Ecosystem Service Value of Urban Green Spaces in Addis Ababa, Ethiopia

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Abstract

Ecosystems directly or indirectly provide materials and energies to human, as well as numerous ecosystem services, such as air purification and climate adjustment. Urban development has greatly affected the ecosystem, but green space in urban area still has a certain ecological service function, which plays a role in alleviating urban air pollution, water shortage, urban heat island and other problems. In recent years, in the urbanization of Addis Ababa, the capital of Ethiopia, more and more attention has been paid to the construction of urban green space, but there are very few reports on the evaluation of ecological service value for urban green space. To this end, this study explores the potential effects of ecosystem services-oriented urban green space planning and design in Addis Ababa, Ethiopia, and quantifies the economic value of ecosystem services provided by urban green space, in order to provide data and support for the ongoing eco-friendly urbanization in Addis Ababa, Ethiopia.

Through satellite image interpretation, literature analysis and field investigation, Landsat data and measurable indicators were used to classify land cover, analyze land use change in Addis Ababa from 2013 to 2023, and assess landscape dynamics and ecosystem service value within urban green Spaces. Driven by factors such as population growth, infrastructure needs and economic activity, resulting in rapid urban development, a reduction in crop and grassland area, and an increase in built-up and bare land area, the study results show that the green area of Addis Ababa has declined from 44.8 percent in 2013 to 15 percent in 2023. The annual monetary value of ecosystem services has declined significantly, from $146.3 million in 2013 to $97.6 million in 2023, below the criteria recommended by the World Health Organization, with the potential for significant loss of ecosystem service functions in the short term. Air filtering value decreased from 145,685.16 USD in 2013 to 34,446.12 USD in 2023, The microclimate regulation value has declined from $588,051.00 in 2013 to $420,132.00 in 2023. The noise reduction value has declined from $1,460,898.00 in 2013 to $1,043,736.00 in 2023. Rainwater drainage regulating value was 685,882.00 USD in 2013 but decreased to 497,511.00 USD in 2023. The sewage treatment value has declined from $2,267,395.00 in 2013 to $1,277,846.00 in 2023. The recreation and cultural value has also declined from $966,914.00 in 2013 to $565,244.00 in 2023. Due to a decrease in tourism, a loss of cultural heritage, and a decline in the quality of life for residents. It is important to take steps to conserve and restore Addis Ababa's green spaces to protect the city's natural and cultural resources and improve the quality of life for its residents.

Therefore, the study emphasizes the need for immediate action to prevent further loss of ecosystem services, and calls for concerted efforts by all parties, including government departments, relevant stakeholders and environmental organizations, to conserve biodiversity through landscape restoration and management, improve air and water quality, and promote recreational activities. In addition, city managers should prioritize maintaining adequate green space, balancing regulation and recreation services, listening to citizens, improving green space management systems, and using high-resolution data for accurate land cover mapping and ecosystem service valuation. Policymakers should incorporate the value of urban ecosystem services into green space planning and development to maximize the benefits of urban ecosystems and build resilient and ecologically healthy cities.

Keywords: Urban Green Spaces, Monetary Value, Landsat data, ecological conservation

1.Introduction

Urban green spaces play a crucial role in meeting ecological conservation and environmental protection needs[1]. Green spaces act as the lungs of urban areas, preserving life within the built-up environmen. UGS offers essential ecosystem services such as enhancing air quality, removing pollution and reducing noise, conserving water and soil, regulating microclimates, and mitigating urban heat islands[2]-[3].

However, these services are often undervalued and overlooked in economic decision-making. This is particularly true in rapidly growing cities like Addis Ababa, where the demand for urban green space is increasing, and the pressure on the natural environment is mounting. The study aimed to assess the land use land cover changes in Addis Ababa, Ethiopia in three different epochs based on remotely sensed data gained from satellite images, and estimate the economic values of UGS to highlight the conservation and restoration of ecosystem values of urban green spaces.

Addis Ababa city is experiencing rapid population growth with an increase in the density of built spaces, housing expansion, space development, and restructuring of industrial areas. Greater population density in urban areas increases demand for green areas but cities are facing a diminishing of green spaces[4].

Addis Ababa green space has been converted to other land use types, pulling the suggested UN health organization standards of green spaces per capita far lower than 20 square meter[5]. Unplanned urban growth, increased urbanization, and development have placed urban green spaces under extreme pressure.

Valuing ecosystem services can help to determine whether a policy intervention that alters an ecosystem condition delivers net benefits to society; providing evidence on which to base decisions on ‘value for money’ and prioritizing funding; and choosing between competing uses. The case for ecosystem service values of urban green spaces is not properly identified with adequate information because of a lack of comprehensive studies on the valuation of the multi-functions and services of UGSs. Thus, studies on the valuation of the multi-functions and services of UGS are necessary to be used as a base for decisions and policy development on environmental issues[6, 7].

However, research has not yet been undertaken in Ethiopia in general and in the capital city Addis Ababa in particular. Therefore, related and specific studies are required in terms of their context. The goal of the current study is to fill this knowledge gap. The study intends to estimate the ecosystem service values of urban green spaces of Addis Ababa by using multi-temporal satellite image analysis underpinned by field surveys. The result may help decision makers to compare the environmental and developmental values and the allocation of the budget for the city UGS enhancement and management programs.

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This is mainly because lack of knowledge on the multidimensional values of UGS for society including the environmental policy makers and hence absence of strong national UGS policies or strategies are the other fundamental reasons that aggravate the depreciation of these resources. Unless restoration, enhancement, conservation, and management mechanisms for these ecosystems are implemented, the above multiple UGS benefits will be lost as a result.

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1.1. Research Objectives

The primary goal of this investigation is to determine the monetary worth of the ecosystem services offered by urban green spaces in Addis Ababa, Ethiopia. Additionally, the study will analyze the alterations in the city's landscape through the utilization of a fragment analysis technique. The assessment will also concentrate on the incorporation of ecosystem service values into the planning and administration of urban green spaces within the city. Finally, valuable suggestions will be put forth to guarantee the long-term viability and improvement of the ecosystem service value of urban green spaces while maintaining cost-effectiveness.

1.2 Significance of the Study

The value of ecosystem services provided by urban green spaces holds significant theoretical implications for understanding their role in sustainable urban development. Quantifying the diverse benefits of green spaces could contribute to a comprehensive understanding of ecological, social, and economic urban sustainability. This information can inform policy and management decisions related to urban planning, land use, and environmental conservation. It can also shed light on the factors influencing the provision and use of urban green spaces, guiding future research on urban ecology and environmental governance.

The result of the study provides a framework for understanding the economic value of ecosystem services, enriching economic theory by applying economic principles to natural resources and environmental conservation. It also aids in better resource allocation and decision-making by providing insights into the trade-offs involved in different land use options, thus helping policymakers make informed decisions about conservation and development.

The practical values of estimating ecosystem service values of urban green spaces Firstly, the study can provide a basis for the development of strategies to enhance the provision and maintenance of urban green spaces. This can include identifying areas where additional green spaces are needed, as well as determining the types of green spaces that are most beneficial for the local community. Secondly, the study can assist policymakers in making informed decisions about the allocation of resources for urban planning and management.

This can include decisions about land use, zoning, and the provision of public services. Thirdly, the study can inform the development of educational programs and outreach initiatives aimed at raising awareness about the importance of urban green spaces and their role in promoting sustainable urban development. Finally, the study can provide a framework for evaluating the effectiveness of policies and management practices.

