ASSESMENT ON ECOSYSTEM SERVICE VALUES OF URBAN GREEN INFRASTRUCTURE, THE CASE OF ADDIS ABABA, ETHIOPIA

MSC THESIS

SAMSON ANDEMESKEL GEBREMEDHIN

HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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SAMSON ANDEMESKEL GEBREMEDHIN

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OCTOBER, 2019

Declaration

I the under signed, declare that this thesis is my original work and has not been presented in other Universities; all sources of materials used have been duly acknowledged.

Name: Samson Andemeskel

Signature: ___________________________

Date of submission: September 2019

This thesis has been submitted for examination with the approval of university advisor

Name: Dr. Tefera Belay

Signature: ____________________________

Date of submission: September 2019

To: Department Graduate Committee

From: ___________________________

Major supervisor and member of the Board of Examiners of the open defense examination of Master thesis research entitled, **“Assessment on ecosystem service values of Urban Green Infrastructure, the case of Addis Ababa, Ethiopia”**.

The examining board had finally accepted the thesis with minor editorial corrections (SGS article number 2.3) and had delegated the committee consisting of the advisors, **Dr. Tefera Belay** and **Dr. Mikias Biazen** , to see that the student **Samson Andemeskel Gebremedhin** has taken care of all the suggestion of editorial correction indicated by the member of examining board to the best satisfaction. This is, therefore, to testify the student **Samson Andemeskel Gebremedhin** has met the requirements and that he is recommended for graduation.

Sincerely,

CC:

SGS

Name of Student: **Samson Andemeskel Gebremedhin**

Hawassa University

HAWASSA UNIVERSITY WONDO GENET COLLEGE OF FORESTRY

AND NATURAL RESOURCE,

School of Graduate Studies

This is to certify that the thesis prepared by Samson Andemeskel, entitled: **Assessment on Ecosystem services values of Urban Green Infrastructure, the case of Addis Ababa, Ethiopia** and submitted in the partial fulfillment of the requirement for the degree of Master of Science in **forest resources assessment and monitoring** complies with the regulations of the university and meets the accepted standards with respect to the originality and quality.

Signed by the examining committee:

Examiner______________________ signature ______________ date______________

Examiner ______________________ signature______________ date _____________

Advisor ________________________signature ______________ date _____________

Chair of Department or Graduate Program Coordinator

A B S T R A C T

Assessing urban ecosystem service monetary values based on remotely sensed data and measurable indicators is essential to raise awareness of their importance and stimulate support for appropriate conservation measures, furthering policy design and for sustainable urban ecosystems management. The objectives of the study is to assess the Urban Green Infrastructure dynamics and measure its total economic contribution to society using fragment analysis of multi-temporal Landsat data and the updated valuation scheme proposed by Costanza et al. (2014).

Six land cover classes were derived with an overall accuracy of 83% and Kappa coefficient 0.74. The Urban Green Infrastructure land cover is decreased from 44.8% in 2010 to 20.4% in 2019, however the built up plus bare land cover has increased from 55% to 80% in the stated period. As a result, the Urban Green Infrastructure of Addis Ababa city has only 19.95 million USD worth services every year for its residents, which was 150.7 million USD ten years ago and 115.0107.6 million USD before the last three years. The result is warning us that we already started to cross the standard recommended by UNHO at negative 9.58%, and if no remedial action is taken we may completely loss the ecosystem services within seven years.

Key words: *Urban Green Infrastructure, Ecosystem Services Valuation, Landsat data Sustainable Development.*

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ABRREVATIONS and ACRONYMS

AA: Addis Ababa

AAEP-GDC: Addis Ababa environmental protection and green development Comission

AI: Aggregate Index

CBA: Cost Benefit Analysis

EPGC: Environmental protection and Greening commission

ES: ecosystem service

ESV: ecosystem service valuation

GBG: Gullele botanical garden

GI: green infrastructure

ha: hectares

IPCC: International Panel for Climate Change

LM: landscape matrix

LPI: Largest Patch Index

PD: Patch Density

PFM: participatory forest management

NP: Number of Patches

UGI: urban green infrastructure

UN: United Nation

UNHO: United Nations Health Organization

UTM: Universal Traverse Mercator

1 Introduction

1.1 Back ground statement

Urban environmental quality of the world is deteriorating every day. Large cities are reaching human saturation levels, and are unable to cope up with diverse types of human-induced pressures. According to the United Nations report 54% of the world population is living in urban areas (United Nations, 2014). It is also expected to rise at 66% in 2050(United Nations, 2014). This ever increasing urban population growth across the globe can put enormous pressures on the natural environment (Sudha *et al*., 2012) and the loss of urban green spaces, biodiversity and the ecosystem services it provides (Mng'ong'o, 2005; McDonald *et al*., 2013).

Urban green spaces refer to soft landscape elements such as grass, shrubs and trees situated within city limits (Jim and Chen, 2006; Lo and Jim, 2012). Which exist mainly as public parks, gardens, playgrounds, sports fields, greenways, and woodlots (Kaplan and Kaplan, 1989; Jim, 2004).

Urban Green Infrastructure (UGI) is an evolving concept to provide abiotic, biotic and cultural functions in support of sustainability (Ahern, 2007). Several studies confirmed that urban green spaces as a resource that improves the environmental quality of life, promoting public health and providing valuable ecosystem services, urban tourism, active and passive recreations to urban dwellers (Haq, 201; John, 2011 and Martin, *et al*., 2013).

Other studies have also confirmed that green spaces are essential for improving air quality (Nowak, et al., 2006; Jim and Chen, 2008) and providing habitats for wildlife (Dallimer et al., 2014; Li, *et al*., 2017).

Many of these functions, which have been seen as important for sustainable urban development, should be realized within limited space (Baycan-Levent *et al*., 2009; James *et al*., 2009).

Important examples of regulating services, like air purification (Bell et al., 2011; Tallis et al., 2011; Saebo *et al*., 2012), water and climate regulation (Bowler *et al*., 2010; Depietri *et al*., 2012), carbon storage (Davies *et al*., 2011; Strohbach *et al*., 2012) and storm water regulation (Zhang *et al*., 2012) can be traced. Besides they are crucial for biodiversity conservation within urban areas (Goddard *et al*., 2010; Nielsen *et al*., 2014). There is also an increasing interest in the perception of urban nature by humans (Chiesura, 2004; Standish *et al*., 2013), relationships between biodiversity and health benefits (Fuller *et al*., 2007; Jorgensen and Gobster, 2010; Dean *et al*., 2011; Wolch *et al*., 2014) and generally in human environment interactions (Kabisch *et al*., 2015).

Cultural ecosystem services such as recreation, aesthetics and cultural heritage, are often prioritized in planning, design and management of urban green infrastructure. Urban green spaces also offer possibilities for restoration (Nordh *et al*., 2009), physical activity (Hillsdon *et al*., 2006; Gardsjord *et al*., 2014), and social interaction and community attachment (Seeland *et al*., 2009; Arnberger and Eder, 2012; Kazmierczak, ´ 2013). Because of the considerable health benefits urban green space provide (e.g., Tzoulas et al., 2007), access to green space has been a central issue in green space research in relation to human well-being (e.g., Barbosa *et al*., 2007). Provisioning services of urban green space have gained increasing attention over last decade, e.g., concerning urban agriculture (De Bon *et al*., 2009) and community gardening (Holland, 2004; Guitart *et al*., 2012).

The term ‘infrastructure’ in UGI therefore, sends to managers and decision-makers the message that GIs are as necessary for the society as highways, bridges or sewage systems, to retire pollutants from the air, sequester carbon, contribute to rainwater infiltration (decreasing flood risk), provide shade, cool the air through tree transpiration and reduce energy consumption in summer and the urban island heat effect (Ahern, 2007 and Janet, 2007). Hence, UGI must be analyzed, planned and managed to optimize its benefits to the individuals and society, at multi-scale levels and from a multi-functional perspective.

However, these green spaces are depleting at an alarming rate all over the world, a study indicated that in 25 European cities 4.3-41% land reserved for urban green spaces has been changed to other land use types (Theodomir, 2019). About 1.4 million hectares UGI in 174 metropolitan areas of USA converted to other land uses between 1990 and 2000 (Theodomir , 2019).

Hence ecosystem services valuation of these GI helps to raise awareness of their importance and stimulate support for appropriate conservation measures, furthering policy design and development of incentive schemes such as Payment for Ecosystem Services (PES) to incentivize local communities.

