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IMPACT OF LAND USE AND LAND COVER CHANGES ON ECOSYSTEM SERVICE VALUES IN THE KALMUNAI URBAN AREA

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ABSTRACT : The impact of land use and land cover (LULC) change on ecosystem services has increased in Kalmunai, a coastal city located on the Bay of Bengal in Sri Lanka. To address these issues and analyse the extent of change in urban land use and landscape in Kalmunai, this study uses satellite imagery from 2003, 2013, and 2023. The primary objective of this study is to quantitatively assess the impact of LULU dynamics and the ecosystem services value (ESV) in Kalmunai. Therefore, urban ecosystems provide a wide range of services to sustain human life, social relationships, and health, among other things, and to address challenges such as climate change and environmental pollution. Although it is accepted that urban ecosystems contribute significantly to human well-being in cities, little attention has been paid to considering the value of urban ecosystem services in urban planning and policymaking. Therefore, understanding and addressing the factors responsible for the rapid change in land use and landscape is of paramount importance for sustainable urban management. Therefore, to conduct a comprehensive analysis of the loss of ecosystem services, the ESV technique has been used to identify trends and patterns of land use and landscape changes using satellite data from 2003 to 2023. Specifically, from 2003 to 2023, land use and landscape change have caused a loss of -27.87% in the value of ESV during the period of study. The study results show that this represents a loss of -416.79 million US dollars. However, the study results indicate that the total ESV has decreased by -8.80% or -393.23 million USD during 2003-2013 and by -19.06% or -23.56 million USD during 2013-2023. It also identified that water bodies, vegetation and agricultural land are the three main contributors to ESV in our study area. These findings highlight the effectiveness of the ESV method as a valuable tool for policy makers, urban planners and environmentalists. The ESV Land Use and Land Use Analysis emphasises the critical need for strategic interventions to mitigate the adverse impacts of urban planning and ensure sustainable conservation and development of the Kalmunai region.

KEYWORDS: Ecosystem Services, Urban, Planning, Land Use and Land Change, Value

INTRODUCTION

Urbanisation has been one of the most significant global trends since the mid-20th century, ushering in what is termed the “century of the city” (Anonymous, 2010). This process is most evident in developing countries (Cohen, 2006) and has resulted in large-scale land degradation due to the conversion of natural landscapes for human use (Karl, 2010). Land use and land cover (LULC) changes directly affect ecosystem service values (ESVs), which represent the benefits humans derive from ecosystems such as food, water, climate regulation, and cultural values (Burkhard *et al.,* 2010; Talukdar *et al.,* 2020). Since different land covers provide different services (Li *et al.,* 2019), assessing LULC–ESV relationships is essential for sustainable development planning (Chang *et al.,* 2011).

Land use and land cover (LULC) changes directly influence ecosystem service values (ESVs), which represent the benefits that humans derive from ecosystems, including food, timber, water regulation, climate regulation, and aesthetic values (Talukdar *et al.,* 2020; Burkhard *et al.,* 2010). Since different land cover types provide varying ecosystem services (Chang *et al.,* 2011; Li *et al.,* 2019), examining the relationship between LULC dynamics and ESVs is critical for planning and sustainable development. Natural ecosystems use land as a carrier, meaning that any land use change significantly alters ecosystem services. Numerous studies demonstrate that land use categories can serve as proxies for ecosystem services by linking them to corresponding biomes (Cai *et al.,* 2013; Sawut *et al.,* 2013). Consequently, assessments of environmental change are often conducted through the lens of land use change (Collard and Zammit, 2006; Li *et al.,* 2010).

Ecosystems are spatially explicit units of Earth's surface where organisms interact with their physical environment through exchanges of energy and materials (Chapin *et al.,* 2012). They deliver direct goods such as food and fresh water, along with regulating and cultural services, including climate regulation, carbon sequestration, water purification, and aesthetic value (MEA, 2005). These functions sustain ecological processes and provide essential resources for living organisms (Sharma *et al.,* 2019). Each ecosystem offers distinct services; for example, forests differ considerably from deserts or grasslands in their service provision (Costanza *et al.,* 1997). Ecosystems also play an important role in economic development (Vargas *et al.,* 2019). However, over the past decades, ecosystems have undergone profound changes due to mounting pressures on natural resources (McLaughlin and Mineau, 1995; Steffen *et al.,* 2015). Drivers of ecosystem service change include land use/cover conversion (Elias *et al.,* 2019; Rodríguez-Echeverry *et al.,* 2018; Akber *et al.,* 2018; Song and Deng, 2017), urbanisation (Das and Das, 2019; Liu *et al.,* 2019), overexploitation (Kronenberg, 2014), wildfires (Vukomanovic and Steelman, 2019), and natural hazards (Talbot *et al.,* 2018). Collectively, these factors pose significant threats to the sustainability of natural resources and to future generations (Western, 2001; Xiao *et al.,* 2019).

Globally, around 13 million hectares of land are converted annually to agriculture, largely at the expense of forest ecosystems. Nearly 60% of the world's ecosystems have been degraded over the past 50 years due to population growth, resource over exploitation (Mittal, 2013), economic expansion (Alvarado and Toledo, 2017), and uncontrolled urbanisation (Liu *et al.,* 2015; MEA, 2005). These changes have led to marked reductions in ESVs (Ferreira *et al.,* 2019). LULC changes often result in either declines or total losses of services (Haase *et al.,* 2012; Rodríguez *et al.,* 2006). For example, in Sri Lanka, significant areas of green cover have been converted into urban settlements and development projects over recent decades. In the past 25 years alone, approximately 890,003 ha (13.5%) of land have been altered, while 72,266 ha (1%) have been disturbed but not permanently transformed (Liu *et al.,* 2015).