2.Materials and Methods

2.1 Description of the Study Area

Addis Ababa city, which is the capital of Ethiopia located on the coordinate between 9°0′19.4436′′ N and 38°45′48.9996′′ E, at elevations ranging from 2015 to 3152 meters above sea level. The total population of Addis Ababa in 2023 was 5,228,000, at 4.43% increase from 2021. The city is home to an estimated 5.2 million inhabitants and constitutes approximately 20 percent of Ethiopia's urban population [38]. It was established as a nation seat in 1886. It is the major political and economic center of the country, as well as the seat of the African Union (AU). It is divided into eleven sub-cities and 121 districts, called Woreda. Land use and land cover changes increased the mean land surface temperature in Addis Ababa city, Ethiopia, by 8.3 °C over the last three decades. The extremely high temperatures in urban areas impose dangerous heat-related health issues on urban citizens.

The spatial distribution of the urban green shows that seven major and six medium rivers receive water flow from 75 small tributaries. The existing forest area is mostly found in the northern part, (which is also the highest altitudinal range), northwest, southwest, northeast, and west part of the city or known by the local names of Entoto, Yeka, Ankorcha, and Gullele. The major sites of which are mainly Koye, Wedesso, Idoro, Feche, Akakibeseka, Abeora, Dongora, Harbu, Jemo, Bulbula, Bole weregenu, Diremigra Mekanissa, Lafto & peacok.

There are also eleven formal functional parks with total area coverage of 110 hectares; these are Ambassador, Hamle 19, Behere Tsige, Peacock, Yeka, Ferensay, Sheger, Anbassa gibi, Gola Michaele and Kolfe Parks.

Altitudinal zones of Addis Ababa range from 2054 m to 3023-meter asl, situated in the foothills of the Entoto Mountains, spread across many wooded hillsides and gullies, cut through with fast-flowing streams. At present, the city is divided into 11 sub-cities and 116 Woreda (administrative districts), with the total population of Addis Ababa is 3,775,348, which is about 60% of the total urban population in Ethiopia.

The rainfall and the temperature conditions of these areas is described based on the data collected by the Ethiopian Meteorological Service Agency (EMSA) from Entoto station. According to the data from EMSA, the result of the analysis showed that the mean annual temperature of the study area is about 13.4 degree celucious. The range of mean monthly minimum and maximum temperatures of the study area is 7.5 degree celucious and 20.7 degree celucious in December and February, respectively.

The mean annual minimum and maximum temperature is 8.4 degree celucious and 18.4 degree celucious respectively. The hottest month in 2023 was February with a maximum temperature of 20.7 degree celucious, followed by March (20.2 degree celucious) and May (20 degree celucious) and the coldest month in the same year was December with a minimum temperature of 7.5Co. The mean annual rainfall of these areas is 1215.4 mm per year and is bimodal type. The mean monthly minimum and maximum rainfall is 16.6 mm (January) and 278 mm (August), respectively. The short rainy season extends from March to May and the long rainy season starts from July and extends to September, but unexpected showers may occur in all months of the year he city vegetation is mostly covered by exotic tree species like; Eucalyptus globules, Gravilla robusta, Phonix reclinata, Casuarina, Omedla, and Jacaranda, but the land closer to the river banks and inaccessible areas in the upper catchment are covered by more than 250 trees, shrubs, herbs, climbers, ferns and other plant species. It is depicted in the Fig. 1 below

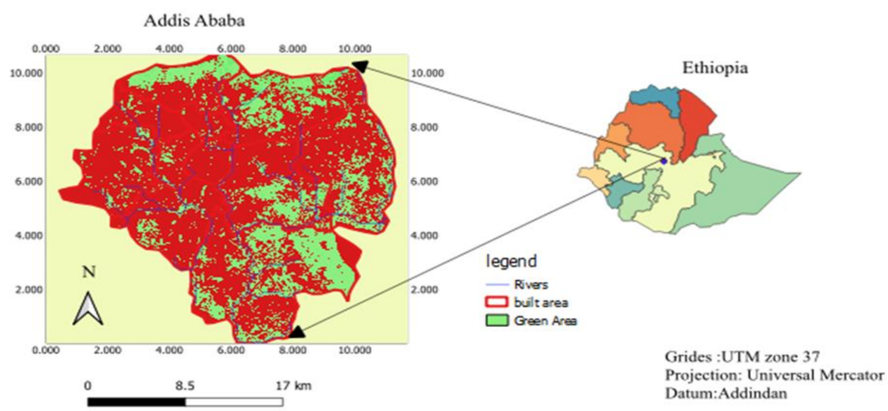

Figure 2.1 Location of Addis Ababa City and Its Topographic Characteristics

2.2 Data Set Description

The data sources for this research were primarily collected from Landsat images. Secondary data was reviewed from the National Meteorology Agency of Ethiopia, the Central Statistical Agency, and the Addis Ababa Environmental Protection Authority. The population census data will be collected from the Central Statistical Agency.

As the source of thematic data, especially data on land cover characteristics and surface elevation remote sensing is the practice of gathering information about an object, event, or area using a device that does not make physical contact with the target. This data is typically captured in the form of images, which can then be analyzed to extract temporal details and identify surface features[8].

There are more than a thousand active satellites orbiting the Earth and quite a number of satellites with their sensors usually acquire images of Earth's surface continually at different spatial resolutions, ranging from sub-meter to kilometers, and temporal resolutions ranging from 30 minutes to weeks or months[9].

A geographic information system [10] is a computer-based tool that manages geospatial data, solves spatial problems and supports the collection, storage, transformation, analysis, retrieval, and display of data in an effective manner. It consists of hardware, software, and procedures to achieve these functions[11]. GIS and remote sensing tools are utilized collaboratively to determine the location within the catchment area and to analyze the spatial connections between various physical characteristics of the catchment, including land cover, water bodies, and vegetation cover[11].

The remotely sensed data, Landsat 8 OLI (Operational Land Imager), by three different times 2013, 2019, and 2023. All the images were collected with archive https://ers.cr.usgs.gov/. The acquisition dates of the satellite images were carried out in February 2023 because, this time in Addis Ababa, a dry season clear sky and we can properly discriminate the required information about the vegetation and distinguish it from other farmland and grassland. A semi-automatic Classification PlUGSn (CSP) in QGIS version 3.28 was used for further image processing and classification. For LULC classification and analysis all the reflective bands were used.

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2.3.1 Remote sensing

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2.4 Methods

Scientists have developed toolsets to measure values such as a sense of place and traditional ecological knowledge. In an urban context, the integrated assessment method is strongly recommended to encompass the total complexity of ecosystem service values of urban green spaces[15]. Different values and perceptions should be considered to make well-informed decisions in the management of urban ecosystem services. [16] The choice of which specific values should be assessed and articulated in the processes of urban planning depends on the characteristics of the urban ecosystem services that are being valued in the institutional, sociocultural contexts in which decisions are taken place.

Hedonic pricing methods are used to determine the value of cultural UESs, such as the esthetic of green areas. A major difficulty in the application of hedonic methods is the limitation to the assessment of use values, such as those provided by cultural services and some regulating services, depending on the scale. Hedonic methods require large data sets and complex methods of data analysis. Another monetary valuation approach is contingent valuation[17]. To obtain socio-cultural values, methods are needed that often demand the use of holistic approaches that may include qualitative measures, constructed scales, and narration In some cases, translating these values into quantitative metrics is difficult or senseless.