Economic values of ecosystems are simply measures of how important ecosystem services are to people ((De Groot et al., 2012; Pagiola et al., 2004). and a reflection of what we, as a society, are willing to trade off to conserve the natural resources. It can also make explicit to society in general and policy makers in particular, that ecosystem services are scarce and that their depreciation or degradation has associated costs to society.

Ethiopia is one of the least urbanized but rapidly urbanizing countries in sub-Saharan African (Theodomir M, 2019). Its urban population was 7.1% in 1994, 16% in 2016, and expected to reach 60% by 2040 with current annual growth rate of 3.5% (Theodomir M, 2019).

Currently, Addis Ababa city administration covers an area of 54,000 hectares (540 km^2), out of which about 22,000 hectares of land is designated for green use (Environmental function). Within the designated green space, there are seven major and six medium rivers which receive water flow from seventy five small tributaries. The urban area covered by forest was expected at about 10,100 hectares. The urban Agriculture to covers an estimated area of 7309 ha. There are also eleven formal functional parks with total area coverage of 110 hectares.

Thus, an important starting point towards solution to these serious problems providing ES values information can be used as an input to policy makers and managers about the value of such ecosystems. In order to estimate the value of the UGIs ecosystem services, it is necessary to use either absolute monetary or relative service values offered by ecosystems (De Groot et al., 2012; Sukhdev et al., 2010). In this study absolute monetary based valuation of ecosystem services is used in order to estimate the economic contribution of multiple goods and services which are provided by UGIs ecosystems of Addis Ababa city.

1.2 Problem statement

Despite, these above stated crucial roles that UGIs ecosystem plays, the resources are facing critical problems for high degree of exploitation and degradation. The main factors which threaten the UGI ecosystems and fueled the degradation of the resources in the city include the expansion of poverty, ever mounting population pressure and a long history of human settlement, climate change, reduction and even extinction of biodiversity, soil erosion and hence reduction of soil fertility, over exploitation and lack of intervention by government are some of them. The climate change vulnerability feature of urban green spaces ecosystem has also aggravated the degradation (IPCC, 2001). Due to the above mentioned factors 10,000ha of Addis Ababa green space has converted to other land use types(Wondimu, 2007), which pulled the suggested UN health organization standards of green spaces per capita far lower than 20 square meters.

This is mainly because humans are less likely to take necessary steps to protect ecosystem services if they do not understand or appreciate the values these ecosystem services have on their quality of life. Lack of knowledge on the multidimensional values of UGI for the society including the environmental policy makers and hence absences of strong national UGIs policy or strategy are the other fundamental reasons that aggravate the depreciation of these resources. Unless restoration, enhancement, conservation and management mechanisms to these ecosystems are implemented, the above multiple UGIs benefits are being lost as a result.

In a policy appraisal context, therefore valuing ecosystem services can help in: determining 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; choosing between competing uses.

A considerable number of studies, especially in Europe and North America, have looked at the use, perception, and management system of green spaces (Chiesura, 2004; Sanesi and Chiarello, 2006; Arnberger, 2006; Neuvonen et al., 2007; Schipperijn et al., 2010; Fischer et al., 2018; Aziz et al., 2018).

Literature related to urban green spaces in sub-Saharan African countries are mainly on the extent and distribution of green spaces (McConnachie et al., 2008; McConnachie and Shackleton, 2010; Lindley et al., 2015), abundance and composition of street trees (Kuruneri-Chitepo and Shackleton, 2011), depletion of green spaces (Mensah, 2014), provision of ecosystem services (Cilliers et al., 2013; Du Toit et al., 2018) and planning aspects (Cilliers, 2009; Fohlmeister et al., 2015).

A generalized study indicated that the values of UGI in Ethiopia have classified in two categories as socio-economic and environmental benefits; such as human health and well- being, recreation, education, job opportunity creation and energy saving as well as biodiversity conservation, carbon sequestration, improves air quality and climate change adaptation.

However, in Ethiopia, comprehensive studies on valuation of the multi-functions and services of UGI ecosystems that can be used as a base decision have not yet been undertaken in the country in general and the capital city UGIs in particular.

In order to fill this gap, this study was conducted to estimate ecosystem service values of Addis Ababa UGIs and their future fate at business as usual scenario, by using multi-temporal satellite image analysis underpinned by field survey. Therefore, decision makers can use the result to compare the environmental and developmental values and on allocation of budget for the city UGIs enhancement and management programs based on the result of such study.

1.3 Research Question

- How much is the monetary value of Addis Ababa GI ecosystems in monetary terms?
- How do the city landscape changed during the last ten years?

1.4 Objectives

1.4.1 General Objective

The general objective of this study is to estimate the total value versus economic contribution of the Addis Ababa GI ecosystem to the society, in such a way that can ensure its sustainability, by using fragment analysis of multi-temporal Landsat images.

1.4.2 Specific Objectives

- To assess the landscape dynamics of Addis Ababa using fragment analysis
- To estimate the monetary values of the city UGI

1.5 Significance of the study

Urban green space ecosystem services can no longer be treated as inexhaustible and free ‘goods’ and their true value to society as well as the costs of their loss and degradation, need to be properly accounted (Costanza *et al*., 1997; Blignaut and Moolman, 2006; Carpenter *et al*., 2006; TEEB, 2011; TEEB, 2010) in monetary units as it is an important tool to raise awareness and convey the relative importance of ecosystems and biodiversity to policy makers.

Likewise information on monetary values of Addis Ababa UGIs ecosystem therefore enables to raise policy makers’ awareness on how much these ecosystems are important to society thereby, efficient use of limited funds through identifying where protection and restoration is economically most important and can be provided at lowest cost (Crossman and Bryan, 2009; Crossman *et al*.,2011). It can also assist the determination of the extent to which compensation should be paid for the loss of ecosystem services in liability regimes (Payne and Sand, 2011).

1.6 Limitation of the study

Undertaking original environmental valuation research incurs high cost. In addition to remote sensing data analysis, the study implemented field survey in order to collect ground control points from the case study areas which cover a total of about 54,000 ha. Thus, collection of the data is very difficult and too costly. Therefore, financial constraint was the main limitation of the study that affected the size of the sample size and design. The other limitation of the study was time constraint. This is because it took long time to collect the data.

2 Literature review

2.1 Urban ecosystems

An ecosystem can be defined as ‘‘a set of interacting species and their local, non-biological environment functioning together to sustain life’’ (Moll and Petit, 1994). However, the borders between different ecosystems are often diffuse. In the case of the urban environment, it is both possible to define the city as one single ecosystem or to see the city as composed of several individual ecosystems, e.g. parks and lakes (Rebele, 1994). For simplicity, we have chosen to use the term urban ecosystems for all natural green and blue areas in the city, including in this definition street trees and ponds. In reality, street trees are too small to be considered ecosystems in their own right, and should rather be regarded as elements of a larger system.

We identify six different urban ecosystems which we call natural, even if almost all areas in cities are manipulated and managed by man. The ecosystems are street trees, parks, urban forests, cultivated land, wetlands, and streams. Street trees are stand-alone trees, often surrounded by paved ground. Parks are managed green areas with a mixture of grass, larger trees, and other plants. Areas such as playgrounds and golf courses are also included in this group.

Urban forests are less managed areas with a denser tree stand than parks. Cultivated land and gardens are used for growing various food items.

Wetlands consist of various types of marshes and swamps, while streams refer to flowing water. Other areas within the city, such as dumps and abandoned backyards, may also contain significant populations of plants and animals. It should be possible, however, to place most urban ecosystems or elements in one of the above mentioned categories.

2.2 Importance of urban green infrastructure

Urban green spaces provide essential benefits to urban dwellers (e.g., Pauleit, 2003; Tzoulas *et al*., 2007; James et al., 2009), while also offering crucial habitat for wildlife (Goddard *et al*., 2010). Green space multi-functionality has often been emphasized as relating to recreation, social interaction, aesthetics, cultural heritage and ecological functions (Pauleit, 2003; Priemus *et al*., 2004; Mell, 2009). Many of these functions, which are seen as important for sustainable urban development, have to be realised within limited space (Baycan-Levent *et al*., 2009; James *et al*., 2009). The concept of ecosystem services(Costanza *et al*., 1997; Millenium Ecosystem Assessment, 2003), embodying the human benefits derived from ecosystem functions, has also been applied to urban green spaces (Tratalos *et al*., 2007; Ernstson et al., 2008; Niemelä *et al*., 2010; Young, 2010; Kabisch, 2015; Hansen *et al*., 2015).