Several methods have been developed to quantify ESVs in response to land use change, ranging from benefit transfer approaches to advanced GIS and remote sensing techniques (Costanza *et al.,* 1997; Haase *et al.,* 2012; Rodríguez *et al.,* 2006). Remote sensing and GIS in particular have revolutionised land cover mapping, enabling precise assessments of ecosystem service dynamics. Although methodological inconsistencies remain a challenge for integrating ESV estimates into national accounts and policy frameworks, the growing body of research has significantly advanced ecosystem service valuation. For instance, Bandara *et al*., (2021) analysed LULC and ESV changes in Sri Lanka's Hantana mountain range between 1956 and 2019 using Landsat datasets and value coefficients from Costanza *et al*., (1997). The study revealed a decline in ESVs from Rs. 547 million in 1976 to Rs. 208 million by 2019, primarily due to land degradation, urban expansion, and socio-economic pressures. Similarly, Sharma *et al*., (2023) assessed Chandigarh (India) from

1990–2020, identifying a 104.61% increase in built-up areas, alongside significant reductions in forests (−4.19%) and agriculture (−37.01%). Consequently, the city's ESV decreased by 2.54%, underscoring how urbanisation compromises ecosystem services. Such findings highlight the value of integrating LULC and ESV assessments into urban planning and policy.

Comparable trends have been observed globally. In the Munesa landscape of the Ethiopian highlands, ESVs fell from US$164.6 million in 1973 to US$118.7 million by 2012, reflecting degradation of critical services such as erosion control, nutrient cycling, climate regulation, and water purification (Kindu *et al.,* 2016). In this context, the present study focuses on the Kalmunai urban area, which has experienced rapid urbanisation in recent decades. The objectives are: (1) to assess LULC changes from 2003–2023, (2) to evaluate ESV changes in response to LULC dynamics, and (3) to analyse the elasticity of ESV responses by adjusting value coefficients. The study employs remote sensing, GIS, and benefit transfer methods to provide evidence for ecological protection and sustainable development in Kalmunai.

METHODOLOGY

2.1 Study Area

The Kalmunai Municipal Council, located in the Ampara district of the southeastern region of Eastern Sri Lanka, is situated between 7° 25' 24" - 7° 27' 25" North latitude and 81° 45' 31" - 81° 50' 32" East longitude. Geographically, it is bordered by the Batticaloa district to the north, the Bay of Bengal to the east, the Karaithivu Divisional Secretariat to the south, and the Sammanthurai and Navithanveli Divisional Secretariats to the west. The area receives increased rainfall during the Northeast monsoon from November to January (November: 231.7 mm, December: 304.6 mm, January: 191.5 mm), with rainfall below 100 mm in other months, averaging throughout the year (source: Department of Meteorology, Regional Office, Pottuvil, 2000/2001).

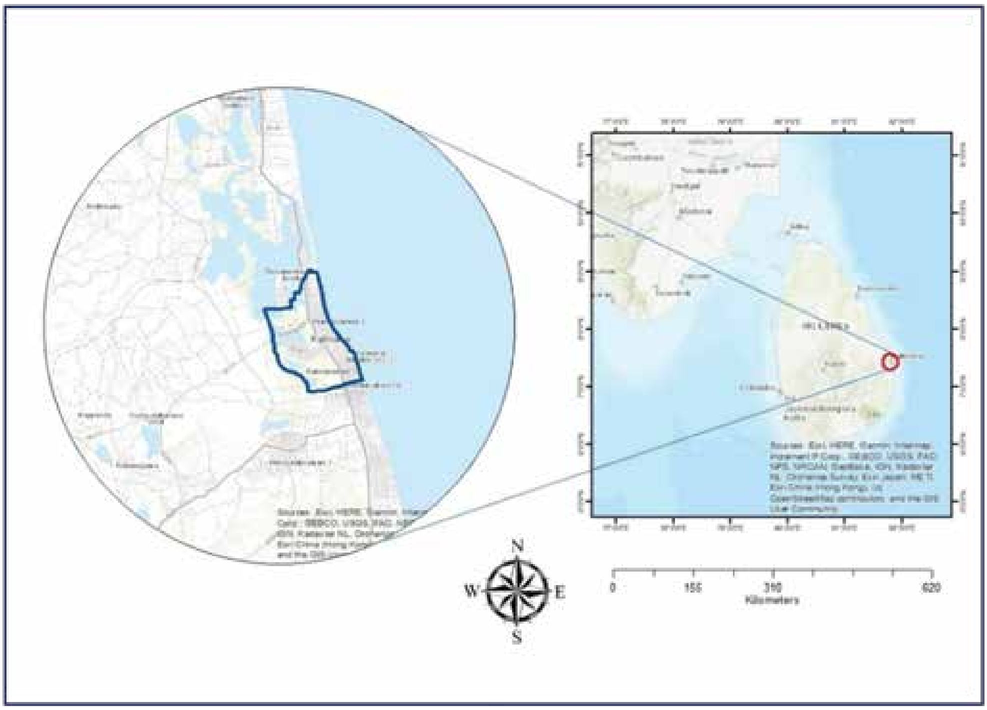

FIGURE 01: Geographical Location of Study Area

The Kalmunai Municipal Council, characterised by diverse terrains, is a region with multiple ecosystems and a rich cultural heritage. Its landscape includes coastal plains and elevated areas, featuring sandy beaches, wetlands, and urban zones, all subject to environmental changes due to sea erosion and land reclamation. Additionally, the region experiences a wet and dry tropical climate influenced by the monsoon in the Bay of Bengal. As an area with high population density and urban landscapes, residential, commercial, and industrial zones, Kalmunai is rapidly urbanising economically. The region also boasts a variety of flora and fauna, including unique coastal vegetation and birdlife. Furthermore, land use and land cover are crucial in maintaining the overall health and sustainability of the local environment, providing biodiversity and ecosystem services. Despite this ecological importance, the area faces challenges such as land degradation and loss of green spaces, leading to ecosystem service impacts. This study aims to assess these changes.

