that pressure shifted decisively

Table 2: Land use change and ecosystem service value in Dhaka, 1990 to 2020.

Indicator	1990	2020	Change
Built-up land	Baseline	Increased over the period	+188.35 percent; average annual growth 6.28 percent
Ecosystem service value (million USD)	142.72	57.72	Decline of 85 million USD, or 59.55 percent
Elasticity of service value to land transition	Not applicable	Not applicable	0.33

Table 3: Change in water bodies and lowland areas in Dhaka City, 1960 to 2008 (hectares).

Land cover type	1960	1988	2008	Change 1960 to 1988	Change 1988 to 2008	Change 1960 to 2008
Water bodies	2952.02	2103.62	1990.71	-848.40 (-28.74 percent)	-112.91 (-5.37 percent)	-961.31 (-32.57 percent)
Lowlands	13527.58	12717.73	6414.57	-809.85 (-5.99 percent)	-6303.16 (-49.56 percent)	-7113.01 (-52.58 percent)

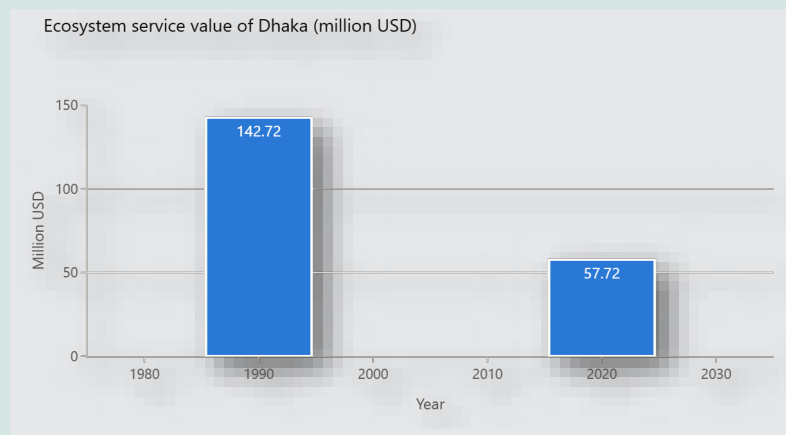


Figure 1: Decline in ecosystem service value of the Dhaka metropolitan area, 1990 to 2020.

Table 4: Surface water coverage of Dhaka City, 1990 to 2021.

Year	Share of area under surface water (percent)	Reported water surface area (square kilometers)
1990	11.82	26.23
2000	10.77	32.99
2010	9.36	28.67
2021	5.16	15.82

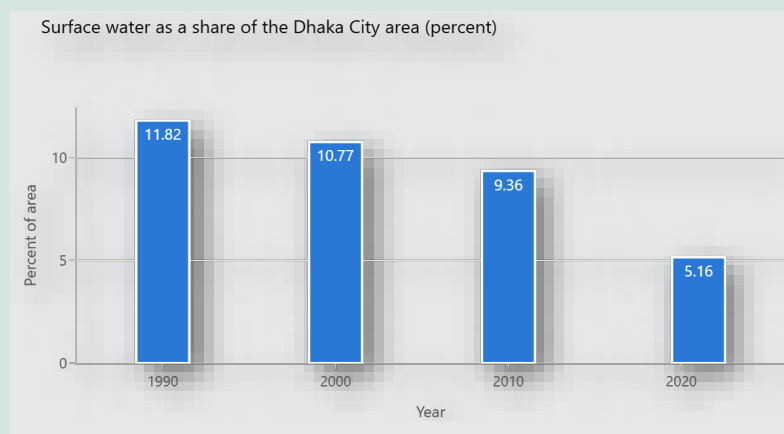


Figure 2: Surface water share of the Dhaka City area, 1990 to 2021.

onto lowlands in the later period. More than 49 percent of the total wetland area was lost over the interval.

At metropolitan scale, approximately 29 square kilometers of rivers and canals and 130.17 square kilometers of wetlands existed in 1978, against only 10.28 square kilometers of rivers and canals and 53.6 square kilometers of wetland in 2009, together about 21 percent of the metropolitan area compared with approximately 52 percent in 1978. Total loss of rivers and canals was 18.72 square kilometers, or 64.55 percent, with 7.97 square kilometers lost between 1978 and 1998 and 8.44 square kilometers between 1998 and 2009, equivalent to 27.48 percent and 29.10 percent of the 1978 stock. Loss concentrated along the Turag from Aminbazar to its confluence with the Buriganga, and along the Buriganga at Kamrangirchar and on both banks between the Bangladesh China Friendship Bridge and Lalbagh.