Regulating services, like air purification (Bell *et al*., 2011; Tallis *et al*., 2011; Saebo *et al*., 2012), water and climate regulation (Bowler *et al*., 2010; Depietri *et al.*, 2012), carbon storage (Davies *et al*., 2011; Strohbach *et al*., 2012) and stormwater regulation (Zhang *et al*., 2012) are important examples. They are also crucial for biodiversity conservation within urban areas (Goddard *et al*., 2010; Nielsen *et al*., 2014).

Cultural ecosystem services such as recreation, aesthetics and cultural heritage, are often prioritised in planning, design and management of urban green spaces. Urban green spaces offer possibilities for restoration (Nordh *et al*., 2009), physical activity (Hillsdon *et al*., 2006; Gardsjord et al., 2014), and social interaction and community attachment (Seeland *et al*., 2009; Arnberger and Eder, 2012; Kazmierczak, ´ 2013). Because of the considerable health benefits urban green space provide (e.g., Tzoulas *et al*., 2007), access to green space has been a central issue in green space research in relation to human well-being (e.g., Barbosa *et al*., 2007).

Provisioning services of urban green space have gained increasing attention over last decade, e.g., concerning urban agriculture (De Bon *et al*., 2009) and community gardening (Holland, 2004; Guitart *et al*., 2012). The importance of studying interrelations, especially synergies of ecosystem services or functions has been highlighted (Shmelev and Shmeleva, 2009). Provision of vital multiple ecosystem services makes urban green space a fundamental part of sustainable urban development.

2.3 Types of ecosystem services of cities similar with Addis Ababa

Ecosystem services are defined as ‘‘the benefits human populations derive, directly or indirectly, from ecosystem functions’’ by Costanza *et al.* (1997) and they also identify 17 major categories of ecosystem services.

Since this paper focuses on issues relevant for urban areas, the attention is on direct and locally generated services relevant for Addis Ababa. From the 17 groups of services listed by Costanza *et al*. (1997), six are considered to have a major importance in the urban areas: air filtering (gas regulation), micro-climate regulation, noise reduction (disturbance regulation), rainwater drainage (water regulation), sewage treatment (waste treatment), and recreational and cultural values.

2.3.1 Air filtering

Air pollution caused by transportation and heating of buildings, among other things, is a major environmental and public health problem in cities. It is clear that vegetation reduces air pollution, but to what level seems to depend on the local situation (Svensson and Eliasson, 1997). The reduction is primarily caused by vegetation filtering pollution and particulates from the air.

Green infrastructures have a positive impact on air quality. Vegetation is capable of removing ammonia (NH3), carbon dioxide (CO2), oxides of nitrogen (NOx), ozone (O3), particulate matter (PM; dust) and sulphur dioxide (SO2) from the air (Nowak *et* *al*., 2006 and Powe *et al.*, 2004). The ability of trees to intercept pollution varies between species, throughout the age of the tree, and with the planting design (Martin, 2013). A case study carried out in West Midlands on urban forest reported that some species of tree have a greater potential to improve air quality (O3, NO2, HNO3, NO and PAN) while others could have a detrimental impact (Nowakn *et al*., 2006).

In Addis Ababa the percentage of vegetated area, is clearly below the UNHO standard. In fact, approximately 9.5% (5000 ha) of the land area in the city of Addis Ababa is currently covered by forest, agriculture, wet and open land. Such a small amount of forest couldn't have a significant air filtering capacity which leads to an reduction of air quality.

2.3.2 Micro-climate regulation

Local climate and even weather are affected by the city. In studies of US cities, some of these differences have been quantified, and expressed as changes compared with surrounding country-side: air temperature is 0.7°C higher measured as the annual mean, solar radiation is reduced by up to 20%, and wind speed is lowered by 10–30% (Haughton and Hunter, 1994). The phenomenon, sometimes called the urban heat island effect, is caused by the large area of heat absorbing surfaces, in combination with high amounts of energy use in cities.

All UG ecosystems in urban areas will help to reduce these differences. Water areas in the city will help even out temperature deviations both during summer and winter. Vegetation is also important. A single large tree can transpire 450 liters of water per day. This consumes 1000 MJ of heat energy to drive the evaporation process. In this way city trees can lower summer temperatures of the city markedly (Hough, 1989). Vegetation can also decrease energy use for heating and air conditioning substantially in urban areas by shading houses in summer and reducing wind speed in winter.

In Chicago it has been shown that an increase in tree cover by 10%, or planting about three trees per building lot, could reduce the total energy for heating and cooling by US$50–90 per dwelling unit per year. The present value of long-term benefits by the trees was found to be more than twice the present value of costs (McPherson *et al*., 1997).

Hence the micro-climate in Addis Ababa is not regulated to a great extent by the large bodies of water in the city, as the city is not situated on a number of wetlands. Addis Ababa also benefits from the vegetation, for example by reduced heating costs.

2.3.3 Noise reduction

Noise from traffic and other sources creates health problems for people in urban areas. The overall costs of noise have been estimated to be in the range of 0.2 –2% of GDP in the EU (Kommunfo ¨rbundet, 1998). In Sweden, maximum noise levels of 55 dB outside and 30 dB inside buildings have been established as the long-term goal (Naturva rdsverket, 1996).

The distance to the source of the noise is one key factor, and a doubling of the distance decreases the equivalent level by 3 dB. Another key factor is the character of the ground. A soft lawn, rather than a concrete pavement, decreases the level by another 3 dB (SOU, 1993). Vegetation also contributes to the decrease, but at what level is uncertain. One source states that a dense shrubbery, at least 5 m wide can reduce noise levels by 2 dB and that a 50-m wide plantation can lower noise levels by 3–6 dB (Naturva rdsverket, 1996). Another source claims that 100 m of dense vegetation is only reported to decrease noise by 1–2 dB (Kommunfo rbundet, 1998). Sounds propagate long distances on water (Naturva rdsverket, 1996).

2.3.4 Rainwater drainage

The built-up infrastructure, with concrete and tarmac covering the ground, results in alterations of water flow compared to an equivalent rural catchment. A higher proportion of rainfall becomes surface-water run-off which results in increased peak flood discharges and degraded water quality through the pick-up of e.g. urban street pollutants (Haughton and Hunter, 1994). The impervious surfaces and high extraction of water cause the groundwater level of many cities to decrease.

Vegetated areas contribute to solving this problem in several ways. The soft ground of vegetated areas allows water to seep through and the vegetation takes up water and releases it into the air through evapotranspiration. Even if the built city surface primarily seals the ground from rainwater, it has been suggested that urbanization also creates some new, unintended pathways for recharge. These include leaking water mains, sewers, septic tanks, and soak ways (Lerner, 1990).

In vegetated areas only 5–15% of the rainwater runs off the ground, with the rest evaporating or infiltrating the ground. In vegetation-free cities about 60% of the rain water is instead led off through storm water drains (Bernatzky, 1983).

This will of course affect both the local climate and the groundwater levels. Valuation of this service depends on the local situation. Cities with a high risk of flooding will benefit more from green areas that take up water than do other cities.

The drinking water in Addis Ababa is supplied by lake/ dam water. Therefore, the ground water levels in the city are not heavily affected. Stockholm could however benefit from improved rainwater drainage through soft ground since the building and maintenance of the storm water drainage system involve large costs. Using the ecosystem service could lower the cost.

2.3.5 Sewage treatment

Addis Ababa has no functional sewage treatment plant. In many cities, large scale experiments are taking place where natural systems, mainly wetlands, are being used to treat sewage water. The wetland plants and animals can assimilate large amounts of the nutrients and slow down the flow of the sewage water, allowing particles to settle out on the bottom.

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 (Ewel, 1997).

The city has very few natural wetlands available for sewage treatment, but it is possible to construct more wetlands for cleaning sewage water.

2.3.6 Recreational and cultural values

A city is a stressful environment for its citizens. The overall speed and number of impressions cause hectic lifestyles with little room for rest and contemplation.

The recreational aspects of all urban ecosystems, with possibilities to play and rest, are perhaps the highest valued ecosystem service in cities.

