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Addis Ababa University
Addis Ababa Institute of Technology (AAiT)
School of Civil and Environmental Engineering
Geodesy and Geomatics Program
(Geomatics stream)

Assessment of Vegetation Cover Change in Urban Green Spaces, a Case Study of Addis Ababa, Ethiopia"

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A thesis submitted to the School of Civil and Environmental Engineering Graduate Studies of Addis Ababa Institute of Technology in Partial Fulfilment of the Requirement for the Degree of Master of Science in Geodesy and Geomatics Program (Specialization in Geomatics).

Addis Ababa, Ethiopia, June 2024

A Thesis Submitted to the School of Civil and Environmental Engineering of Addis Ababa University in Partial Fulfilment of Degree of Masters of Science in Geodesy and Geomatics.

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Declaration

I declare that this thesis is my original work performed under the supervision of research Advisor Dr. Andinet Ashagrie. The work has not been presented as a thesis for a academic degree in any other university in Ethiopia. Where material has been used from other sources, it has been properly acknowledged.

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This thesis has been presented for evaluation with my endorsement as an academic mentor at the university.

Andenet Ashagrie (phd) ______________________ ______________________

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Abstract

Urban green space (UGS) is crucial for maintaining ecological balance in rapidly urbanizing areas. This study aimed to estimate UGS and quantify oxygen production in Addis Ababa, Ethiopia, for the years 2017 and 2024 using Geographic Information System (GIS) and Remote Sensing (RS) technologies. Sentinel-2A satellite imagery was employed to analyze the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built-up Index (NDBI), assessing changes in vegetation cover and built-up areas. UGS was categorized into dense vegetation, sparse vegetation, and shrub and grassland to estimate oxygen production. The results revealed a significant decline in green spaces and an expansion of built-up areas from 2017 to 2024, indicating rapid urbanization. In 2017, UGS covered 18,818.33 hectares, producing an estimated 33,872.994 tons of oxygen per year. Detailed oxygen production for 2017 included dense vegetation (2,663.39 tons/year), sparse vegetation (2,613.72 tons/year), and shrub and grassland (3,299.22 tons/year). By 2024, UGS reduced to 16,842.17 hectares, with an estimated oxygen production of 30,315.906 tons/year, including dense vegetation (2,862.129 tons/year), sparse vegetation (3,017.96 tons/year), and shrub and grassland (2,402.379 tons/year). Accuracy assessments using Google satellite imagery and ground-collected GPS data validated the classification results. These findings highlight the ecological impact of diminishing green spaces due to urbanization. This research underscores the urgent need for sustainable urban planning and the preservation of green spaces in Addis Ababa to mitigate adverse environmental effects and maintain ecological balance.

Keywords: Urban green space, oxygen release, GIS and Remote Sensing, sentinel 2A image

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List of Abbreviations

UGS	Urban green space
NDVI	Normalized Difference Vegetation Index
NDBI	Normalized Difference Built up Index
OBIA	Object based image analysis
RS	Remote Sensing
GIS	Geographic Information System
LUE	Light Use Efficiency
SWIR	Shortwave-infrared
NIR	Near-infrared
LULC	Land use land cover classification
SVM	Support vector machine
GPS	Global positioning system
UHI	Urban heat island effect

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Urban green spaces (UGS) enhance physical activity, psychological well-being, and overall health for urban residents, while also providing essential ecological services (Assaye et al., 2017; Bekele et al., 2022). These spaces encompass parks, forests, green roofs, wetlands, and areas covered with vegetation such as grass, trees, and shrubs. Urban waters, including ditches, canals, rivers, and riverside greens, are also considered part of UGS (Warkaye et al., 2018). UGS offers a range of ecosystem services, including flood resilience, pollution mitigation, and erosion control from stormwater runoff (Wolch et al., 2014). However, urban expansion leads to the degradation of vegetation, and the benefits of green spaces are often inequitably distributed. Globally, the demand for UGS is rising and is a key issue on city policy agendas (Haase et al., 2014).