2.2 Data Collection Method

This study focuses on the assessment of ESV based on LULC change to analyse the 30-year changes in the Kalmunai urban ecosystem services using this data. Landsat images from three years 2003, 2013, and 2023 were downloaded from the official website of the United States Geological Survey (USGS) (www.earthexplorer.usgs.gov).

To minimize data set disturbances in this study, only images taken during dry seasons with a cloud cover of 5% were evaluated. This involved processes such as clipping images using study area shape files, stacking different bands, creating multiband images, supervised maximum likelihood classification, and accuracy assessment to maintain data precision. Additionally, one of the preprocessing procedures performed in the study is image cropping. Image cropping aims to control and focus the image area according to the research area. Furthermore, the cropping process contributes to the analysis by reducing the large size of Landsat image data to a manageable size, thereby decreasing memory usage during data processing.

2.3 Data Analysis

2.3.1 Land Use and Land Cover (LULC) Classification

The surface reflectance values obtained after preprocessing through radiometric and atmospheric correction in the previous stage were used to derive LULC maps. The study area was classified into five broad LULC categories (Table 2), corresponding to 16 biomes established by Costanza et al. To classify the Landsat images into these five LULC classes, a supervised classification method was employed. These LULC classes are presented in Table 2. These LULC types were selected considering the biome categories used to calculate ecological value.

TABLE 01: Details of Landsat Image Data

Year	Image Type	Date	Cloud Type
2003	Landsat – 7	13.03.2003	5%
2013	Landsat – 8	24.09.2013	5%
2023	Landsat – 9	05.04.2023	5%

TABLE 02: Description of Land Use and Land Cover Categories

Classes	Description
Water Bodies	River, lake, pond, canal, lowland, and wetland.
Vegetation Cover	Trees, mixed forests, natural vegetation, plantations, parks, and sports fields.
Agricultural Land	Cropland and pasture, orchards, groves, and other agricultural lands.
Built-up Area	Urban area, residential, commercial, industrial zones, mixed-use areas, housing, transportation, and other man-made structures.
Barren Land	Open space, non-vegetated land, sand, transitional areas, and bare soil.

The supervised classification method was used to categorise LULC classes. This method has several advantages over the unsupervised classification method. Supervised classification is a powerful tool for classifying image data. It uses the user's prior knowledge to assign pixels in an image to specific classes. This method is highly accurate, easy to operate, and efficient because the algorithms learn the characteristics of the objects in the image with user prior knowledge, providing a very accurate classification. Images are fully developed with classes based on the user's prior knowledge information.

In addition to measuring LULC type, LULC change analysis was performed during the study period, as LULC changes affect ecosystem services and their function. Subsequently, the land use dynamic index was used to understand LULC changes over time. The following equation was used to calculate the land use dynamic index (Equation 1).

$$K= \frac{Aj - Ai}{Ai} \times \frac{1}{T} \times 100\% \qquad (1)$$

In this equation, K represents the dynamic index of land use for the LULC category. Here, A*i* is the initial area of a specific LULC category, A*j* is the final area, and T is the study period.

2.3.2 Assessment of Ecosystem Services Values (ESV)

Ecosystem service valuation is gaining increasing attention and is being used globally to understand the numerous benefits provided by ecosystem services. Many studies have been conducted over the past few decades to assess the value of ecosystem services, including the economic valuation of tropical forests, endangered species management, and protected areas. However, the ecosystem service valuation 1 model provided by Costanza et al (1997 is considered a robust method for estimating the economic value of ecosystem services. They identified 05 ecosystem service functions from 16 biomes to calculate ESV.

TABLE 03: Biome equivalents and associated ecological values (US cu $ha^{-1}yr^{-1}$) for five land-use types.

LULC Classes	Equivalent Biome	ES Coefficient (US$ ha-1/y)
Water Bodies	516.75	14785
Vegetation Cover	811.53	2007
Agricultural Land	698.74	92
Built-up Area	76.30	0
Barren Land	147.11	0

Since its development, this approach has been widely applied in studies across the world to estimate ecosystem service values. In the present study, the same method was employed to evaluate the ecosystem services of the Kalmunai urban area. For this purpose, each of the five identified LULC categories was matched with the most appropriate biome among the 16 defined by Costanza *et al.,* which served as proxies for valuation. The corresponding biomes and their value coefficients are summarised in Table 3. The total ecosystem service value (ESV) was then derived by multiplying the area of each LULC type by its assigned value coefficient, following the formula outlined in Equation 2.

In this equation, *Ak* represents the area in hectares, and *VCk* represents the value coefficient (US$ $ha^{-1}yr^{-1}$).

$$ESV = \sum (A_k \ X \ VC_k) \qquad (2)$$

To determine the change in ecosystem service value 'k' for each LULC type, the differences between the estimated ESV for each LULC type in 2003, 2013, and 2023 were calculated. The following equation was used to calculate the ESV change rate (Equation 3).

$$ESVcr = \frac{ESVj - ESVi}{ESVi} \times \frac{1}{T} \times 100\% \qquad (3)$$

ESVcr represents the annual *ESV* change rate for a single LULC type. *ESVi* and *ESVj* are the initial and final ecosystem service values, and T is the study period.