Table 4 reports satellite monitoring of surface water. The share of the Dhaka area under surface water fell from 11.82 percent in 1990 to 10.77 percent in 2000, 9.36 percent in 2010, and 5.16 percent in 2021. Loss was gradual across the first two decades and abrupt in the final decade. By 2021 the water surface had diminished to approximately 15.82 square kilometers, with remaining public water bodies consisting mainly of minor ponds and lakes on the outskirts surrounded by dense urbanization, a loss attributed principally to low-lying urbanization and real estate development. Figure 2

Service consequences have been measured directly: 59.4 percent of surveyed respondents reported drainage congestion and waterlogging, 30.8 percent reported problems with groundwater recharge capacity, and 5.9 percent identified loss of water reservoirs. Lowlands act as detention storage where storm runoff accumulates before draining to peripheral rivers through canals, and Dhaka's drainage system historically consisted of forty three major canals, many no longer existing.

Regulating services

Table 5 summarizes regulating indicators. Land surface temperature rose across the record, with the range widening from 23.26 to 39.94 degrees Celsius in 1993 to 23.69 to 43.35 degrees Celsius in 2007 and 24.44 to 44.58 degrees Celsius in 2020, alongside a 67 percent increase in built-up area between 1993 and 2020 achieved by replacing lowland first, followed by vegetation, bare soil, and water bodies. Between 2012 and 2018, water bodies declined by 2 percent and vegetation by 5.3 percent while construction and bare land increased by 4 percent and 3.4 percent. The spatial correlation between PM2.5 and vegetation was negative at 0.212 and between PM2.5 and water bodies negative at 0.028, while landscape pattern metrics showed correlations with PM2.5 of 0.01 for aggregation, 0.158 for contagion, and positive 0.06 for the landscape index. Projected annual average PM2.5 for 2024 was 188 to 312 micrograms per cubic meter, and air pollution alone accounts for 17.6 percent

Table 5: Regulating service indicators for Dhaka's green and blue space.

Indicator	Findings
Land surface temperature, 1993	Range 23.26 to 39.94 degrees Celsius
Land surface temperature, 2007	Range 23.69 to 43.35 degrees Celsius
Land surface temperature, 2020	Range 24.44 to 44.58 degrees Celsius
Built-up area change, 1993 to 2020	Increase of 67 percent, replacing lowland, vegetation, bare soil, and water bodies
Land cover change, 2012 to 2018	Water bodies -2 percent; vegetation -5.3 percent; construction +4 percent; bare land +3.4 percent
Correlation of PM2.5 with vegetation	-0.212
Correlation of PM2.5 with water bodies	-0.028
Projected annual average PM2.5 for 2024	188 to 312 micrograms per cubic meter
Share of mortality and disability risk attributable to air pollution	17.6 percent
Groundwater level decline, 1995 to 1999	1.02 to 2.46 meters per year
Share of water supply drawn from groundwater	Approximately 95 percent
Number of major canals in the historical drainage system	43

Table 6: Documented water quality parameters of Dhaka rivers.

Parameter	Reported range or value
pH, Turag River	6.6 to 7.98
Conductivity, Turag River	160 to 1107 microsiemens per centimeter
Dissolved oxygen, Turag River	0.11 to 6.8 milligrams per liter (WHO guideline 6; ideal 14.6)
Biological oxygen demand, Turag River	10 to 180 milligrams per liter
Chemical oxygen demand, Turag River	21 to 220 milligrams per liter
Free carbon dioxide, Turag River	5 to 22 milligrams per liter
Zinc, Turag River	0.04 to 0.4 parts per billion
Cadmium, Turag River	0.043 to 2 parts per billion
Arsenic, Turag River	1.15 to 4.8 parts per billion
Lead, Turag River	2.29 to 18.62 parts per billion
Mercury, Turag River	0.12 to 1.45 parts per billion
Dry season biological oxygen demand	Turag 46; Tongi Khal 42; Shitalakhya 30; Buriganga 18; Balu 8; Dhaleshwari 4 milligrams per liter
Dhaleshwari wet season biological oxygen demand	2 milligrams per liter

of mortality and disability risk. Carbon dioxide accounts for more than ninety percent of air pollution, with denser roadside greenery absorbing more vehicular carbon dioxide. Groundwater levels declined by 1.02 to 2.46 meters per year during 1995 to 1999, against a supply system drawing approximately 95 percent of its water from underground sources.