All ecosystems also provide aesthetic and cultural values to the city and lend structure to the landscape. Botkin and Beveridge (1997) argue that ‘‘Vegetation is essential to achieving the quality of life that creates a great city and that makes it possible for people to live a reasonable life within an urban environment’’. According to the Swedish economist Nils Lundgren, a good urban environment is an important argument for regions when trying to attract a highly qualified workforce (N. Lundgren, Nordbanken, personal communication).

Green spaces are psychologically very important. One example is a study on the response of persons put under stress in different environments (Ulrich *et al.*, 1991). This study showed that when subjects of the experiment were exposed to natural environments the level of stress decreased rapidly, whereas during exposure to the urban environment the stress levels remained high or even increased. Another study on recovery of patients in a hospital showed that patients with rooms facing a park had 10% faster recovery and needed 50% less strong pain-relieving medication compared to patients in rooms facing a building wall (Ulrich, 1984). These studies imply that green spaces can increase the physical and psychological well-being of urban citizens.

The scientific values of ecosystems are also included in this group, e.g. providing information services. The urban ecosystems can function as indicators of the state of the urban environment.

Lichens, for example, cannot grow in areas with polluted air, and can thus be used to indicate the air quality (Miller, 1994).

Table 1 Potential ecosystem services linked to land cover classes in Addis Ababa, Ethiopia

Types of services	Cropland	Forest (tropical)	Wetland (river/lake)	Residential land	Open/grass land
Provision		X	X		X
Production	X	X	X		
Regulation		X	X	X	X
Supporting				X	
Cultural and Educational				X	
Waste treatment				X	

2.4 Valuation of UGI

Different values and perceptions should be considered to make well-informed decisions in the management of urban ecosystems (De Groot et al. 2010b). The choice of which specific values should be assessed and articulated in the processes of urban planning depends on the characteristics of the UESs that are being valued and the institutional and socio cultural contexts in which decisions take place.

Approaches to economic valuation have the common characteristic of using monetary units as an indicator. Nevertheless, this indicator can be derived by different methods. Provisioning UESs, consisting of directly marketable goods, such as drinking water, food, and raw materials, are directly valued through market observations of reference prices (Tong et al. 2007). By contrast, studies that examined regulating UESs used revealed preference methods to derive UES values based on secondary markets.

Hedonic pricing methods are often used to determine the value of cultural UESs, such as the esthetic of green areas (Tyrva¨inen 2001). 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 (Boyd and Banzhaft 2007; Tong *et al*. 2007), which does not rely on existing markets. It uses stated preferences collected through surveys. This approach is, in that aspect, closely related to socio-cultural valuation methods. 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 (Patton 2001; Chan *et al*. 2012). In some cases, translating these values into quantitative metrics is difficult or senseless. However, scientists have developed toolsets to measure values such as sense of place (Williams and Roggenbuck 1989; Shamai 1991) and traditional ecological knowledge (Gomez-Baggethun *et al*. 2010) using constructed scales when appropriate. Additional sets of values that can be labeled as socio-cultural include sense of community, social cohesion, and spiritual values (Gomez Baggethun *et al*. 2013). Contingent valuation allows for simultaneous accounting of multiple ES. However, in a complex policy setting involving multi-dimensional scenarios, respondents may not be able to accurately state their preferences (Nijkamp *et al*. 2008). Although temporal and spatial value transfers are often conducted (Kreuter *et al*. 2001; Zhao et al. 2004; Troy and Wilson 2006), monetary values are generally highly context dependent (Ma¨ler *et a*l. 2008) with regard to socio-ecology, politics, and economics at any given time. Monetary valuation approaches can provide relevant information for policy decisions affecting ecosystems and the services they provide (Costanza *et al*. 1997). However, in practice, their focus tends to be too narrow to encompass the total complexity of socio-ecological systems (Chee 2004). The integrated assessment (Brouwer and Van Ek 2004) of monetary values in an urban context is strongly needed.

2.4.1 Indicators for UES Assessment

Understanding the factors influencing UESs requires the use of linked or bundled indicators that track driving social–ecological forces as well as pressures on ecosystems. Researchers are increasingly developing and testing ES indicators from a wide scale to a local site scale. Indicators allow researchers to analyze, monitor, and efficiently measure the conditions, characteristics, trends, and rates of change of UESs (Layke 2009; Sparks *et al*. 2011) and help reduce complexity. An indicator is defined as a measure or metric based on verifiable data that conveys information about more than itself. Indicators help track and communicate how ecosystems support the physical, economic, and socio-cultural well-being of people.

2.4.2 Linking landscape matrix with dynamics of ecosystem services

Quantifying the forest ecosystem fragmentation using the NP and the CA indices enhanced a better understanding on the degree and intensity the linked regulating and provision services are altered. Urban sprawl in the urban fringe zones can affect cropland, potentially leading to the reduction of the area reserved for food production services.

In the study area, the change in land cover is affecting the landscape dominance and composition. As the patch area is changing, the corresponding ecosystem services and its estimated value is affected as well. Our findings are further illustrating that one class of patches express one-to-many relationship with linked ecosystem services given that one ecosystem can simultaneously generate more than one ecosystem services. The AI which is useful to illustrate patch dominance yields potential to investigate ecosystem dominance and stability as well, e.g. built up which is dominating the landscape in all the three considered epochs is considered as stable ecosystem despite the reduction of its estimated value. The establishment of reliable links between LM and ES in terms of land cover changes and implications is still to be achieved.

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 for 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, whilst the crops can be consumed anywhere else on the globe. Cultural and recreational services on the contrary are only enjoyed and perceived by humans that are actually at the site of ES provision. Furthermore, the socio-economical context defines how and which services are used. Ecosystem services in Addis Ababa are mostly experienced locally or in the surrounding hinterland as might be in similar capitals in Sub-Saharan emerging economies. Supporting services are universal and exceed the local study area boundary and several goods that are produced in the study area also transported outwards.

2.4.3 Data and Models of UES Quantification

Quantitative modeling plays a major role in assessing UESs, because the urban ecological system is very different from non-urban ecological systems (Gomez-Baggethun *et al*. 2013), models used for urban valuation need to be adjusted to the complex, multi-functional urban environment (Pataki *et al.* 2011). Various models are used to value ES demand and provisioning, including biophysical, empirical, GIS-based, statistical and survey-based models and less widely applied approaches such as qualitative studies, causal loops and look-up tables. In addition, monetary modeling approaches use the identification and valuation of ES as input to cost-benefit analyses (CBA) or willingness-to-pay (WTP) analyses.

Bio-physical evaluation models are able to analyze complex ecological systems and impacts but are limited in that they tend to focus on provisioning services. With respect to indicators and service providing units, these models tend to focus on the potential for forests to reduce air pollution (Jim and Chen 2009).

A number of empirical studies examine the provision of biodiversity and carbon sequestration and storage by trees. Some empirical studies use a combination of quantitative and qualitative assessment data, utilizing land cover data and GIS (Burkhard *et al*. 2009, 2011).

GIS-based models can be used to assess and analyze the provision of UES and, to a lesser degree, have also assessed or analyzed the demand for these services. GIS-based models are useful for demand and provision analyses because spatial data, such as land cover and land use data, can serve as a basis for estimating quantities of the particular UESs associated with vegetation types, soil and other landscape features. Moreover spatial dynamics can reveal heterogeneity and trends in the distribution of

UESs over urban landscapes, which can be of importance for urban sustainability planning.

2.4.4 Monetary and Non-monetary Valuation

The pluralism of values with respect to UESs has been highlighted from both theoretical and empirical perspectives (Chiesura 2004; Hubacek and Kronenberg 2013). Thus, different values and perceptions should be considered to make well-informed decisions in the management of urban ecosystems (De Groot *et al*. 2010). The choice of which specific values should be assessed and articulated in the processes of urban planning depends on the characteristics of the UESs.

Although there has been a recent thrust to apply monetary means to value ES and biodiversity, these means can be inappropriate when they fail to take into account the totality and plurality of values, which are also characteristic of non-monetary indicators (TEEB 2011).

Ecological valuation does not directly consider human needs or stated preferences and wants. It instead considers physical or nonphysical environmental outputs, which have indirect value for humans (Winkler 2006).