The change in ESV over different periods (2003, 2013, 2023) was calculated using the following equation (Equation 4).

ESV change percentage represents the annual change rate of ESV. *ESV* start year and *ESV* end year represent the initial and final ecosystem service values.

$$\text{ESV change percentage (\%)} = \frac{ESV_{end\ year} - ESV_{start\ year}}{ESV_{start\ year}} \times 100\% \qquad (4)$$

ESV change percentage represents the annual change rate of ESV. *ESV* start year and *ESV e*nd year represent the initial and final ecosystem service values.

RESULTS AND DISCUSSION

4.1 Land Use and Land Cover (LULC) Change

The spatial distribution and trends of LULC changes in the Kalmunai urban area over the past three decades are presented in Figure 2 and Table 3. According to that in 2003, the northern part of the Kalmunai urban area was primarily non-vegetated or barren land with small areas of recently developed residential zones and sparsely vegetated areas. Similarly, the eastern part had a high concentration of residential areas and low vegetation cover, with minimal barren land. The southern part was predominantly densely vegetated, comprising forests, fields, and grasslands, with some residential areas and minimal agricultural land. The western part had a significant water body presence and low vegetation cover, while the central part had high vegetation cover with minimal agriculture and water bodies. This information is visualised in the LULC map of Figure 2.

In 2003, the water bodies in the Kalmunai urban area covered 516.75 ha, representing 22.96% of the total area. Vegetation cover was 811.53 ha, accounting for 36.06% of the total. Agricultural land covered 698.74 ha, which is 31.05% of the total. Residential areas and barren land covered 76.30 ha and 147.11 ha, respectively, representing 3.39% and 6.54% of the total area (Table 4). The 2013 LULC map clearly shows differences from the 2003 map, particularly in vegetation cover changes (Figure 2). In 2013, the northern part of Kalmunai was primarily vegetated and barren land with small areas of recently developed residential zones and sparsely vegetated areas. The eastern part had a high concentration of residential areas and vegetation cover, with minimal barren land. The southern part was predominantly densely vegetated with minimal residential and agricultural land. The western part had a significant water body and vegetation cover, while the central part had high vegetation cover with minimal agriculture and water bodies. This information is visualised in the LULC map of Figure 2.

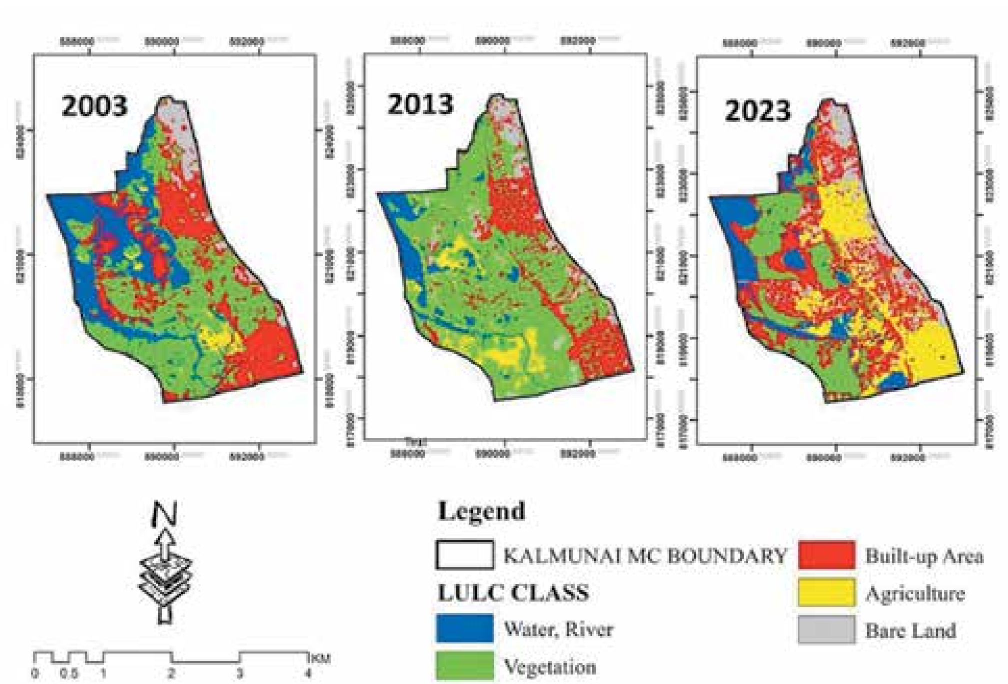

FIGURE 02: Distribution of Land Use and Land Cover map in 2003 – 2023

In 2013, the water bodies in the Kalmunai urban area covered 202.98 ha, representing 9.02% of the total area. Vegetation cover was 1175.11 ha, accounting for 52.22% of the total. Agricultural land covered 450.72 ha, which is 20.03% of the total. Residential areas and barren land covered 167.18 ha and 254.43 ha, respectively, representing 7.43% and 11.31% of the total area (Table 4). The 2023 LULC map provides crucial information about the distribution of LULC in the area, enhancing the understanding of environmental dynamics (Figure 2). The 2003 LULC data reflect the size, extent, and vegetation health of LULC during that period. Over time, it has undergone various changes due to natural and anthropogenic influences. Significant changes in land cover distribution occurred between 2003 and 2013. Analysing the 2023 LULC map with the 1993, 2003, and 2013 data provides a comprehensive understanding of how the area's vegetation has evolved and transformed over time. In 2023, the land distribution in the area underwent substantial changes.