Water quality

Table 6 reports documented parameters. Dissolved oxygen in the Turag ranged from 0.11 to 6.8 milligrams per liter, against a WHO guideline of 6 and an ideal of 14.6 milligrams per liter. Biological oxygen demand ranged from 10 to 180 and chemical oxygen demand from 21 to 220. In dry season monitoring the highest biological oxygen demand was at the Turag at 46 milligrams per liter, followed by Tongi Khal at 42, the Shitalakhya at 30, the Buriganga at 18, the Balu at 8, and the Dhaleshwari at 4, with the lowest value of 2 recorded at the Dhaleshwari in the wet season; dissolved oxygen was lowest in the dry season at all rivers, particularly the Buriganga and Turag. Heavy metals in the Turag were recorded in parts per billion as zinc 0.04 to 0.4, cadmium 0.043 to 2, arsenic 1.15 to 4.8, lead 2.29 to 18.62, and mercury 0.12 to 1.45. These waters are unsuitable for use in the dry season but usable in the wet season, when monsoonal flows increase by between 50 and 90 percent and improve quality through dilution.

Provisioning service valuation

Table 7 reports market price valuation. Total gross value of assessed provisioning services was 5,340,233 Taka per year in 2016, approximately 68,465 US dollars at an exchange rate of 78 Taka to 1 US dollar. Rooftop gardens contributed 3,839,533 Taka from fruits and vegetables, or 72 percent of the total. The jheel ecosystem contributed 1,080,000 Taka from fish and 144,000 Taka from fodder, the National Botanical Garden contributed

276,334 Taka from fruits and seedlings, and cultivated land contributed 365 Taka from water supply. About 35 percent of surveyed households maintained rooftop gardens, almost 70 percent belonging to property owners, with mixed gardens at 36 percent and fruit gardens at 32 percent of gardens.

Cultural service valuation and social findings

At the National Botanical Garden, travel cost analysis of 100 visitors estimated willingness to pay of 0.955 US dollars with an annual consumer surplus of 593,634.5 US dollars; the contingent valuation estimate was 0.225 US dollars and the revenue maximizing fee 0.376 US dollars. At Bhawal, a survey of 418 visitors estimated average willingness to pay of 188.99 Taka, equivalent to 1.72 US dollars, at least nine times the prevailing fee, with peak season willingness approximately 91 percent higher than off-peak. Both findings indicate that charges and public spending fall below expressed willingness to pay. Demand is differentiated: recreation was the most preferred category and respondents were dissatisfied with green space quantity; higher income respondents valued cultural heritage while lower income and less educated respondents valued recreation; daily visitors prioritized recreation and social cohesion; single and teenage respondents preferred active recreation and young and older respondents preferred passive recreation; and women reported higher engagement but faced constraints from insecurity and traffic congestion. International estimates reinforce the order of magnitude, with aggregate willingness to pay for one Brazilian park between 550,547.94 and 1,445,188.35 US dollars from 338 households, and 58 percent of respondents willing to pay to visit a Brazilian ecological park.

Observed condition and stakeholder perspectives

Table 8 summarizes field and consultation findings. Green

Table 7: Gross value of provisioning ecosystem services in Dhaka, 2016.

Ecosystem	Service	Gross value	Note
Rooftop gardens	Fruits and vegetables	3,839,533	72 percent of total
Jheel	Fish	1,080,000	Part of remaining 28 percent
National Botanical Garden	Fruits and seedlings	276,334	Part of remaining 28 percent
Jheel	Fodder	144,000	Part of remaining 28 percent
Cultivated land	Water supply	365	Part of remaining 28 percent
Total	Provisioning services assessed	5,340,233	Approximately 68,465 USD

Table 8: Observed condition of ecosystem services and principal pressures

Service category	Observed condition	Principal pressures	Implication
Provisioning	Active in rooftop and homestead gardens; constrained in rivers in dry season	Limited cultivable land; seasonal water quality decline	Market value concentrated in domestic gardens
Regulating, climate	Measurable cooling in parks and near water; insufficient citywide	Loss of vegetation and water surface; impervious expansion	Rising surface temperature range and heat exposure
Regulating, air quality	Local removal by dense vegetation; inadequate against citywide load	Traffic emissions; declining vegetation cover	Persistent exceedance of particulate concentrations
Regulating, drainage and recharge	Retained in intact wetlands and canals; reduced in filled areas	Encroachment, waste dumping, paving of lowlands	Recurrent waterlogging and falling groundwater levels
Cultural	Widely used and valued; concentrated in few sites	Congestion, distance, safety concerns, site condition	Uneven access by gender, age, and income
Supporting, habitat	Present in parks and wetland remnants; fragmented	Habitat fragmentation; loss of tree cover	Declining bird richness with imperviousness

spaces were functionally intact but quantitatively insufficient, maintaining recreation, cohesion, and measurable shading while serving populations far exceeding their area, consistent with ward-level green coverage of 2.24 percent, only 2 of 110 wards exceeding 20 percent coverage, and a maximum per capita green space of 0.003207 square meters. Provisioning functions were most evident in the domestic sphere, where rooftop and homestead gardens were actively cultivated. Blue spaces showed a sharper contrast between potential and realized supply. Intact lakes and wetland remnants retained thermal regulation, storage, and groundwater interaction functions, but encroachment, waste dumping, and paving of lake margins were observed at multiple sites, and water quality constraints eliminated dry season provisioning use. Riverfront reaches of the Buriganga and Turag showed the most degraded condition. Canals were frequently fragmented or obstructed, reducing their drainage and hydrological connectivity functions.