However, in practice, their focus tends to be too narrow to encompass the total complexity of socio-ecological systems The integrated assessment of monetary values in an urban context is strongly needed.[18]. Researchers are developing and validating Ecosystem Services indicators at various scales, allowing for a comprehensive assessment of Urban Ecosystem Services conditions, trends, and changes.,[19]] Understanding the factors influencing Urban Ecosystem Services requires the use of interconnected indicators that monitor the interaction between social-ecological dynamics and ecosystem pressures.

nother aspect of the valuation process was the Contingent Valuation Method based on the amount that households were willing to pay for the restoration of the rivers. Furthermore, the study also assessed the recreational value of Parks, a significant urban green space in Addis Ababa. By employing the Travel Cost Method, the researchers estimated the value that residents derived from visiting the park. This emphasizes the importance of preserving and enhancing the Park as a recreational asset, promoting the well-being and quality of life for the city's inhabitants. According to this scheme, the total value of ecosystem service is equal to the products of the areas covered by the corresponding service and the estimated value in US dollars

3.RESULTS

3.1 Spatial distribution of UGS in Addis Ababa

Agricultural land occupied 16,219 hectares (30.0%), while Natural Vegetation covered 2,637 hectares (4.88%). Wetlands spanned 2,885 hectares (5.34%), and open land accounted for 1,373 hectares (2.54%) in 2013. By 2019, the distribution had changed, with agricultural land decreasing to 13,860 hectares (25.63%) and 11,391 hectares (21.07%) by 2023. Natural vegetation shrank to 1,955 hectares (3.62%) in 2019 and to 1,884 hectares (3.48%) in 2023. Wetlands decreased to 1,647 hectares (3.05%) and to 1,513 hectares (2.80%) in 2023. Open land was reduced to 1,599 hectares (2.96%) by 2019 and to 1,239 hectares (2.29%) by 2023.

Table 3 Land covers class area coverage and percentage

Land cover class type	Percentage of Land Cover Area in Three Epochs					
	2013	%	2019	%	2023	%
Non-green Space	30,953	57.25	35006	64.75	38040	70.36
Agriculture	16,219	30.00	13860	25.63	11391	21.07
N. Vegetation	2,637	4.88	1955	3.62	1884	3.48
Wet Land	2,885	5.34	1647	3.05	1513	2.80
Open land	1,373	2.54	1599	2.96	1239	2.29
Green Space	23,114	42.75	19061	35.25	16027	29.64
	54,067	100	54067	100.00	54067	100.00

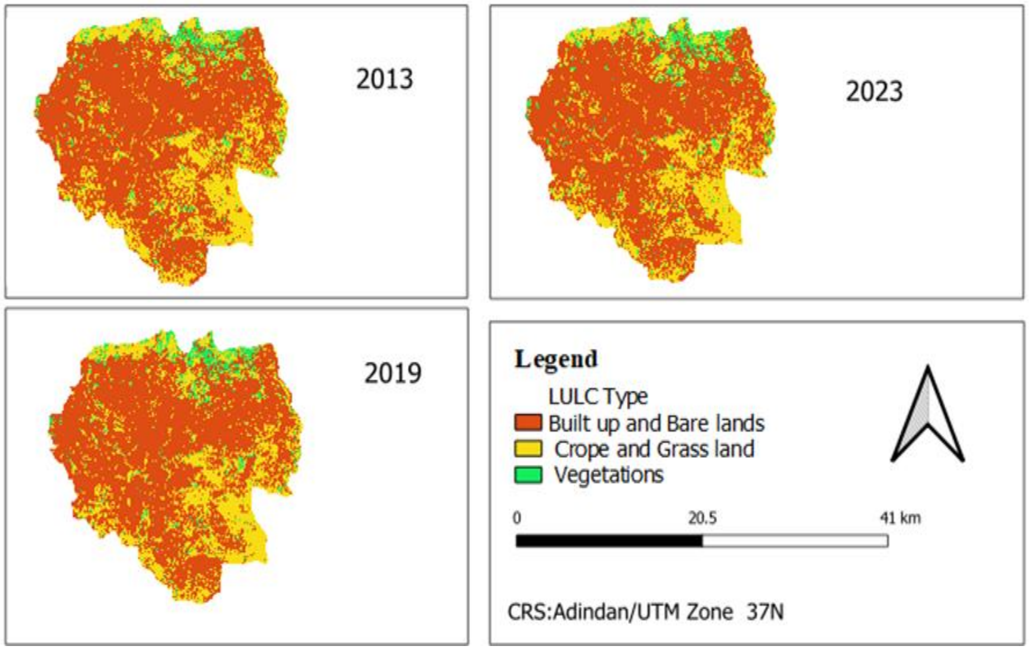

Figure 2.2 Classified Land Use Land Cover Type of Addis Ababa

3.2 Urban Spatial Pattern of Addis Ababa

Land-use/cover dynamics are a major component of land degradation, which affects overall ecosystem services. This is a key factor behind accelerated soil loss, increased sediment yields, and reduced protection against erosion[20]. In the study area, the change in land cover is affecting the landscape's dominance and composition. As the patch area is changing, the corresponding ecosystem services and their estimated value are affected as well.

The most prominent landscape change in Addis Ababa from 2013 to 2023 was the conversion of cropland to other land-use types; the process of land-cover change was more intense from 2013 to 2019 than from 2019 to 2023 The high agricultural intensity in cropland areas impacted class connectivity compared to other patch mosaics in the study area. The study found that the decrease in UGS class areas affected the estimated value of ecosystem services.

At the landscape level, the NP of built-up and bare land has decreased from 6448 in 2013 to 5216 patches in 2023. It appears that Addis Ababa City experienced intensive assimilation after 2013 due to the dominance of built-up pockets in the urban fringe and peripheral areas. PD remain constant from 2013 to 2023 with values of 3.17 patches per 100 hectares. A high LPI value is found for agriculture decreasing from 67.8 % in 2013 to 46.31 % in 2023). Regarding landscape configuration, the AI was more than 80% at the landscape level with an incremental decrease from 68.2% in 2013 and 66.4% in 2023.