Urban vegetation also plays a crucial role in reducing the urban heat island (UHI) effect, which occurs when cities replace natural land cover with materials that retain heat, leading to higher temperatures, reduced night time cooling, and increased air pollution (Yang et al., 2016). This exacerbates heat-related health issues, including respiratory difficulties and heat exhaustion (EPA, 2022). Moreover, UGS contributes to mitigating climate change impacts (Muluneh et al., 2017; Hou et al., 2018). Therefore, city planners must implement policies to enhance urban ecosystem services and ensure equitable access to UGS. However, managing UGS amid rapid urban growth is a major challenge for governments due to ongoing environmental, social, and economic changes in cities.

Addis Ababa, Ethiopia's capital, is experiencing rapid population growth, leading to increased built-up density, infrastructure development, and residential expansion. This has resulted in the conversion of green spaces into built-up areas, causing the loss of native biodiversity and regulated microclimate (Biernacka & Kronenberg, 2018). Detailed UGS mapping is essential for policymakers to implement sustainable land management and assess UGS based on availability, quantity, and distribution (Seifu & Stellchmacher, 2020). Various methodologies, including remote sensing and GIS, are used to map UGS. These technologies help identify green spaces, analyse land use and land cover, assess vegetation cover using the Normalized Difference Vegetation Index (NDVI), detect changes, and provide valuable information for decision-making (Hoang & Tran, 2021). Recent advancements in remote sensing, such as high spatial resolution imaging and free data access, have made it easier to study UGS without extensive field surveys, even in complex urban environments (Pu & Landry, 2012).

Despite significant research on UGS in many parts of the world, Sub-Saharan Africa, particularly Ethiopia, has seen limited studies on UGS accessibility. This study aims to examine the demand and accessibility of public parks at the sub-city level in Addis Ababa, focusing on urban forests, agricultural land, and public recreational parks. The study utilizes Sentinel-2A satellite imagery, Google Earth Engine, ground truth data, and land-cover assessment indices (NDVI and NDBI) to monitor and assess vegetation and built-up areas. The classification was conducted using support vector machine and object-based image analysis (OBIA), with accuracy checked via a confusion matrix. Post-classification analysis identified land-use and land-cover areas, and public park accessibility within sub-cities was examined using network analysis proximity indicators. The research highlights the application of remote sensing and GIS in assessing the accessibility and demand for UGS in Addis Ababa.

Currently, cities occupy only 2.7% of the Earth's surface but are responsible for 75% of energy use, 80% of greenhouse gas emissions, and have a significant impact on natural resources (UNESA, 2014; Gret-Regamey et al., 2013). To address the challenges posed by urbanization, UGS is increasingly recognized as an effective strategy worldwide. Despite the benefits of UGS, many cities are losing green spaces. For instance, in Europe, 75% of the population lives in urban areas, a figure expected to rise to 80% by 2050 (Giuliani et al., 2021). In the USA, 1.4 million hectares of green space have been converted to other land uses in 274 metropolitan areas (McDonald et al., 2010). In Africa, green spaces make up a small portion of land, and access to public recreational parks is limited (Adjei, 2014). While most research on UGS focuses on developed countries, the availability and accessibility of UGS in rapidly urbanizing cities in developing countries have received little attention. Studies have predominantly concentrated on wealthy nations (Giles-Corti et al., 2005; Kabisch & Haase, 2013; Baycan-Levent & Nijkamp, 2009), overlooking the distinct social, economic, cultural, and political contexts of rapidly urbanizing African countries.

1.2 Statement of the problem

Urban green spaces are vital landscapes that contribute to the natural environment and enhance various aspects of life. They are integral components of any urban structure. However, unplanned urbanization and the conversion of green areas into built-up structures have negatively impacted ecosystems (Manea & Gabriela, 2011). The demand for urban green spaces varies based on population changes, urban expansion types, and geographical locations (Klopp & Petretta, 2017). Rapid urban growth and widespread unplanned settlements have made green spaces the most threatened urban natural ecosystems (Cilliers et al., 2012). In many large and rapidly growing cities in developing countries, the number and size of green spaces are insufficient and unevenly distributed (Kestermont et al., 2011). Moreover, the degradation of essential green areas, especially in urban regions, is contributing to human-induced climate change, leading to significant and unmanaged temperature increases. Consequently, urban heat stress adversely affects city residents and the environment (Haaland & Bosch, 2015). Given the urgency of this issue, the current study aims to explore the distribution of urban green spaces and assess their accessibility across eleven service areas (sub-cities). Additionally, the study will investigate the current demand for green spaces in relation to population settlements, ultimately providing relevant recommendations and suggestions upon the completion of this research.