Methods for assessing socio-cultural indicators and values take into account socio-cultural perceptions of ES in terms of their importance to human well-being. They are mainly used for ES that are not valued within markets (Chan *et al*. 2012 for a theoretical explanation; Ambrey and Fleming 2011; Calvet-Mir *et al.* 2012 for case studies). Approaches to economic valuation have the common characteristic of using monetary units as an indicator. Nevertheless, this indicator can be derived by different methods. Provisioning UESs, consisting of directly marketable goods, such as drinking water, food, and raw materials, are directly valued through market observations of reference prices (Tong *et al*. 2007).

2.5 Importance of UGI ESs valuation for future planning

For the most part, policy decision-making processes take account only of traded goods, for example, the market price of land or the value of crops it will produce. They ignore the value of the majority of ecosystem services that will be altered by land use change. The valuation of benefits enables decision-makers to place a value on changes in services that are not captured by markets, Valuation is not intended to displace the broader factors already present in environmental decision-making frameworks, and most commentators agree that its application to ecosystem services should be regarded as a complementary, rather than sole, component in decision-making.

Most of the benefits tend to be undersupplied, due to the emphasis on provisioning services from which land managers can secure market returns, in this case timber as a resource for industry.

Policies tend to take more account of shorter term and more localized private gains of benefits (such as increased agricultural productivity from wetland drainage) than longer term and more distant loss of public benefits (such as increased risk of flooding and decreased water quality). If an ecosystem is managed primarily to deliver one ecosystem service, such as a provisioning service, this may reduce levels of other ecosystem services supported by the ecosystem.

For example, a forest managed exclusively for timber production may have less recreational value, store less carbon and be less effective at retaining nutrients. The role of economic analysis in environmental policy is to determine where a change in practices or policies may be in the wider public interest. Public benefits from regulating and supporting ecosystem services over a long-term horizon, such as climate regulation or flood alleviation, have frequently not been accounted for in such analysis.

Valuation of ecosystem service benefits is one means of incorporating their consideration in decision making. However, no single approach, such as valuation, is likely to provide sufficient understanding of the relationships between services and how best to manage their interaction. A whole toolbox of approaches will be needed, such as participatory methods, to provide a wider array of inputs and understandings of the numerous and diverse values held by stakeholders in decision-making.

Moreover, economic analysis, in the form of CBA, is the most frequently used policy decision support tool for quantifying trade-offs between economic benefits and environmental and social losses. The 'right' decision in economic analysis has a precise meaning: a decision that, on the whole, has more benefits to society than costs. There is an extensive academic literature on the effectiveness of CBA and alternative economic analysis tools.

2.6 Trade-off and controversy in monetary based valuation of ecosystem services

Monetization of ecosystem services has been advocated by many as a strategy to make nature visible to decision makers and financial markets. Once this visibility is perceived, this could be a baseline for cost benefit analysis for sustainable use of natural resources and for advocating for willingness to pay. The latter is regarded as measure of human-being satisfaction. However, ESV based on market values has been criticized due to the underestimated values of ES. Indeed, it is believed that benefits and services derived from the nature are beyond monetary based value. For instance, the value of regulating services derived from forest ecosystem could be expressed in terms long-term preservation, which is difficult to estimate in market price. Some controversial arguments emphasized that the economic valuation of the ES is seen as "selling out on nature" (McCauley, 2006) or as the nature monetization which can be interpreted as underestimating the real value of nature productive goods and services (Gómez-Baggethun and Ruiz-Pérez, 2011; Sagoff, 2008). The ESV in the present study can be seen as an informative global estimate. The values presented here do not reflect actual and customized market values. Service values should be interpreted in the lens of willingness to maintain ecosystems and can be used in preparing actual valuation schemes for payment of environmental services. The results are, however potential inputs for guiding the preparation of cost-benefits transfer methods of ecosystem service. Furthermore, the values of urban ecosystem services and urban green spaces need more detailed remote sensing data and appropriate sampling for sound valuation. Alternative approaches for overcoming the limitation of monetary based approach could be the use of high resolution images and representative sample size.

3 Materials and Methods

3.1 Materials

3.1.1 Description of the area

Addis Ababa, capital of the country, the seat for AU and other international organizations, is located within the central plateau of Ethiopia, extending between 8^0 55 'and 9^0 05' North latitude. The total physical land area of the current city administration is 54,000 hectares, Out of which about 22,000 hectares of land is designated for green use (Addis Ababa master plan, 2014). The spatial distribution of the urban green shows that there are seven major and six medium rivers which receive water flow from seventy five small tributaries. The existing forest area is mostly found at the northern part, (which is also the highest altitudinal range), northwest, south west, north east and west part of the city or known by the local names of Entoto, Yeka, Ankorcha and Gullele.

Within the designated green space, currently urban Agriculture also covers an estimated area of 7309 ha. 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, Ambassagibe, Gola Michaele and Kolfe Parks. The total area of the parks including the non-functional ones viz. Pyness Park, Ethio-cuba Park, Aratkilo (Congress Hall Park) National theatre (Street Park), and Akaki is estimated to be 121 hectares.

Altitudinal zones of Addis Ababa range from 2054 m to 3023 masl, 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 in to 10 sub-cities and 116 woredas (administrative districts), with the total population of Addis Ababa is 3,775,348, which is about 60% of the total urban population in Ethiopia.

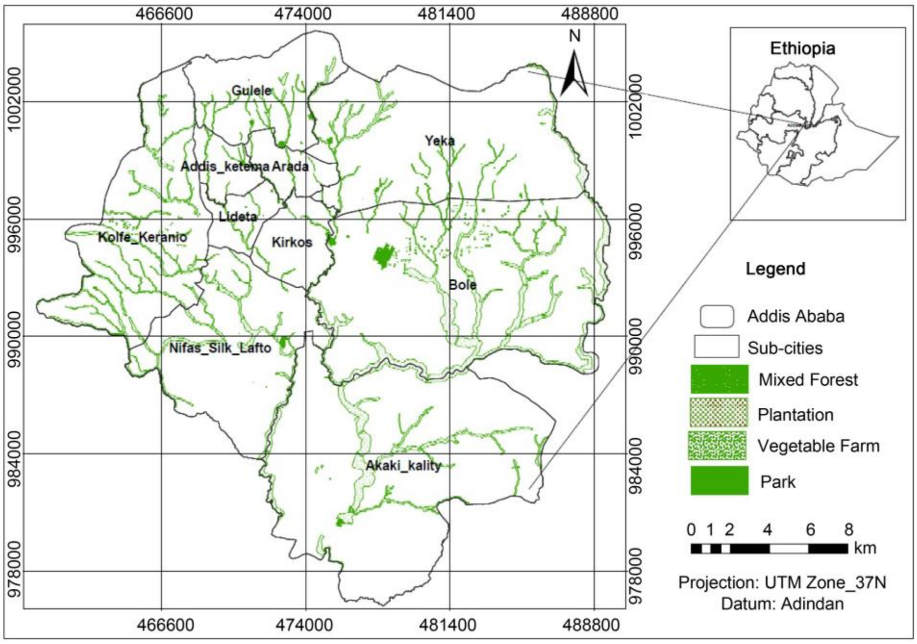


Fig. 1 Location of Addis Ababa City and its topographic characteristics

3.1.2 Climate

The rainfall and the temperature condition of these areas were 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 13.4C^o. The range of mean monthly minimum and maximum temperatures of the study area is 7.5C^o and 20.7C^o in December and February, respectively. The mean annual minimum and maximum temperature is 8.4C^o and 18.4C^o, respectively. The hottest month is February with maximum temperature of 20.7C^o, followed by March (20.2C^o) and May (20C^o) and the coldest month is in December with minimum temperatures of 7.5C^o. 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 (Birhanu Belay, 2009).

3.1.3 Vegetation

The city vegetation is mostly covered by exotic tree species like; Eucalyptus globulus, 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. From this there are also some endemic and endangered plant species. Some of the dominant indigenous woody species include; Juniperus procera, Hypericum revolution, Olinia rechetiana, Myrsine melanophleos, Myrsine africana and Erica araborea.

3.2 Data sources and sampling

The data sources for this research primarily came from Landsat images. Secondary data were from National Meteorology Agency of Ethiopia, Central Statistical Agency and Addis Ababa Environmental Protection Authority. The population census data were collected from Central Statistical Agency. The three Landsat images included Landsat ETM for 2010 and, TM+ for 2016 and 2019. All images were georectified to a common UTM coordinate system. For the image, 250 ground control points were selected to generate coefficients, and for a first-order polynomial, and a nearest-neighbor method was applied to resample the image according to their original theoretical spatial resolution.