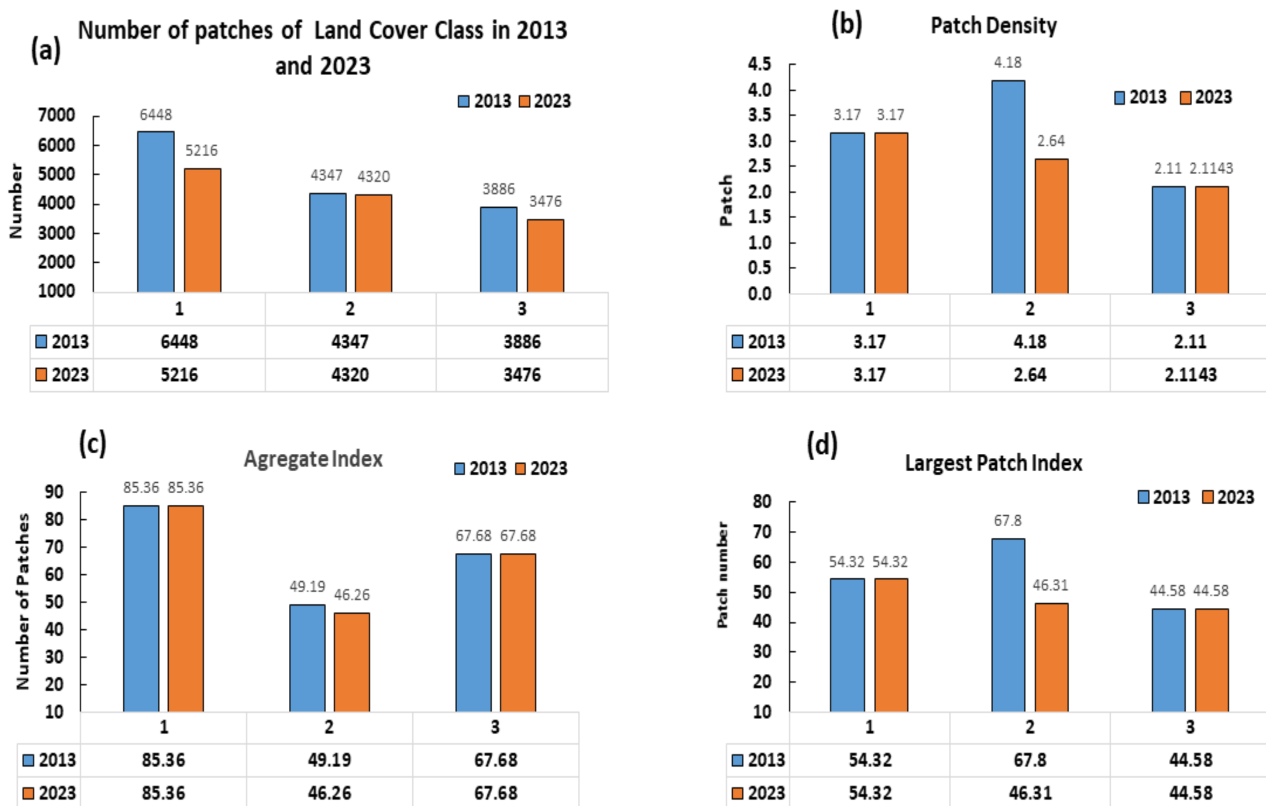

Figure 2.3 Landscape composition indices from 2013 to 2023

The main challenges lie in the vast variation of landscape composition, scale dependency, and in the spatial distribution of ecosystem provisioning land cover types and benefitting human population. Supporting services e.g. considered less location dependent as their services are not directly enjoyed by humans in the vicinity, i.e. pollination of crops can occur anywhere, while the crops can be consumed anywhere else on the globe.

3.3 Variation of biota mass in urban green spaces

Urban green spaces (UGS) that comprise forests, pastures, residential yards, parks, grassy lawns, and engineered green roofs and rain gardens provide multiple ecosystem services to humans and the environment[21], [22]. The ecosystem services provided by these UGS, including environmental services (e.g., reducing elevated urban heat, pollution, flood mitigation, and offsetting greenhouse gas emissions), ecological services (e.g., providing habitats for urban wildlife and biodiversity conservation), and social and human health benefits[23].

The results of the study on land cover dynamics in Addis Ababa from 2013 to 2023 reveal significant changes in ecosystem service values (ESV) for different land cover types. The data shows a concerning trend of decreasing ESV for urban ecosystem services (UGS) in Addis Ababa. In 2013, the estimated value of UGS was 146.3 million USD per year, but this value decreased to 115 million USD in 2019 and further declined to 97.6 million USD per year in 2023. This downward trend in UGS values indicates potential degradation or loss of urban ecosystem services over the years, which could have negative impacts on the city's environment and residents.

On the other hand, the expansion of built-up areas in Addis Ababa is evident from the data. Built-up areas increased from 30,953 hectares in 2013 with an ESV of 206.2 million USD to 35,006 hectares in 2019 with an ESV of 233.2 million USD and further grew to 38,040 hectares with an ESV of 253.4 million USD by 2023. This expansion of built-up areas signifies urban development and infrastructure growth in Addis Ababa, which may have contributed to the decline in UGS values due to land transformation and habitat loss. The relentless expansion of built-up areas encroaches upon green spaces. High population density exacerbates the scarcity of UGS. Weak enforcement of development plans and policies hinders UGS preservation. Lack of Priority: Insufficient emphasis on UGS development contributes to its degradation.

3.4Temporal change of UGS in Addis Ababa (2013-2023)

Addis Ababa city's residents face inadequate access to recreational UGS. Between 2013 and 2023, the land use for UGS in Addis Ababa decreased by 13..11%. Urban agriculture saw a significant decline of 9.9%, followed by urban forests at 1.4%. The per capita park area stands at a mere 0.37 square meters, far below the Ethiopian UGS standards of 15 square meters. Shockingly, over 90% of the population lacks access to existing parks within the minimum walking distance thresholds. In 2013, the land cover of Addis Ababa was composed of built-up and bare lands or non-green spaces covering 30,953 hectares or 57.25 percent of the total area, and green spaces covering 23,114 hectares or 42.75 percent of the total area in 2013. The detail revealed in Table 3 below

Table 3.2 Comparing Area coverage of Green and non-green space in Three Eparches

Land Cover Type	land Area coverage and percentage in three Epochs					
	2013		2019		2023	
	Area	%	Area	%	Area	%
Green Space	23,114	42.75	19,061	35.25	16,027	29.64
Non-Green Space	30,953	57.25	35,006	64.75	38,040	70.36
Total	54,066.95	100	54,066.95	100	54,066.95	100

3.5 **Spatial pattern and influence factor analysis of ESV of Urban Green Spaces**

In this study, the services and benefits gained from ecosystems were first inventoried by referring to the ecosystem services. Classified land cover classes were converted into ecosystems and each of the predefined ecosystems was assigned to its perceived services and benefits. The valuation of ES consisted of estimating the approximate monetary values in US dollars using the updated valuation scheme[24].

, six economic services (air filtering, microclimate regulation, noise reduction, rainwater drainage, sewage treatment, and cultural services are calculated based on field data and standard values per hectare per year in USD. The detail is depicted in the table below.

Table 3.3 Estimated Values of Ecosystem Service Values of Addis Ababa 2013 to 2023

Ecosystem service Functions	Forest	Grassland	Water bodies	Total Value 2013	Total Value 2023
Gas or Air Quality Regulation	13.68	7		45,685.16	34,446.12
Micro Climate regulation	223			588,051.00	420,132.00
Noise Reduction	554			1,460,898.00	1,043,736.00
Erosion control/rainwater drainage	245	29		685,882.00	497,511.00
Sewage Treatment	87	87	665	2,267,395.00	1,277,846.00
Recreation & Culture	114	2	230	966,914.00	565,244.00

Local conservative coefcients ($ ha−1 year−1), adopted from Kindu et al. (2016)

The data on ecosystem service functions for Forest, Grassland, and Water bodies reveals significant contributions to various aspects of the environment. In terms of Gas or Air Quality Regulation, Forests provide a value of 13.68, Grasslands contribute 7, and Water bodies offer 45,685.16 units. The total value in 2013 for this service was 34,446.12 units. Micro Climate Regulation is primarily driven by Forests with a value of 223, while Water bodies significantly contribute 588,051.00 units. Noise Reduction services are substantial, with Forests providing 554 units and Water bodies contributing 1,460,898.00 units. Erosion Control and Rainwater Drainage services see Forests with a value of 245 and Grasslands with 29 units in 2013. Sewage Treatment is a vital service, with Forests and Grasslands each providing 87 units, while Water bodies contribute 665 units. Lastly, Recreation & Culture services are valued at 114 for Forests, 2 for Grasslands, and 230 for Water bodies in 2013. The total values for these services in 2023 are not available for comparison

3.5.1 Quantitative assessment of air filtering value of urban green space

Air pollution ecosystem health, crops, climate, visibility, and man-made materials. Health effects related to air pollution include impacts on pulmonary, cardiac, vascular, and neurological systems[25]. The reduction is primarily caused by vegetation filtering pollution and particulates from the air[26]. The ability of trees to intercept pollution varies between species, throughout the age of the tree, and with the planting design[27]. Trees can lower air temperatures, potentially decreasing emissions from human activities[28]. Trees release different amounts of volatile organic compounds[29].[30]. Sulfide and nitride are present in the air, at the intersection of absorption range and plant resistance[31, 32].