Urban green spaces play a critical role in sustainable urban development, offering numerous environmental, social, and health benefits. Among these ecological services, oxygen production through photosynthesis is crucial for maintaining air quality and supporting urban life. In rapidly expanding cities like Addis Ababa, where industrial activities and vehicle emissions significantly contribute to air pollution, understanding and quantifying the oxygen production of urban green spaces is increasingly important.

Despite the recognized importance of urban green spaces, there is a shortage of detailed and accurate data on oxygen release from these areas in Addis Ababa. Traditional methods for estimating oxygen production are often labour-intensive and time-consuming, making them impractical for large-scale urban applications. Remote Sensing (RS) technology presents a promising solution by enabling efficient and precise assessment of vegetation health and coverage, directly related to oxygen production capabilities.

This study seeks to fill the current knowledge gap by using Remote Sensing techniques to estimate oxygen release from urban green spaces in Addis Ababa. By combining satellite imagery with ground-based observations, this research will provide a comprehensive analysis of the spatial distribution and contribution of green spaces to the urban environment’s oxygen levels. The findings underscore the ecological value of urban green spaces and inform urban planning and policy-making to enhance green infrastructure in Addis Ababa.

The central issue addressed in this thesis is the absence of a reliable, scalable method for estimating oxygen release from urban green spaces in Addis Ababa, which limits effective urban planning and environmental management. By developing and validating a Remote Sensing-based approach, this research will contribute to a better understanding of how urban green spaces can be optimized to improve air quality and support sustainable urban development.

1.3 Research objectives

1.3.1 General objective

The main objective of the study is to estimate the amount oxygen released by urban green space in Addis Ababa using GIS and remote sensing

1.3.2Specific objective

1 Quantifying and Mapping of oxygen release by urban green space of Addis Ababa city since 2017 to 2024

2 Mapping the distribution of UGS using NDVI

1.4 Research Question

How to map and quantify the amount of oxygen realised by urban green space using GIS and RS

How to map vegetation distribution using NDVI

1.5 Significance of the study

The study on "Estimating Oxygen Release by Urban Green Space Using GIS and Remote Sensing in Addis Ababa" holds substantial significance for various stakeholders, including urban planners, environmental policymakers, and the general public. Firstly, by estimating the oxygen release from urban green spaces, this research provides critical data to enhance urban air quality in Addis Ababa, a city facing significant challenges from industrial activities and vehicular emissions. Increased oxygen levels contribute to healthier urban environments, reducing respiratory and cardiovascular diseases among residents. Furthermore, the findings will equip urban planners with essential information to design and implement green infrastructure more effectively. Understanding the spatial distribution and oxygen production capacity of existing green spaces will aid in developing urban plans that maximize ecological benefits, promote biodiversity, and create more livable urban areas.

Additionally, this study offers valuable insights for environmental managers regarding the maintenance and expansion of green spaces. By identifying areas with high oxygen production, managers can prioritize conservation efforts and implement strategies to enhance vegetation health and coverage, optimizing the ecological functions of urban green spaces. The application of GIS and Remote Sensing (RS) technologies in this context represents a significant advancement in urban ecological research. The methodologies developed and validated in this study can be adapted and applied in other urban settings, contributing to the broader scientific understanding of urban green space benefits. Moreover, the study's outcomes can raise public awareness about the critical role of green spaces in urban ecosystems. Educating the community about the importance of preserving and expanding urban green areas can foster greater public support and engagement in environmental conservation efforts.

Finally, policy makers can utilize the study's findings to develop and implement policies that support the creation and maintenance of urban green spaces. This research provides empirical evidence needed to advocate for investments in green infrastructure, aligning with global sustainability goals and improving overall urban resilience. In summary, this study is pivotal in providing a scientific basis for enhancing urban green spaces in Addis Ababa through advanced GIS and RS technologies, offering practical solutions for urban sustainability, public health, and environmental management.

1.6 Scope of the study

AABPCDAA (2015) reports that urban green spaces include public parks, greenery alongside road and road divide, road squares, urban forest, trees in churches and non-religious institutions. There are different UGSs found in the study area giving services to the public. Due to the time limitation and availability of resources (financial and material), the study will emphasis on mapping only major UGSs (dense and healthy vegetation, healthier vegetation, low to moderate vegetation cover Sparse vegetation) The study emphasized on the application of Remote Sensing and GIS technologies on generating a valuable information regarding NDVI, and estimating oxygen realise using Light Use Efficiency (LUE) Model , therefore the study is limited on estimating oxygen realised by urban green space in addis Ababa.