Questionnaire findings confirmed that recreation, cooling, and relief from air pollution were the benefits most frequently associated with green and blue space, while the problems most frequently reported were monsoon waterlogging, waste accumulation, and heat. Access constraints included distance, traffic, safety concerns, and site condition, with safety and condition reported disproportionately by women and younger respondents. Interviews identified four recurring themes: institutional fragmentation across agencies with overlapping mandates and weakly coordinated responses; enforcement failure, with legal instruments described as adequate on paper but circumvented through filling, encroachment, and irregular land transfer under pressure from vested interests; the absence of routine monitoring, so loss becomes visible only after it is irreversible; and weak community participation, with consultation occurring after decisions were taken.

Discussion

The continuous contraction of Dhaka's ecological infrastructure reflects rapid, unplanned urbanization trends observed across major megacities in the Global South. The observed 59.55% reduction in total ecosystem service value between 1990 and 2020, amounting to an \$85 million loss, which points toward the severe ecological costs associated with urban spatial expansion. The systemic sensitivity of this system is further evidenced by an elasticity of 0.33, demonstrating that ongoing land conversion directly erodes urban habitability.

The systematic conversion of wetlands and vegetation into impervious surfaces has degraded critical microclimatic regulation services. The expansion of land surface temperatures, widening from 23.26°C-39.94°C in 1993 to 24.44°C-44.58°C in 2020, illustrates a narrowing thermal relief window for residents. Simultaneously, the loss of natural detention basins and canals has crippled the city's natural drainage capacity, leaving 59.4% of surveyed residents vulnerable to recurrent waterlogging and drainage congestion. The distribution of residual green and blue infrastructure exhibits acute spatial and social inequities. With an average ward-level green cover of just 2.24% and maximum per capita availability failing to meet basic international standards, service deficits disproportionately impact lower-income

populations, women, and younger residents who face safety and accessibility barriers. Despite existing regulatory frameworks like the Water Body Conservation Act, enforcement mechanisms remain compromised by institutional fragmentation, conflicting agency mandates, and speculative real estate development. This study has some analytical limitations. The integration of secondary datasets across varying administrative boundaries requires cautious spatial comparisons. Additionally, stated preference methods used for contingent valuation remain susceptible to hypothetical bias, meaning willingness-to-pay figures reflect relative demand orders rather than precise absolute economic values.

Conclusion

This study provided a multi-decadal analysis mapping, monitoring, and valuing the ecosystem services provided by Dhaka's green spaces and water bodies. Between 1990 and 2020, built-up land expanded by 188.35%, while surface water coverage shrank to 5.16% of the city area by 2021. These structural transformations resulted in an \$85 million loss in ecosystem service value. Empirical findings supported both research hypotheses, confirming that rapid urban conversion causes non-linear declines in service values and that public willingness to pay for environmental preservation significantly exceeds current municipal fees.

Acknowledgements: The author expresses sincere gratitude to the faculty at the Department of Environmental Science, Bangladesh University of Professionals (BUP), for their institutional support throughout this research. The author also acknowledges the key informants, survey participants, and local community members across the Dhaka metropolitan area who provided valuable insights during primary data collection. Special thanks are extended to the open-source satellite data platforms and institutional repositories for providing access to essential spatial and environmental records.

Funding: This research was supported by the National Science and Technology (NST) Fellowship provided by the Ministry of Science and Technology, Government of the People's Republic of Bangladesh. The funder had no role in study design, decision to publish, or preparation of the manuscript.

Conflicts of interest: The author declares no conflicts of interest, financial or otherwise, regarding the publication of this manuscript.

Data availability statement: The primary data collected through field observations, questionnaires, and key informant interviews supporting the findings of this study are available in the manuscript and can also be collected from the corresponding author upon request. Secondary environmental and spatial datasets utilized in this study are derived from publicly available repositories (including USGS Landsat/Sentinel archives via Google Earth Engine) and previously published peer-reviewed literature cited within the article.

Author contributions: NM was responsible for the conceptualization, methodology design, formal Analysis, investigation, data curation, visualization and writing of the original draft, followed by review and editing.

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