The estimated ecosystem service value associated with air quality promotion provided by urban green spaces decreased from 145,685.16 USD in 2013 to 34,446.12 USD in 2023, indicating a substantial decline. This decline in the air quality promotion value of urban green spaces can be attributed to various factors such as urbanization, pollution, climate change, and land use changes. As cities grow and expand, green spaces may be lost or degraded, reducing their ability to mitigate air pollution and improve air quality. Additionally, increased pollution levels and changing environmental conditions can also impact the effectiveness of urban green spaces in providing these ecosystem services.

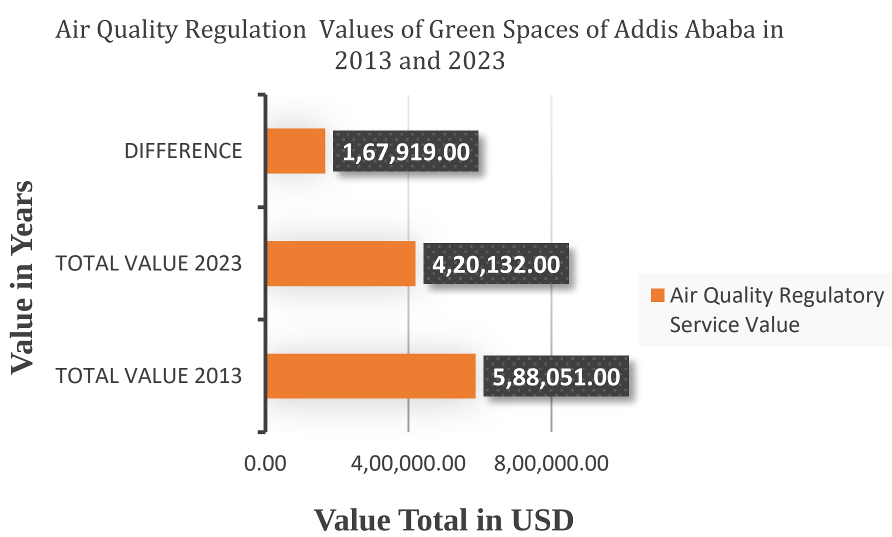

Figure 3.1 Air Quality Regulation Values of Green Spaces of Addis Ababa in 2013 and 2023

3.5.2 Quantitative assessment on micro-climate regulation of UGS

City trees can lower the summer temperatures of the city markedly [37]. One large tree can transpire 450 liters of water per day and this consumes 1000 MJ of heat energy to drive the evaporation process. City trees can also lower the summer temperatures of the city markedly[38]. It is widely established that UGS could reduce local UHI levels while UGI-associated vegetation has been shown to increase evapotranspiration and shading and reduce radiation, absorption, and the amount of heat stored within urban surfaces[33, 34].

In the study, a replacement cost method (RCM) was deployed to evaluate the climate regulation benefit provided by UGS within the target area. The RCM looks at the cost of replacing a damaged or lost asset and uses this cost as a partial proxy or measure of its value [35], [36] The decline in the microclimate regulation value of Addis Ababa's forests is concerning, as it could lead to several negative consequences, such as increased air pollution, higher temperatures, and more frequent heat waves. It is important to take steps to conserve and restore Addis Ababa's forests to protect the city's microclimate and improve the quality of life for its residents.This indicates a decline in the climate regulation benefits provided by urban green spaces in the city during this time frame.

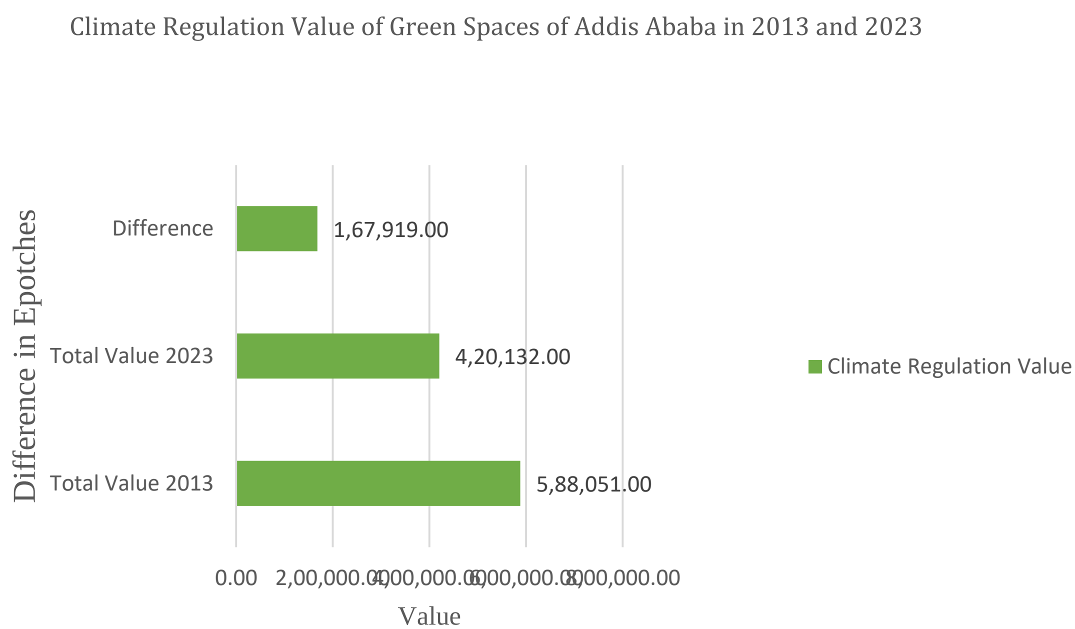

Figure 3.2 Climate Regulation Value of Green Spaces of Addis Ababa in 2013 and 2023

3.5.3 Quantitative assessment of Noise reduction

Sounds propagate long distances on water[37]. The distance to the source of the noise is one major factor when doubling the distance decreases the equivalent level by 3 dB. The other key factor is the character of the ground for instance a soft lawn, rather than a concrete pavement, decreases the level by another 3 dB.[38].

The existing literature addresses the function of vegetation in the absorption and insulation of noise, while urban greening has a certain commonality when it comes to noise attenuation[39]. The value of the noise reduction provided by UGS is directly related to the performance of any given forest on its own[50, 85]. We thus used the afforestation cost method to evaluate the ES value of noise reduction. To be clear, the afforestation cost method refers to the construction cost of the forest area, which can reduce an equal amount of noise enough to replace the values of other (more costly) means of urban noise reduction[40].

Currently, the afforestation method is a widely used approach to estimate the value of forest ecosystems at the axis of noise reduction is based on a 15% afforestation cost[40,42]. Afforestation cost is determined by the average afforestation cost multiplied by the volume of mature forest per unit area, and total forest area. According to the Environment Protection Bureau of Addis Ababa, the average afforestation cost is approximately USD Cost of afforestation per USD 19,045.57/hectare. The estimated noise reduction value of Addis Ababa was 1,460,898 in 2013 and it reached 1,043,736 USD in 2023.

Forests play a crucial role in reducing noise pollution. They act as sound barriers, absorbing and scattering sound waves. Forests also help to reduce wind speeds, which can further reduce noise levels. The noise reduction value of Addis Ababa City green spaces derived from forests has declined from $1,460,898.00 in 2013 to $1,043,736.00 in 2023. This decline is likely due to a decrease in the area of forest cover in Addis Ababa.

The decline in the noise reduction value of Addis Ababa City green spaces is concerning, as it could lead to a number of negative consequences, such as increased noise pollution, sleep disturbance, and stress. It is important to take steps to conserve and restore Addis Ababa's forests in order to protect the city's noise environment and improve the quality of life for its residents.