The three Landsat images with 30m resolution were downloaded from the United States Geological Survey (USGS) resource repository (https://earthexplorer.usgs.gov/). Images with almost same anniversary dates were selected. All images were taken on satellite track path/row 168/54. All acquired data were projected in Universal Transverse Mercator (UTM) with the WGS-84 datum. All images are Level 1 products. For cross-checking and land cover validation, Google earth image and the city administration master plan were used. After Image pre-processing, six land cover classes were proposed. Training areas and validation samples were composed of pixels randomly selected on Landsat images using ground truth regions of interest (ROIs) in QGIS 3.6.SVMC. A cross-check of the corresponding landscape features was performed by referring to secondary data including WorldView-2 image and Google Earth. Historical data, i.e. the 2010, 2016 and 2019 images were validated by referring to features affected by less change or not changing across the time.

3.3 Land cover classification

Pixel-based Support Vector Machine (SVM) classification was performed using QGIS 3.6 plug in. SVM is a non-parametric supervised classification algorithm based on statistical learning theory (Kavzoglu and Colkesen, 2009). It was selected because it is considered a supervised classifier generally yielding good classification results. With its capabilities of determining an optimum hyper-plane separating adjacent classes in high dimension feature space, SVM outperform most of parametric and non-parametric algorithms in improving classification accuracy (Foody and Mathur, 2004; Huang *et al*., 2002; Kavzoglu and Colkesen, 2009; Niu and Ban, 2013; Shao and Lunetta, 2012).

For each of the three images, six land cover classes; forest, open land, built up, bare land, water and agriculture, were determined. A series of post-classification clean-up operations were performed after generating the land cover map. A *Sieve class's* algorithm was first used for filtering the classified images that were suffering from the *salt and pepper* effect, i.e. small erroneously classified pixels. The filtering process allowed a threshold to be specified for the smallest polygon not to be merged into a neighbor.

After filtering the classified image and assigning new value using *Majority Analysis* algorithm, land cover classes were aggregated for producing smoothed and meaningful maps. After post-classification refinements, a confusion matrix and Kappa indices were generated for accuracy assessment.

3.4 Validation and Accuracy assessment

Validation samples were composed of points randomly selected on Landsat images using ground truth regions of interest. A cross-check of the corresponding landscape features was performed by referring to secondary data including Google Earth.

Historical data, i.e. the 2010 and 2016 images were validated by referring to features affected by less change or not changing across the time. Typical features used for validating historical data include Lake upper catchment forest, Akaki River, built-up areas in the core city center, the Meskel square and bare land around Goro areas still present in the study area since before 2010. The images were cross-checked and validated using the Google Earth time slider. Total of 250 ground truth points were selected for each of the three classified images for accuracy assessment.

3.5 Landscape metrics

Landscape metrics were derived with FRAGSTATS Version 4.2.1, a spatial pattern analysis program for quantifying landscape structure. The landscape patterns were computed and analyzed at class and landscape levels. In total, four indices (see Table 1) were generated for characterizing the study area's landscape evolution between 2010 and 2019.

Spatio-temporal urban land cover change dynamics are most of the time coupled with fragmentation and conversion of existing land cover. The level of fragmentation is easily tracked by either counting the change in the number of patches in a particular patch mosaic or the change in the number patches per unit area (i.e. PD). Landscape stability is translated by less fragmented habitat types. This stability can be assessed by examining the patch dominance between two timespan periods.

Thus, the choice for indices should be elucidated and contextualized. Su et al. (2012) reiterated that one of the criteria to use a particular landscape index should be its ability to reflect landscape pattern in the study area. The selected indices such as CA, NP, and PD are useful for quantifying the number and amount of habitat types and, thus, characterizing class dominance and composition in the landscape.

3.6 Valuation of ecosystem services

In this study, the services and benefits gained from ecosystems were first inventoried by referring to the ecosystem services' scheme as proposed by the Millennium Ecosystem Assessment, 2005; TEEB Foundations (2010). 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 dollar using the updated valuation scheme proposed by Costanza et al. (2014).

According to this scheme, the total value of ecosystem service is equal to the products of the areas covered by corresponding service and the estimated value in US dollar as expressed in the Eq. (1).

$$ESV = \sum_{i}^{n} CA_i \; UV \qquad (1)$$

Where;

ESV = Ecosystem service value,

CA*i* = Class area in patch I expressed in ha, n=number of patches per class area,

UV =Ecosystem service unit value expressed in USD

The valuation concerned five ecosystems/biomes namely: wetlands, forest, open land (grass land), agriculture (cropland), and built up. In the present study, the proposed LM indices in Table 1 are used for quantifying and tracking the change in urban patch mosaic and density, their dominance and their spatial patterns. We assume that LM changes are most likely to impact the quantity of ES and thus, their estimated value.

Table 2 Description of the spatial metrics used in this study

Land escape matrices	**Index Description**	**Unit**	**Range**

Number of Patches (NP)	Number of patches of the corresponding patch type	None	NP =1, without limit
Patch Density (PD)	Number of patches of the corresponding patch type divided by total landscape area	Number per100 ha	PD > 0, constrained by cell size
Largest Patch Index (LPI)	Area of the largest patch of the corresponding patch type divided by total landscape area (m2), multiplied by 100	Percent	0 < LPI <= 100
Aggregation (AI)	AI equals the number of like adjacencies involving the corresponding class, divided by the maximum possible number of like adjacencies involving the corresponding class	Percent	0 <=AI>= 100

4 Result

4.1 Estimated values of UGI based on several indices

Prior to ESs value estimation, land cover classification of three periods Landsat images were performed. Then after summarizing class results, landscape metrics are executed first at landscape level and then at class level. This section also includes the results on the potential ecosystem services in the study area and their estimated value.

4.1.1 Classification results

The classification result showed us the increase in built-up areas as illustrated in Fig. 1, with their respective overall accuracy, Kappa coefficient and confusion matrices for the classified images in three considered periods as illustrated in Table. 5.

The most difficult classes to distinguish were the urban Agriculture (crop land) with only 33.25% accuracy in 2016. Open land areas are confused with bare land, whereas the separability between forest and open lands is satisfactory.

In general, forests scored a good classification result in all four periods with more than 79% producer's accuracy. In all of the three classified images, the omission error is high in crop land class with 41% in 2010, 46% in 2016 and 47% in 2019. Table 5 gives more details on classification accuracies in different land cover classes.

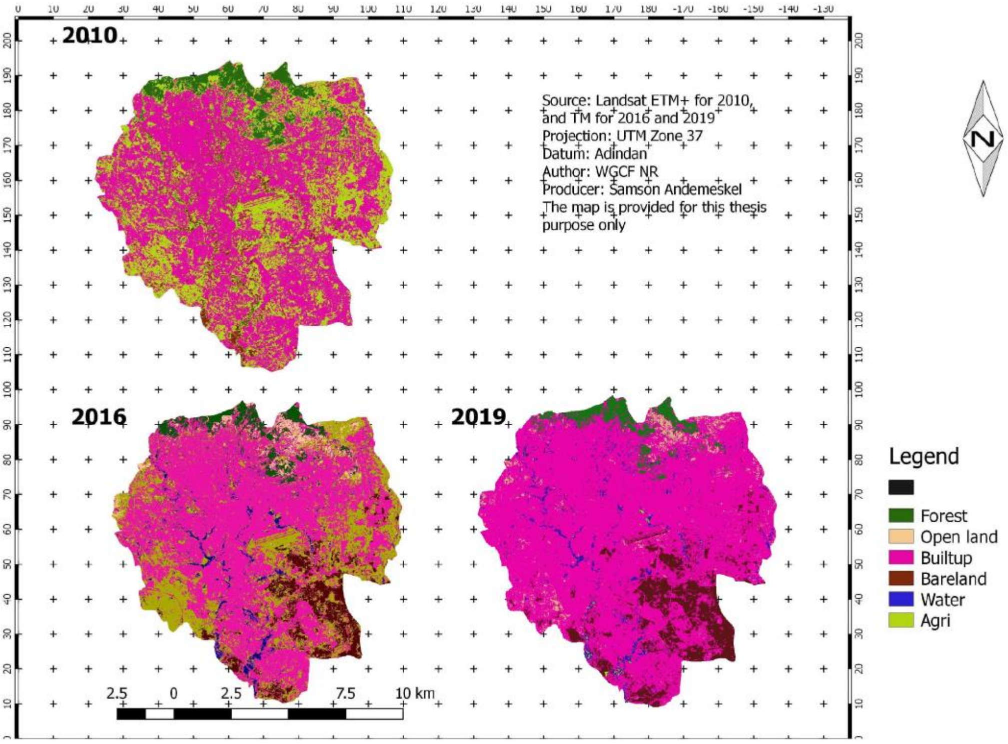


Fig. 2 Supervised classification result of the three epochs

Table 3 Land covers class area coverage and percentage

Land cover class type	Land cover class area (in ha)			Area coverage (in %)		
	2010	2016	2019	2010	2016	2019