In 2023, the northern part of Kalmunai was primarily barren land with small residential areas and minimal water bodies. The eastern part had a high concentration of residential areas and agriculture, with minimal barren land. The southern part was predominantly agricultural with minimal residential and vegetation cover. The western part had a significant water body presence with minimal residential and vegetation cover. The central part had a high concentration of residential areas with minimal agriculture, vegetation, and water bodies. This information is visualised in the LULC map of Figure 2.

In 2023, the water bodies in the Kalmunai urban area covered 286.98 ha, representing 12.74% of the total area. Vegetation cover was 430.11 ha, accounting for 19.12% of the total. Agricultural land covered 692.96 ha, which is 30.79% of the total. Residential areas and barren land covered 487.19 ha and 353.34 ha, respectively, representing 21.65% and 15.70% of the total area (Table 4). In 2023, the vegetation cover decreased due to land use and urbanisation trends, indicating potential environmental impacts. The development of these trends highlights the area's declining resilience. Continuous monitoring and sustainable land management practices are crucial to protect and maintain the unique ecosystem of the Kalmunai area. Therefore, the LULC in Kalmunai has changed between 2003, 2013, and 2023. The water body area, which was 22.96% of the total land in 2003, decreased to 9.02% in 2013 and increased to 12.74% in 2023. Similarly, vegetation cover, which was 36.06% of the total land in 2003, increased to 52.22% in 2013 and decreased to 19.12% in 2023. Expansion

TABLE 04: LULC Values 2003 - 2023 (ha).

Land Use Classes	**Land use (2003)**		**Land use (2013)**		**Land use (2023)**	
	Area (ha)	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**
Water Bodies	516.75	22.96	202.98	9.02	286.64	12.74
Vegetation Cover	811.53	36.06	1175.11	52.22	430.30	19.12
Agricultural Land	698.74	31.05	450.72	20.03	692.96	30.79
Built-up Area	76.30	3.39	167.18	7.43	487.19	21.65
Barren Land	147.11	6.54	254.43	11.31	353.34	15.70
Total	**2250.42**	**100**	**2250.42**	**100**	**2250.42**	**100**

of built-up areas, increased barren land, lack of awareness, and ignorance contribute to these changes. Agricultural land, which was 31.05% in 2003, decreased to 20.03% in 2013 and increased to 30.79% in 2023. Residential areas, which were 3.39% in 2003, increased to 7.43% in 2013 and further increased to 21.65% in 2023. Barren land, which was 6.54% in 2003, increased to 11.31% in 2013 and further increased to 15.70% in 2023.

The land use change dynamic index (k) was computed using Equation (1) to quantify the rate of change across different LULC categories during the study periods. The calculated values are presented in Table 5, where negative values represent a decline and positive values represent an increase in land cover. Results indicate that between 2003 and 2023, agricultural land, water bodies, and vegetation decreased annually by –230.11 ha, –381.23 ha, and –5.78 ha, respectively. Conversely, built-up areas and barren land expanded by 410.89 ha and 206.23 ha per year, respectively, over the same period. The spatial distribution and temporal trends of these LULC transitions are illustrated in Figure 2, Figure 3, and Table 4. To further examine the redistribution patterns, a land use change matrix was generated using ArcGIS 10.8.

4.2 Variation in Ecosystem Services Value (ESV)

Ecosystem service values (ESVs) were estimated for each LULC category using Equation (2), the value coefficients provided in Table 6, and the corresponding land areas shown in Figure 3. Since the coefficients are expressed per hectare, land area units were converted from km² to hectares before calculation. The results are summarised in Table 6, Table 7, Figure 4, and Figure 5.

As shown in Table 6 and Figure 3, the total ESV of the Kalmunai urban area was estimated at USD 933.32 million in 2003, USD 540.09 million in 2013, and USD 516.53 million in 2023. Water bodies, vegetation, and agricultural land were the major contributors, with water bodies providing the highest share of services. In contrast, built-up and barren land had no measurable contribution to ESV. Figure 5 illustrates the temporal trend, revealing a consistent decline in total ESV over the study period. While vegetation and agricultural land showed fluctuations, the sharpest reduction occurred between 2013 and 2023. Given the dominance of water bodies in overall valuation, the observed decline in total ESV largely mirrors the reduction in water-related ecosystem services.Table 6: ESV assessment of Kalmunai Urban Area 2003 – 2023.

TABLE 05: Change of LULC classes of Kalmunai Urban Area in 2003 - 2023

	Area (ha)		
Land Use Classes	**Land Use Changes (2003 - 2013)**	**Land Use Changes (2013 - 2023)**	**Land Use Changes (2003 - 2023)**
Water Bodies	-313.77	83.66	-230.11
Vegetation Cover	363.58	-744.80	-381.23
Agricultural Land	-248.01	242.23	-5.78
Built-up Area	90.88	320.01	410.89
Bare Land	107.33	98.91	206.23