3.5.4 Quantitative assessment of rainwater drainage

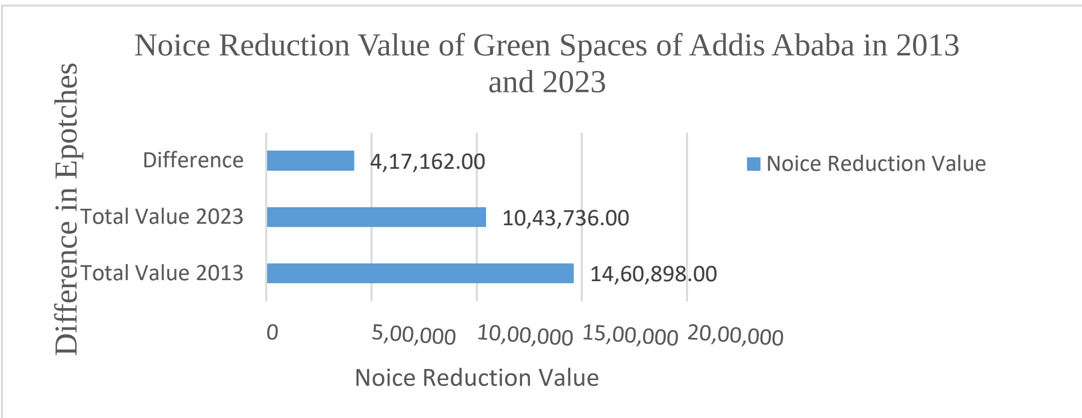

Figure 3.3 Noice Reduction Value of Green Spaces of Addis Ababa in 2013 and 2023

Rainwater drainage ecosystem services refer to the natural processes and functions Manage and regulate the flow of rainwater within ecosystems, reducing the risk of flooding, erosion, and water pollution. 15% of the rainwater runs off the ground, with the rest evaporating or infiltrating the ground. In vegetation-free cities, about 60% of the rainwater is instead led off through storm-water drains(1997, D. B. Botkin`, a.C.E.`, #122).

Existing research has addressed UGS's contribution to water management efforts through runoff prevention and stormwater recapture to facilitate flooding where rain and natural earth filtration occur—both of which also benefit groundwater supply and water reuse for activities such as landscaping[41]. To achieve this, the cost of the flood control project per year was annualized via the amortization of the capital cost to arrive at an annual value for water control and conservation benefits. Thus, SPM is also an implicit form of market price, defined as the marginal price that society invests on the non-marketed ES through the construction of these projects[42, 43]. Scholars have already addressed its applicability for assessing the value of water control and storage[44, 45].

We thus performed an SPM analysis to assess the value of water control and conservation per the ES provided by UGS. Per the Ethiopian Water and Energy Bureau, the average annual precipitation in the flood season in Addis Ababa is 547.5 mm. The national flood control project construction investment is estimated to cost USD 0.67 per 1 m3 of storage capacity[46]. The areas of wetland, water, and forest are regarded as the primary UGS for water control.

Forests and wetlands play a crucial role in regulating rainwater drainage. Forests help to slow down the flow of rainwater, which reduces the risk of flooding. Wetlands act as natural sponges, absorbing and storing rainwater. The decline in the rainwater drainage regulation value of Addis Ababa's green spaces is concerning, as it could lead to several negative consequences, such as increased flooding, water pollution, and damage to infrastructure. It is important to take steps to conserve and restore Addis Ababa's green spaces to protect the city's water resources and improve the quality of life for its residents. The data provided indicates a decrease in the rainwater drainage value of the study

3.5.5 Quantitative assessment of Sewage treatment

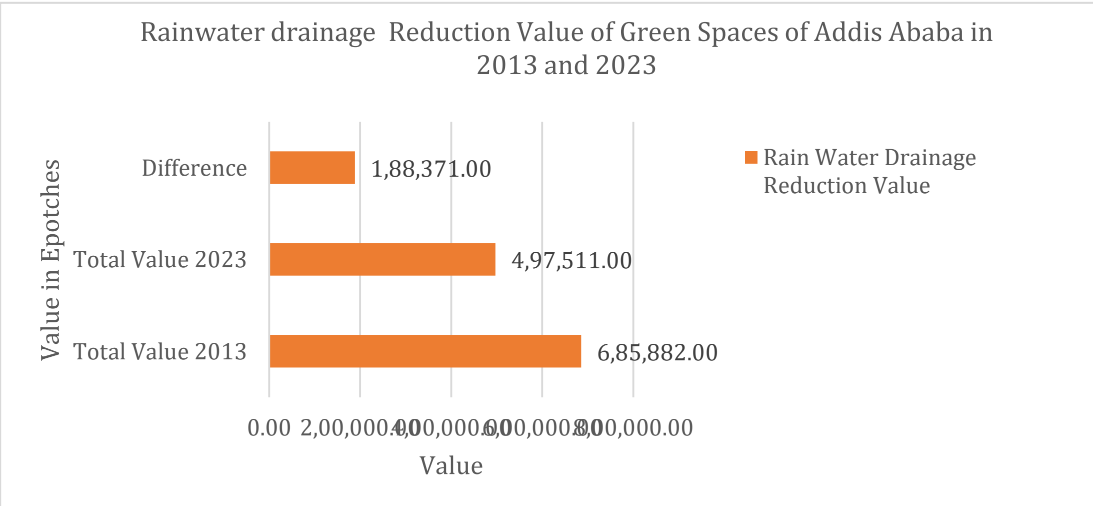

Figure 3.4 Rain Water Drainage Regulating Value of Green Spaces of Addis Ababa in 2013 and 2023

Sewage treatment ecosystem services refer to the natural processes and functions that help remove contaminants and pollutants from wastewater, improving water quality and safeguarding human health and the environment. Up to 96% of the nitrogen and 97% of the phosphorous can be retained in wetlands, and so far wetland restorations have largely been successful, increasing biodiversity and substantially lowering costs of sewage treatment[47].

Addis Ababa has no functional sewage treatment plant. The city has very few natural wetlands available for sewage treatment, but it is possible to construct more wetlands for cleaning sewage water. Up to 96% of the nitrogen and 97% of the phosphorous can be retained in wetlands, and so far wetland restorations have largely been successful, increasing biodiversity and substantially lowering costs of sewage treatment.[46].

Forests and wetlands play a crucial role in treating sewage. Forests help to filter and remove pollutants from water, while wetlands provide a natural habitat for bacteria that break down organic matter. The sewage treatment value of Addis Ababa's green spaces has declined from $2,267,395.00 in 2013 to $1,277,846.00 in 2023. This decline is likely due to a decrease in the area of green spaces in Addis Ababa, particularly forests and wetlands. Sewage treatment of Addis Ababa's green spaces is concerning, as it could lead to several negative consequences, such as increased water pollution, disease outbreaks, and damage to aquatic ecosystems.

It is important to take steps to conserve nd restore Addis Ababa's green spaces to protect the city's water resources and improve the quality of life for its residents.This decline could be attributed to various factors, including increased urbanization, population growth, inadequate infrastructure maintenance, and lack of investment in wastewater treatment facilities. As urban areas expand and populations increase, the demand for sewage treatment services also rises, putting pressure on existing systems and leading to potential degradation of water quality and ecosystems.