Forest	3142.5	1919.7	1952.2	5.81	3.55	3.61
Open land	1241.1	1571.3	1521.3	2.30	2.91	2.81
Built up	23879.9	31348.5	43029.35	44.17	57.98	79.58
Bare land	4682.0	3994.9	5870.3	8.66	7.39	10.86
Wet land	2881.0	1619.3	103.7	5.33	2.99	0.19
Agriculture	18240.5	13613.3	1590.1	33.74	25.18	2.94
Total	54066.95	54066.95	54066.95	100.01	100	99.99

Table 4 Classification accuracies and Kappa Coefficients.

	2010	2016	2019
Overall accuracies (%)	83.99	83.07	88.56
Kappa coefficient	0.75	0.74	0.83

Table 5 Producer and user accuracies (in %)

		Producer accuracy			User accuracy		
No	Land cover type	2010	2016	2019	2010	2016	2019
1	Forest	99.08	79.72	99.54	97.73	100.00	100.00
2	Open land	85.87	91.55	99.29	100.00	100.00	95.58
3	Built up	92.32	96.54	99.57	90.49	87.58	86.66
4	Bare land	77.08	81.30	94.05	92.49	76.13	76.66
5	Wet land	82.27	83.64	45.68	100.00	100.00	69.55
6	Agriculture	56.47	33.25	50.76	41.47	46.13	46.91

4.1.2 Landscape dynamics of Addis Ababa city

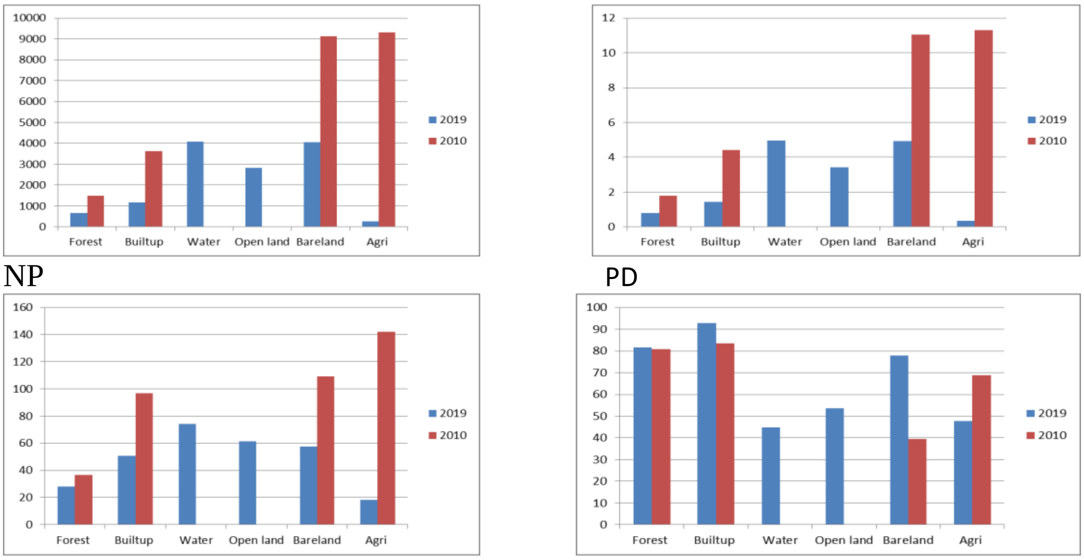
The total landscape area of Addis Ababa is estimated at 54065.78 ha. The landscape is dominated by built up in all four periods. The built up area increased between 2010 and 2019 from 44.17% to 79.58%. The forest cover decreased from 5.81% to 3.55% between 2010 and 2016. However, forest cover increased again between 2016 and 2019 from 3.55% to 3.61.

The increase (stability) of forest after 2016 is attributed to the enforcement of forest policy and regulations such as strict regulations in forest harvesting, forest rehabilitation and management (Ministry of Forestry and Mines, 2010a; Ministry of Forestry and Mines, 2010b; Ministry of Natural Resources, 2014). Built-up areas increased at high pace. The change in bare land can be ascribed to misclassifications given that this class is spectrally confused in some locations with either cropland or forest.

At landscape level, the NP has decreased from 23,552 in 2010 to13,039 patches in 2019. It appears that Addis Ababa City experienced intensive assimilation after 2010 due to the dominance of built up pockets in the urban fringe and peripheral areas. PD almost halved from 2010 and 2019 with values ranging from 28.6 to 15.9 patches per 100 ha, respectively. A high LPI value is found for agriculture that decreased almost twice between the first and the last epochs (109.4% in 2010 against 57.7% in 2016). The schematic representation of the four investigated landscape composition indices is illustrated in Table 4&5 and Fig. 2.

Regarding landscape configuration, the AI was more than 80% at landscape level with incremental decrease from 68.2% in 2010 and 66.4% in 2019. Generally, the AI values indicate that the mosaic of patches in the landscape is aggregated. Nevertheless, the forest and agriculture patch mosaic were found gradually less aggregated as compared to other classes. Even through built-up areas were progressively replacing agriculture (cropland), the former class is still the most aggregated one with more than 92.8%. Fig. 2 illustrates the evolution trends of the four analyzed landscape configuration indices from 2010 to 2019.

Throughout the study, landscape metrics were found to be useful for spatio-temporal evaluation of the urban landscape structure. Currently, with decreased number of patches, two land cover classes, i.e. agriculture and bare land were identified as the most previously fragmented and currently assimilated by built up, in the whole landscape from 2019.



NP PD LPI AI

Fig. 3 Landscape composition indices from 2010 to 2019.

Table 6 2010 Landscape composition indices

	NP	PD	LPI	AI
Forest	1485	1.8009	36.7884	80.8781
Built-up	3637	4.4107	96.8399	83.4615
Bare land	9110	11.048	109.4227	39.4717
Agriculture	9320	11.3026	141.9626	68.8942

Table 7 2019 Landscape composition indices

	NP	PD	LPI	AI
Forest	665	0.809	27.9228	81.7185
Built up	1174	1.4282	50.9291	92.8326
Water	4072	4.9536	74.3717	44.7437
Open land	2811	3.4196	61.2357	53.6363
Bare land	4042	4.9171	57.7054	77.8916
Agriculture	275	0.3345	18.2464	47.7841