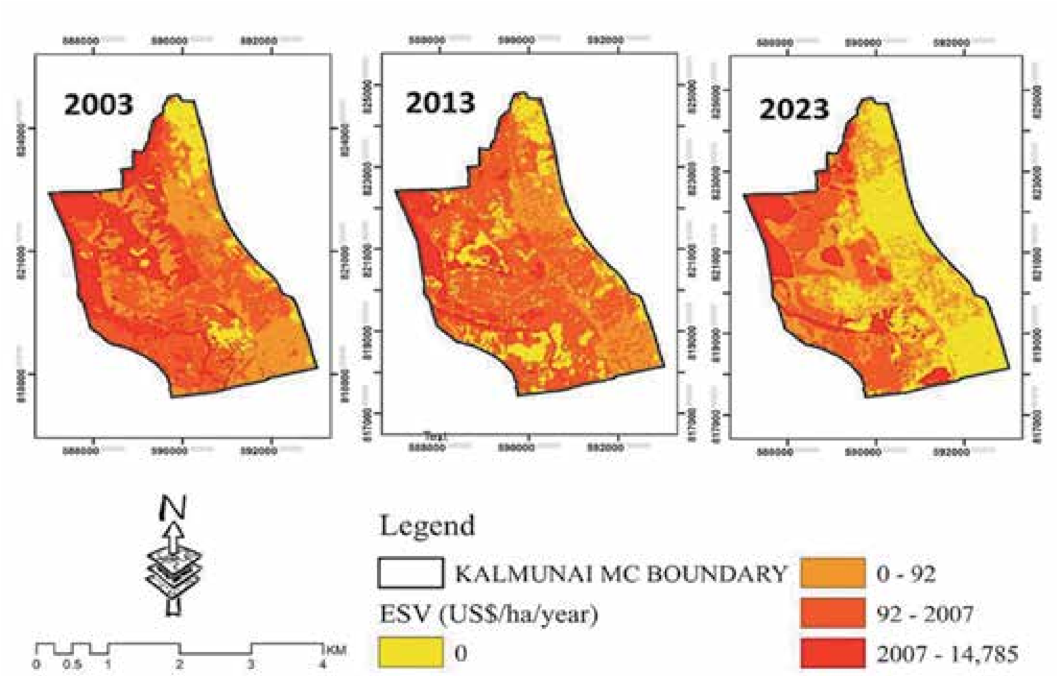

FIGURE 03: ESV map of Kalmunai Urban Area for the years 2003 - 2023

To analyse the annual variation in ecosystem service values (ESVs), the annual rate of change was calculated using Equation (3). Table 7 presents the results for different LULC categories from 2003 to 2023, where negative values represent declines. As illustrated in Figure 6, annual rates were reported only for agricultural land, vegetation cover, and water bodies, since built-up and barren areas do not contribute to ESV. The results show that ESVs derived from agricultural land, vegetation, and water bodies declined annually by 8.80% between 2003 and 2013, 19.06% between 2013 and 2023, and 27.87% over the entire 2003–2023 period.

TABLE 06: need the table heading

Land use classes	ES Coefficient (US$ ha-1/y)	Land use (2003)				Land use (2013)				Land use (2023)			
		Area (ha)	Estimated ESV		%	Area (ha)	Estimated ESV		%	Area (ha)	Estimated ESV		%
Water Bodies	14785	516.75	7640173	764.02	81.86	202.98	3001044.265	300.10	55.57	286.64	4237943.848	423.79	82.05
Vegetation Cover	2007	811.53	1628740.2	162.87	17.45	1175.11	2358435.796	235.84	43.67	430.30	863618.162	86.36	16.72
Agricultural Land	92	698.74	64283.7	6.43	0.69	450.72	41466.55242	4.15	0.77	692.96	63752.12575	6.38	1.23
Built-up Area	0	76.30	0	0.00	0.00	167.18	0	0.00	0.00	487.19	0	0.00	0.00
Barren Land	0	147.11	0	0.00	0.00	254.43	0	0.00	0.00	353.34	0	0.00	0.00
TOTAL	16884	2250.42		933.32	100	2250.42		540.09	100	2250.42		516.53	100

The spatial distribution of ESVs is illustrated in Figure 4 for 2003, 2013, and 2023. In 2003, high ESVs were distributed across most of the city, with the exception of the northern and parts of the southern area. Approximately 90.07% (20.27 km²) of the land recorded values exceeding 640,173.01 USD/ha/year, largely due to the presence of water bodies, forests, and vegetation. By 2013, ESVs had decreased in the northern, southern, central, and western parts of the city as forest and vegetation were converted to built-up land, reducing high-value areas to 81.27% (18.29 km²). A further decline occurred by 2023, particularly in the northern and eastern sections, due to the conversion of water bodies, wetlands, and vegetation into barren and built-up land. At this stage, only 62.21% (14.00 km²) of the area retained ESVs above 14,785 USD/ha/year.he spatial distribution of ESV for the Kalmunai urban area for 2003, 2013, and 2023 is illustrated in Figure 4. This figure indicates that in 2003, the value of ESV was high throughout the city, except for the northern part and a portion of the southern part. Approximately 90.07% (20.27 km²) of the total area had an ESV of > 640,173.01 USD/ha/year.