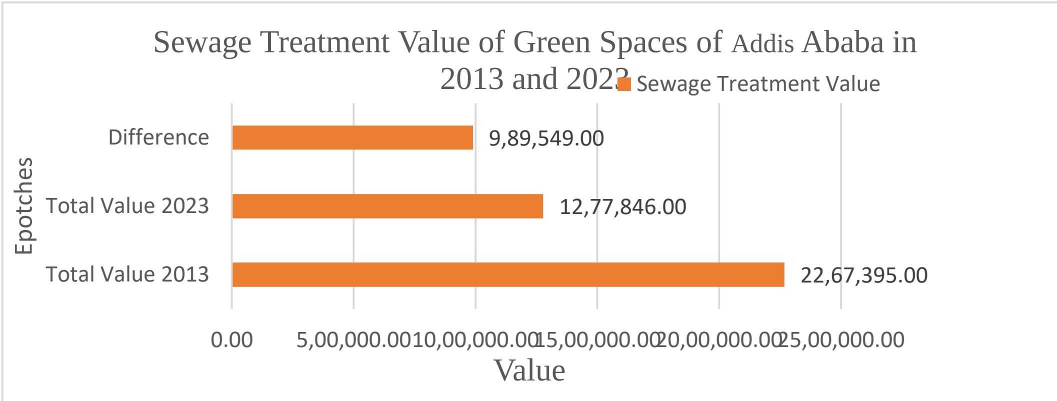

Figure 3.4 Sewage Treatment Value of Green Spaces of Addis Ababa in 2013 and 2023

3.5.6 Quantitative assessment of Recreational and cultural values

Recreation is essential to achieving the quality of life to make it possible for people to live a reasonable life within an urban environment[48] Cultural services (CES) provided by UGS are largely determined by people's subjective perceptions and needs and significantly affect the

Improvement of human well-being per physical and mental health and spiritual culture[24].

The study addresses the Recreational Value of Entoto Park. The study employed the Travel Cost Method to estimate the recreational value of the park based on visitor data. The field estimation of 48,924,400 USD for the recreational and cultural ecosystem However, it's important to note that the field estimation of the recreational and cultural ecosystem service value of the city is significantly higher at 48,924,400 USD.

This suggests that the global standard may not fully capture the true value of these ecosystem services as perceived by residents and visitors. The discrepancy between the Global standard and the field estimation highlights the need to consider local perspectives and values when assessing ecosystem services. It also underscores the importance of engaging with local communities to understand their relationship with recreational and cultural amenities, and to incorporate these perspectives into decision-making processes.

It is service value of Addis Ababa indicates that these services play a substantial role in contributing to the overall well-being and quality of life in the city. As such, policymakers and urban planners need to recognize and protect these valuable ecosystem services through sustainable land use planning, conservation efforts, and community engagement. By acknowledging the higher local estimation of the recreational and cultural ecosystem service value, Addis Ababa can prioritize investments in preserving and enhancing these amenities, thereby promoting a healthier and more vibrant urban environment for its residents and visitors

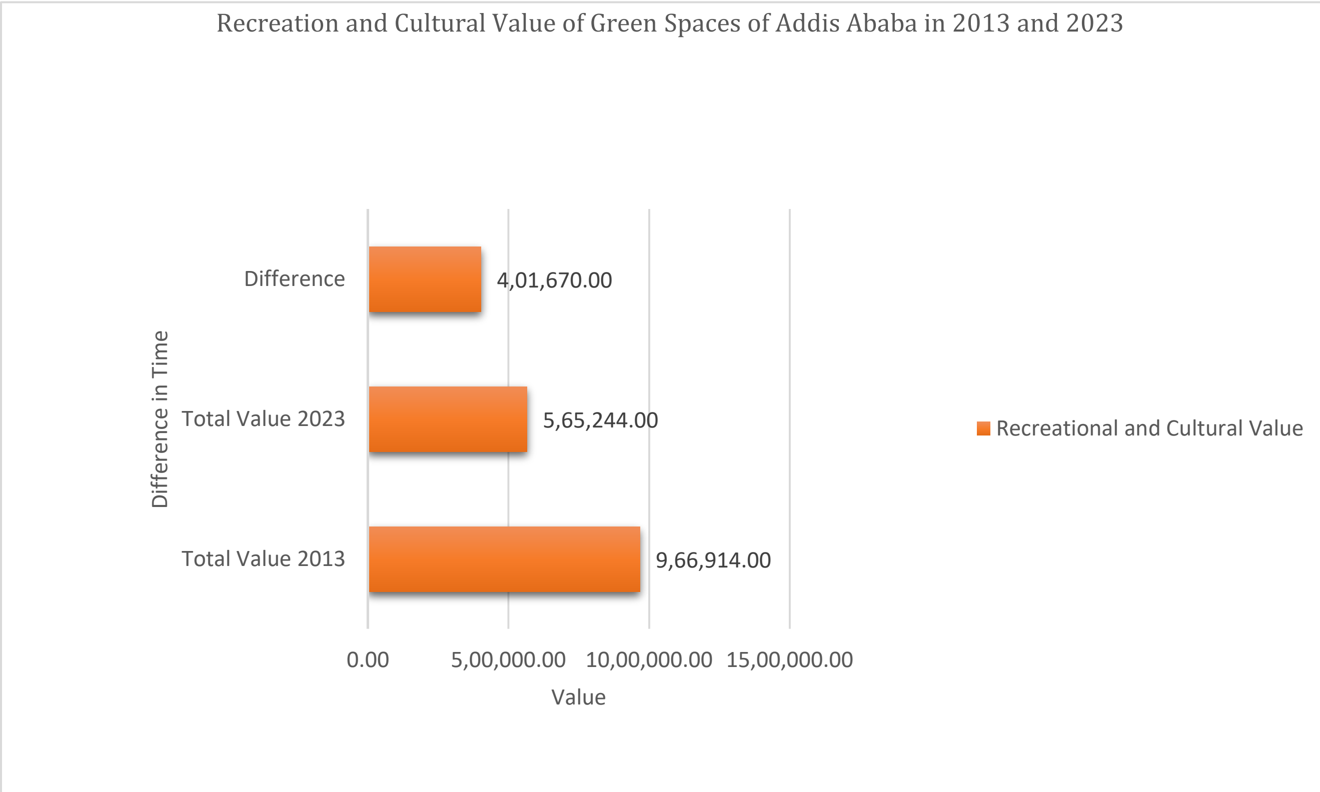

Figure 3.5 Recreation and Cultural Value of Green Spaces of Addis Ababa in 2013 and 2023.

4.DISCUSSIONS

4.1 Spatial pattern and influence factor analysis of ESV of Urban Green Spaces

The area covered by built-up and bare lands (30,953 hectares) has consistently increased from 57.255% in 2013 to 38,040 hectares of coverage or 70.36% of the total land cover in 2023. This indicates rapid urban development and expansion of infrastructure in the city, leading to the conversion of natural and agricultural lands into built-up areas. Conversely, the area occupied by green spaces decreased over the years, from 42.75% in 2013 to 29.64% in 2023. This decline suggests a reduction in agricultural and natural land cover, potentially due to urban encroachment and conversion of these areas for other purposes.

The results indicate a significant shift towards urbanization and development in Addis Ababa, leading to changes in land cover distribution and potential implications for biodiversity, ecosystem services, and overall environmental sustainability in the city. Monitoring and managing these land use changes are essential to ensure sustainable development and conservation of natural resources in Addis Ababa

The decrease in vegetation, crop, and wetland class areas affected the estimated value of the ecosystem services as well. High AI in crop and grassland classes witnesses the class's connectivity compared to other patch mosaics in the study area. It was remarked that deriving ecosystem services for the very same pixel can be subject to errors. The use of similar spatial resolution data as inputs in estimating the value of ecosystem services results in significantly similar estimates of the total value. High-resolution data, like 1m resolution are believed to enhance the correctness of the final land cover map which is subsequently used for computing landscape metrics and ecosystem services valuation.

4.2 Time trend and key drivers' identification of ESV of UGS

The study provides insights into the economic worth and significance of the city's natural assets. By the value of ecosystem services, policymakers and stakeholders can make informed decisions about sustainable urban planning and development. The valuation process involves assessing the various ecosystem services provided by urban green spaces, and quantifying their economic contributions to the city and its residents.