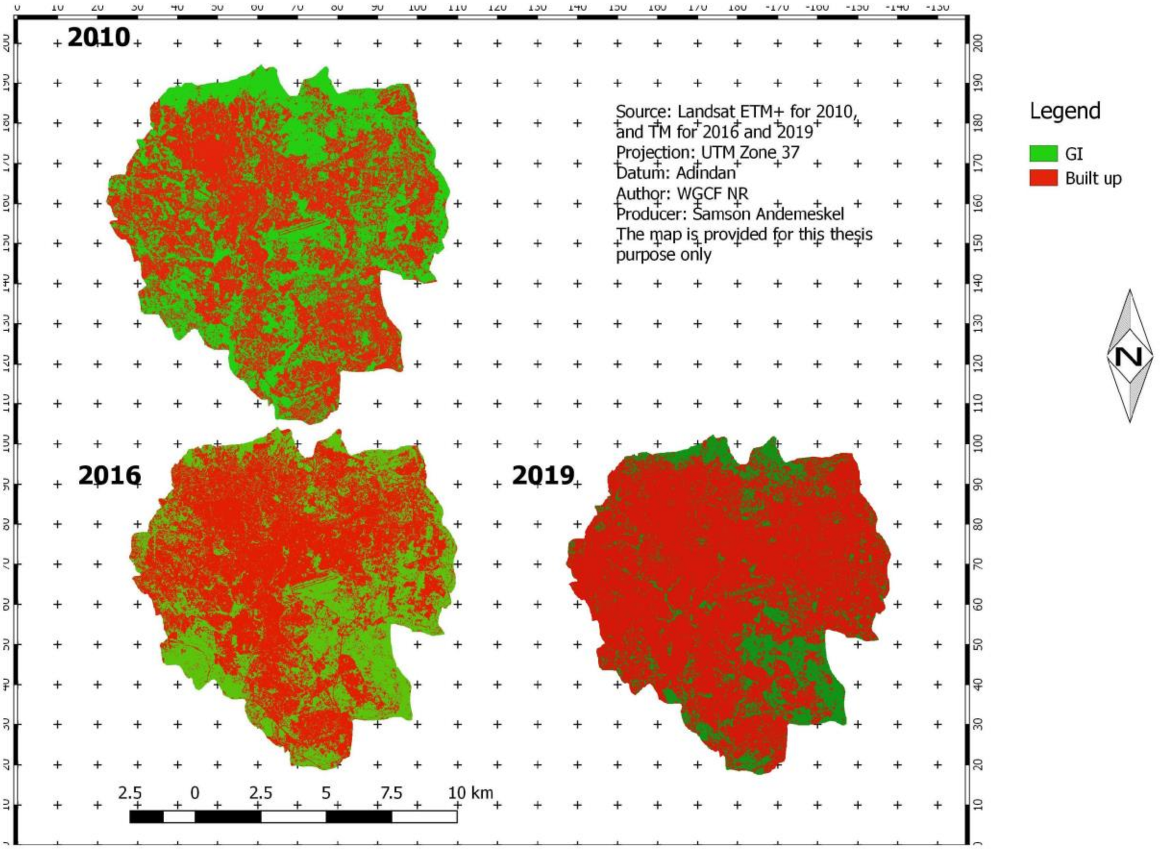


Fig. 4 Maps of the three epochs Reclassified in to GI and Built up

Table 8 Reclassified GI and built up land Area coverage and percentage

Land cover class type	Land cover class area (in ha)			Area Coverage (in %)		
	2010	2016	2019	2010	2016	2019
GI	24263.96	21146.33	10954.69	44.88	39.11	20.42
Built up + bare	29802.99	32919.45	43110.31	55.12	60.89	79.58

land						
Total	54066.95	54065.78	54065.00	100	100	100

4.1.3 Estimated values of urban ecosystem services

The valuation of ES was carried out based on the 2011 global value as updated by Costanza et al. (2014). The authors used a valuation scheme where the unit value US dollar is assigned to a global biome which is comparable to a given ecosystem (see Table 10). The estimated value of urban ES was 324.63 million US dollar per year in 2010. This value increased slightly to 327.69 million US dollar per year in 2016 and decreased to 319.41 in 2019.

The radical ESV increase from 2016 is due to the increase of built-up and open land, with net increase of 80.19% and 22.58%, respectively. Out of the initial ESV of water (river), agricultural and forest supposed to be used was lost by 96.40%, 91.28% and 37.88%, respectively. Built-up, bare land and open land ecosystems systems yield progressively high ESV. Value changes for wetland and open land need cautious interpretation due to misclassifications and spectral variability.

Table 9 Land covers class composition with net change from 2010 to 2019.

Land cover class type	Land cover class area (in ha)			Net change (in %)		
	2010	2016	2019	2010-16	2016-19	2010-19
Forest	3142.5	1919.7	1952.2	-38.91	1.69	-37.88
Open land	1241.1	1571.3	1521.3	26.61	-3.18	22.58
Built up	23879.9	31348.5	43029.35	31.28	37.26	80.19
Bare land	4682.0	3994.9	5870.3	-14.67	46.94	25.38

Wet land	2881.0	1619.3	103.7	-43.79	-93.59	-96.40
Agriculture	18240.5	13613.3	1590.1	-25.37	-88.32	-91.28

Table 10 Estimated value of selected ecosystem services in Addis Ababa

Global terrestrial Biome	Equivalent ecosystems or land cover in Addis Ababa	Estimated ES unit value (in USD/ha/yr)	Estimated ESV (in millions USD)			Net change of ESV between 2010 and 2019 (in %)	Reference
			2010	2016	2019		
Cropland	Agriculture	5,567	103.42	77.19	9.02	-91.28	Costanza, 2014
Wood lot	Forest	5,382	16.91	10.33	10.51	-37.88	De Groot et al. 2012
Lakes/Rivers	Water	12,512	36.71	20.64	1.32	-96.40	Costanza, 2014
Urban systems	Built up	6,661	162.01	212.67	291.91	80.19	Costanza, 2014
Grass/Range land	Open land	4,166	5.27	6.67	6.45	22.58	Costanza, 2014
		Total value	324.63	327.69	319.41	-1.61	

As to the ESV of UGIs the value (agriculture, forest, water and open land) it decreases from 162.63 to 115.01, then to 27.49USD per year; in 2010, 2016 and 2019 respectively. Which showed us that already started to surpass negatively the demanded UNHO standards by 9.58%.

Table 11.Estimated value of UGIs ecosystem services in Addis Ababa (excluding Built up)

Global terrestrial Biome	Equivalent ecosystems in Addis Ababa	Estimated ES unit value (in USD/ha/yr)	Estimated ESV (in millions USD)			Net change of ESV between 2010 and 2019 (in %)
			2010	2016	2019	
Cropland	Agriculture	5,567	103.42	77.19	9.02	-91.28
Tropical forest	Forest	5,382	17.23	10.52	10.70	-37.88
Lakes/Rivers	Water	12,512	36.71	20.64	1.32	-96.40
Grass/Range land	Open land	4,166	5.27	6.67	6.45	22.58
Total value			162.63	115.01	27.49	-83.09

5 Discussion

The disaggregation of land cover classes into sub-classes helped in avoiding class overlap and thus eventually misclassifications. While training data, it was found useful to split the land cover classes into subclasses for avoiding spectral variability in the same land cover class. By referring to the classified satellite images, landscape change is easily quantified using landscape indices and ecosystem service bundles and their estimated values are effectively derived.

The result could be useful in informed decision making and in inciting the willingness to pay for preserving ecosystem integrity. Using fragmentation indicators such as dynamic change in number of patches and landscape splitting index, the urban change intensity could be investigated.

The change in configuration was analyzed through edge and connectivity indices. Edge effects indices which are materialized by the change in physical condition at an ecosystem boundary or within the adjacent ecosystem (Fischerand Lindenmayer, 2007) are useful indicators for investigating the patterns of landscape change trajectory and associated ecosystem services changes.

Nevertheless, the spatial resolution of the image could affect the final classified land cover map and subsequent landscape metrics and derived ecosystem services. For instance, a 30m resolution pixel can encompass more than one land cover class. Built-up area mixed with forest in the same pixel are not easily segregated given that the dominating spectral signatures take the lead in assigning value and this can affect the computed indices such as class area.

The decrease of forest agriculture and water class areas affected the estimated value of forest ecosystem service as well. High AI in cropland class witnesses the class connectivity comparing to other patch mosaic in the study area. It was remarked that deriving ecosystem services for the very same pixel can be subject to errors.

The use of different spatial resolution data as inputs in estimating the value of ecosystem services results in significantly different estimates of the total value. High resolution data, like 1m resolution are believed to enhance the correctness of final land cover map which are subsequently used for computing landscape metrics and ecosystem services' valuation.

6 Conclusion and Recommendation

The study specifically pointed out that the landscape structure of Addis Ababa city has mainly changed in favor of the non-GI since the last ten years, the green spaces has decreased its share from 44.88% in 2010 to 20.42% in 2019. That means 13,576ha of land has been converted to the non-GI land use type.

As a result, currently the UGI of Addis Ababa city is delivering 27.49 million USD worth service every year for its residents, which was 162.63 million USD ten years ago and 115.01 million USD before the last three years. The result is warning us that we already started to cross the standard recommended by UNHO at negative 9.58%, and if no remedial action is taken we may completely loss the ecosystem services within seven years

Hence, the city administration may take this report as good start, with all its uncertainties and controversial, to use it as an input in policy selection and planning, so that to shape a sustainable city any one can comfortably live in. Though, deep study need to be conducted, typically with high resolution imagery and increased ground control samples to minimize error or maximize confidence level.

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