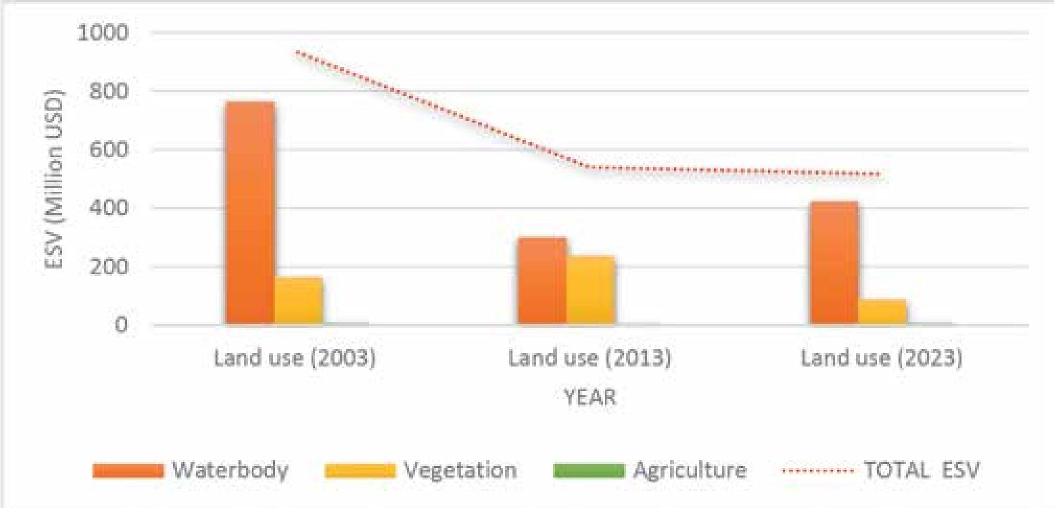

FIGURE 04: Distribution of ESV class limits in 2003, 2013 and 2023

As shown in Figure 5, the overall trend in Kalmunai demonstrates a persistent decline in ESVs from 2003 to 2023, driven primarily by LULC changes. Although reductions in vegetation and agricultural land contributed to the decline, the loss of water bodies was the most influential factor, accounting for –17.64% of the total –27.87% reduction in ESV. This is attributable to both their large spatial extent and high value coefficient. Built-up areas, which do not contribute to ESV, expanded significantly during this period, further intensifying the decline. Similar patterns have been documented in other urbanising regions, where the conversion of agricultural, vegetated, and aquatic areas into built-up land has led to substantial losses in ecosystem services.

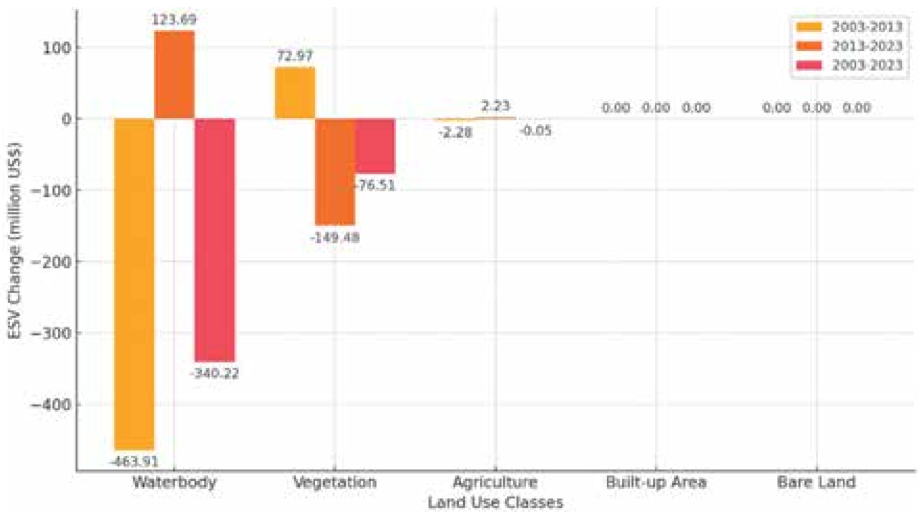

FIGURE 05: Ecosystem Service Value (ESV) Changes by Land Use Class

Based on LULC change, the Kalmunai urban ESV level was calculated for the period from 2003 to 2023. Our findings identify that LULC change is one of the crucial drivers of ecosystem services. However, due to differences in value coefficients and land area, the impacts on ESV of different LULC types vary in magnitude. The ESV trend in the Kalmunai urban area shows a declining change process due to LULC change during the study period. Although the decrease in vegetation cover, agricultural lands, and water bodies contributed to the reduction of ESV, the reduction in water bodies was the primary contributor due to its high-value coefficient and large area compared to the other two. Over the period from 2003 to 2023, the total estimated ESV for the Kalmunai urban area decreased by -27.87%. Among these, the decrease in water bodies accounted for a reduction of -17.64% in ESV. This is consistent with the findings of other studies in the literature mentioned above. Since built-up areas do not generate ecosystem service value, the growth of built-up areas over the past three decades has resulted in a decrease in total ESV. A similar scenario is evident in some other studies showing the growth of built-up areas through the conversion of agricultural land, vegetation cover, and water bodies.

4.2.2 Impact of LULC on ESV Valuation

The literature indicates that no prior research has specifically assessed the impact of LULC changes on urban ESVs in the Kalmunai area. This study demonstrates substantial changes in ESVs over the 2003–2023 period, driven primarily by LULC dynamics. Significant positive contributions were observed for ecosystem functions such as water regulation and water supply, which remain the major contributors to overall ESV. Over the entire study period, total ESVs have been influenced by changes in land use and land cover.

Earlier studies provide a comparative context for these findings. Costanza et al. (1997) examined the influence of LULC on ESVs in various biomes globally. Das and Das (2019) reported a total ESV loss of 0.26 US$ million ha−1 year−1 in a medium-sized city in West Bengal, Eastern India, between 1990 and 2017. Similarly, Li *et al*., (2019) found that the ESV of Karakalpakstan, Uzbekistan, declined by 31.08%, amounting to a total loss of 17.36 billion USD, largely due to reductions in water bodies. He *et al*., (2021) highlighted that the large-scale expansion of built-up areas and degradation of forest and agricultural lands in Guangzhou, China, between 1987 and 2017, caused a 1.16 billion yuan (20.61%) decrease in ESVs. Additionally, Zhang *et al*., (2017) noted that urban expansion in the Beijing-Tianjin-Hebei region, projected from 2013 to 2040, significantly influenced ESV losses, as modelled using the land use scenario dynamics-urban (LUSD-Urban) model.