4.3 Ecosystem Service Values from 2013 to 2023

The data reveals a concerning trend of a significant decrease in the air quality promotion value of urban green spaces in Addis Ababa City from 2013 to 2023. To address this issue, policymakers and urban planners must prioritize the preservation and enhancement of urban green spaces, implement sustainable land use practices, and adopt effective pollution control measures. Efforts to protect and promote green infrastructure will be essential in improving air quality, enhancing urban livability, and safeguarding the health and well-being of city residents.

4.4 Drivers Behind the Fluctuations Ecosystem Service Values

Understanding the drivers behind the fluctuations in open/grassland cover and ecosystem service value is essential for effective conservation and management strategies. It is crucial to identify and address the factors contributing to the decline in open grasslands to ensure the continued provision of ecosystem services and benefits associated with these valuable ecosystems. Conservation efforts, restoration initiatives, sustainable land use practices, and community engagement can play a vital role in safeguarding open grasslands and promoting their ecological resilience and long-term sustainability

The open/grassland cover from 2013 to 2023 shows a fluctuating trend. In 2013, there were 1,373 hectares of open/grassland with an ecosystem service value (ESV) of 5.7 million USD. By 2019, the area increased to 1,599 hectares with an ESV of 6.7 million USD, indicating positive conservation efforts. However, by 2023, the area decreased to 1,239 hectares with an ESV of 5.2 million USD, signaling potential threats to open grasslands. Understanding the drivers behind these fluctuations is crucial for effective conservation strategies to ensure the continued provision of ecosystem services and benefits associated with open grasslands.

The ecosystem service values for Addis Ababa have undergone significant changes between 2013 and 2023. Several ecosystem services have experienced a decline in value, while others have remained relatively stable or even increased.

4.5 The Change in the Value of Ecosystem Service Functions

The information regarding ecosystem service functions for Forest, Grassland, and Water bodies underscores the crucial role these ecosystems play in providing essential services that contribute to the overall well-being of the environment. Notably, Water bodies stand out as the most significant contributor to Gas or Air Quality Regulation, with a value of 45,685.16 units, highlighting their crucial role in maintaining air quality. Forests also play a substantial role in this service, with a value of 13.68 units.

The decline in the air quality promotion value of urban green spaces is attributed to urbanization, pollution, climate change, and land use changes. As cities expand, green spaces may be lost or degraded, leading to a reduction in their ability to mitigate air pollution and improve air quality. Additionally, increased pollution levels and changing environmental conditions may also impact the effectiveness of urban green spaces in providing these ecosystem services. This decrease underscores the importance of monitoring and evaluating the ecosystem service value of green spaces over time and the need for proactive measures to protect and enhance these valuable resources to ensure they continue to provide essential benefits for urban residents and the environment.

In terms of Micro Climate Regulation, Forests lead in providing this service with a value of 223 units, showcasing their importance in regulating local climate conditions. Water bodies also make a significant contribution with a value of 588,051.00 units. The decrease in the Climate Regulation Value of Green Spaces in Addis Ababa City from 2013 to 2023 is a concerning trend that highlights the potential impact on the city's environment and inhabitants. The decline from 588,051.00 USD to 420,132.00 USD represents a significant reduction of 167,919.00 USD over the ten-year period. This decrease indicates a potential loss of benefits such as absorbing carbon dioxide, releasing oxygen, providing shade, reducing urban heat island effect, and improving air quality. It is essential for city planners and policymakers to prioritize the preservation and enhancement of green spaces in Addis Ababa to ensure that the city continues to benefit from their climate regulation services.

Regarding Noise Reduction, Water bodies emerge as the primary contributor to noise reduction services with a value of 1,460,898.00 units, indicating their role in reducing environmental noise pollution. Forests also play a notable role in noise reduction with a value of 554 units. The estimated noise value of Addis Ababa refers to the economic cost associated with noise pollution in the city. The decrease in the estimated noise value from 1,460,898 USD in 2013 to 1,043,736 USD in 2023 indicates a reduction in the economic impact of noise pollution over the decade. This reduction is attributed to various factors including improved urban planning, implementation of noise control measures, and advancements in technology leading to quieter infrastructure and transportation. It is important to note that noise pollution can have significant adverse effects on human health, including hearing impairment, sleep disturbance, stress, and reduced productivity.

5. Conclusions and Recommendations

5.1 Conclusions

The study aimed to analyze changes in land use in Addis Ababa over three time periods using remote sensing data from satellite images. It sought to emphasize the economic value of Urban Green Spaces (UGS) and the need to conserve and restore urban ecosystem values. The research revealed a troubling decrease in green spaces in Addis Ababa, with 7,087 hectares converted from green to non-green spaces. This decline raises concerns about falling below the UNHO recommended standard by -9.58%, potentially resulting in a complete loss of ecosystem services within approximately five years.

Urban ecosystems are crucial for providing essential services such as clean air, water, and food, but their value is often overlooked in economic decision-making processes, particularly in rapidly expanding cities like Addis Ababa. The study found that the total stock value of ecosystem services of urban green spaces in Addis Ababa was around $97.6 million in 2023, equivalent to 0.008 percent of Ethiopia's GDP. This information could be valuable for informed decision-making and encouraging willingness to pay to preserve ecosystem integrity.

The research highlighted a significant trend of urbanization and land use transformation in Addis Ababa over the past decade, with an increase in built-up and bare lands at the expense of crop and grassland areas. This rapid urban development is likely driven by factors such as population growth, infrastructure needs, and economic activities. The study underscored the importance of evaluating land-use changes to measure the values of ecosystem services and ensure urban sustainability for future policy planning and decision-making. The findings can serve as a starting point for policy selection and planning by the city administration to shape a sustainable city.

Recognizing the economic value of urban green spaces can help city officials, urban planners, and stakeholders prioritize sustainable land management practices and ensure the preservation and enhancement of these natural assets. Integrating the valuation of urban ecosystem services into green infrastructure planning and development initiatives is crucial for harnessing the benefits of urban ecosystems while creating resilient and ecologically sound cities. The study also noted that the spatial resolution of the image could impact the final classified land cover map and derived ecosystem services. Using high-resolution data was considered to enhance the accuracy of the final land cover map used for computing landscape metrics and ecosystem services valuation

5.2 Perspectives

The city administration should utilize this report as a foundational step in policy selection and planning for creating a sustainable urban environment. However, further in-depth studies are necessary, leveraging high-resolution imagery and increased ground control samples to minimize errors and enhance confidence levels in the data. Integrating the valuation of urban ecosystem services into green space planning and development initiatives is crucial for decision-makers to maximize the benefits of urban ecosystems and foster resilient and ecologically sound cities. The valuation of urban ecosystem services in Addis Ababa shall serve as a cornerstone for informed decision-making and sustainable urban development, emphasizing the economic value of green spaces to prioritize sustainable land management practices.

Maintaining adequate green spaces within limited areas, balancing regulating and recreational services, incorporating citizen input into green space planning, and implementing improved green space management systems are essential. Improving spatial resolution, particularly through the use of high-resolution data like 1m resolution, is critical for accurate land cover mapping and ecosystem services valuation. Translating research findings into actionable recommendations for policymakers and stakeholders is essential for effective resource allocation and informed decision-making on urban ecosystem conservation and development. Further studies with high-resolution imagery and increased ground control samples can help minimize errors and increase confidence levels in the data.

By implementing strategies that leverage ecosystem service values to enhance the quality of green spaces, such as maintaining sufficient green spaces, balancing vegetation structure types, incorporating citizen considerations, and improving spatial resolution, cities can thrive as models for sustainable urban development. Prioritizing high-resolution data, such as 1m resolution, can enhance the accuracy of land cover maps and contribute to more reliable calculations of landscape metrics and ecosystem services valuation.

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