Collectively, these studies underscore the crucial role of LULC changes in driving ESV variations, confirming the patterns observed in the Kalmunai urban area.

TABLE 07: Some previous studies on the decline of wetlands due to urbanisation

Research Site	Research Period	Impact of Wetland Decline on Ecosystem Services
Delhi, India	1998 – 2018	Nutrient cycling, climate regulation, raw materials, food production, erosion control
Kolkata Urban Integration (KUA), India	1990 – 2020	Soil formation, pollination, biological control
Shanghai, China	2000 – 2020	Hydrological services, biodiversity services
Benin, West Africa	2010 – 2020	Biological control, nutrient cycling, soil formation, water supply, waste treatment
Dhaka, Bangladesh	2015 – 2020	Water supply, waste treatment, disturbance regulation
Jakarta, Indonesia	1995 – 2014	Carbon sequestration, temperature regulation, runoff regulation

The decline of ecosystem services driven by urbanization has emerged as a critical global concern. Numerous studies across the world have highlighted that urban expansion often leads to reductions in regulating, supporting, and provisioning services (Table 7). In developing countries, rapid urban growth typically results in the conversion of water bodies, vegetation, and agricultural lands, which are key providers of ecosystem services. The loss of these natural resources consequently generates considerable environmental impacts. To mitigate these effects, sustainable urban planning and environmentally conscious regulations are essential to ensure the long-term preservation and functionality of ecosystem services.

5. Conclusion and Recommendations

This study examined the impact of land use and land cover (LULC) changes on ecosystem services in the Kalmunai urban area over the period from 2003 to 2023, using remote sensing and GIS techniques. The analysis highlights how changes in LULC directly influence the value and distribution of ecosystem services (ESV) over time. Findings indicate that built-up areas became the dominant LULC type by 2023, reflecting an 18.26% increase in urbanization from 2003. This expansion significantly affected the total ESV of the city.

Rapid urban growth has led to the reduction of vegetation cover, agricultural lands, water bodies, and forested areas, driven by population migration, industrialization, and socio-economic development. As a result, the total estimated ESV of Kalmunai declined by 27.87% (approximately USD 416.79 million), from USD 933.32 million in 2003 to USD 516.53 million in 2023. The most substantial decrease occurred between 2003 and 2013, with a reduction to USD 540.09 million (90.07% of the 2003 value). Among LULC types, water bodies contributed the most positively to ESV, while vegetation cover and agricultural lands were also key contributors. Urbanization and land use changes in Sri Lanka have led to the loss of green and blue spaces, reducing ecosystem services and increasing urban environmental pressures (Ruzaik, 2016; Sumaiya *et al.,* 2025). Integrating ecosystem service valuation with sustainable urban planning is essential to balance development and environmental conservation in cities like Kalmunai (Niyas & Ruzaik, 2022).

This research provides the first comprehensive assessment of the relationship between LULC change and urban ecosystem services in Kalmunai, emphasizing the importance of ESV in sustainable land use planning. The degradation of natural cover due to urban expansion has direct implications for human well-being, such as exacerbating the urban heat island effect and increasing health risks, which carry socio-economic costs. Understanding how ecosystem services respond to LULC changes is essential for informed decision-making aimed at sustainable urban development. The study highlights that rapid urbanization leads to ecosystem degradation, which affects climate regulation, water supply, and other critical ecosystem services, impacting human well-being. Previous research has also emphasized the utility of remote sensing and GIS approaches for monitoring urban green space and ecosystem services (Zahir *et al.,* 2024; Nuskiya, 2021). Furthermore, urban growth contributes to phenomena such as the urban heat island effect, which has socio-economic and health consequences (Nuskiya & Perera, 2025).

To mitigate these impacts, sustainable urban planning and green infrastructure development are essential. Recommendations include promoting rooftop gardening, forest protection, recycling initiatives, and green infrastructure to maintain ecosystem services. Monitoring LULC changes using remote sensing and ESV valuation can guide timely policy decisions (Nuskiya & Perera, 2024). Community engagement and awareness programs are also critical to ensure that residents understand the importance of ecosystem services in balancing urban development and environmental protection. The study underscores the utility of ESV assessment as a decision-support tool for policymakers, urban planners, and environmental managers. To mitigate the negative impacts of LULC changes, several recommendations are proposed:

- Promote sustainable urban planning and the development of green infrastructure to offset the effects of urban expansion.
- Encourage environmentally friendly practices, including rooftop gardens, forest conservation, waste reduction, and the development of urban green spaces.
- Monitor and regulate land reclamation activities, particularly in coastal regions, to prevent further degradation of critical ecosystems.
- Utilize remote sensing and GIS-based ESV evaluations to track changes in land use and provide timely management interventions.
- Increase community awareness and engagement regarding the importance of ecosystem services in balancing socio-economic development and environmental protection.
- Integrate environmental planning with local and central government policies to safeguard urban blue and green spaces with high ecosystem service values.
- Consider anthropogenic activities carefully, as some may have irreversible impacts on ecosystem services, and implement fair land use policies to maintain ecological balance.

Overall, this study highlights the urgent need for sustainable urban management strategies in Kalmunai to ensure the protection and enhancement of ecosystem services while accommodating urban growth.

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