1.8 Organization of the thesis

This thesis will have six chapters. The first chapter contains introduction, statement of the problem, research objectives, scope and limitation of the study. The second chapter focuses on reviewing literatures on urban green spaces definitions and background, urban green space benefits, land use land cover change, indices for detecting built up and vegetation cover change, spatial analysis of green spaces and the advancement of remote sensing and GIS technologies for mapping urban green spaces and model for estimating urban green space The third chapter emphasizes on study area explanation and justification, resource required and methodology followed. The fourth chapter is about results and fifth chapter on discussion part. The six chapter deals with conclusion and recommendation based on results and discussion presented .

CHAPTER TWO

LITERATURE REVIEW

2.1 Definition of Urban Green Space

Urban green spaces (UGS) have been defined in various ways in the literature. As per Cemil and Gökyer (2012), urban green spaces are areas within cities characterized by natural or semi-natural ecosystems that have been transformed into urban environments due to human activity. Farrar (2009) defines green spaces as encompassing a range of areas including recreational fields, urban agricultural zones, and natural play areas for children, rooftop and balcony gardens, community compost sites, orchards, and cycling routes. Alamrew (2002), drawing from various sources, categorizes urban green spaces into formal and informal types. Formal green spaces include publicly protected parks, street gardens, playgrounds, sports fields, squares, private gardens, and vegetative areas within institutions like schools, hospitals, and religious sites. Conversely, informal green spaces encompass forested areas, river valleys, reserved expansion zones, agricultural lands, and open undeveloped spaces. These green spaces serve as vital connections between urban environments and nature, reflecting natural or semi-natural areas within city spaces. The importance of UGS in enhancing urban environments, improving quality of life, and contributing to sustainable urban planning is on par with other essential infrastructures like water, electricity, sewage systems, and transportation (Fariba, 2013). In the 21st century, there is a strong consensus on the crucial role of urban green spaces in fostering sustainable eco-cities, particularly as increasing traffic and urban heat, especially in developing countries, not only harm the environment but also impose social and economic costs. Urban green spaces must be easily accessible and sufficient in both quality and quantity to meet the social and psychological needs of urban residents (Haq, 2011).

2.2 Types of Urban Green Space

Urban green spaces comprise various physical elements such as urban forests, parks, riverine areas, and street trees. Green spaces can take many forms, including natural play areas, community gardens, urban agriculture, and rooftop gardens (Farrar, 2009; Rodhead, 2009). Natural play spaces, which incorporate natural elements, water, and local plants, are becoming increasingly popular due to their significant benefits for children's health, wellbeing, and development. Community gardens offer substantial social, economic, and environmental benefits, while urban agriculture, with a slightly different focus, plays a crucial role in social movements and food security. Rooftop gardens, provided the building structure can support them, are an excellent source of organic produce for urban dwellers. It’s important to distinguish between green roofs, which are architectural projects involving the integration of vegetation into the structure of a building, and rooftop gardens, which consist of movable planters that do not necessarily require structural modifications.

2.3 Benefits of Urban Green Spaces

The rapid pace of urbanization has led to increased environmental stress in cities, manifesting as poor air quality, noise pollution, heightened traffic congestion, and more frequent extreme heat events. These adverse conditions negatively impact urban populations, contributing to a global rise in pollution-related health issues such as asthma, cancer, and chronic respiratory conditions (Leavell et al., 2019). Maintaining and protecting urban green spaces can counteract these trends and significantly improve the quality of life for city residents by providing cost-effective solutions (Van den Berg et al., 2010). For instance, trees can sequester substantial amounts of dust and carbon dioxide annually. Beyond their environmental benefits, green spaces also offer numerous social and physical benefits, functioning as multifunctional ecosystems.

2.3.1 Social Benefits of UGS

Urban green spaces can foster social interactions that enhance health, wellness, and community cohesion. These spaces are linked to improved health outcomes by encouraging social interaction and physical activity. UGSs provide opportunities for people of all ages to engage socially, which can alleviate symptoms of depression and enhance social health (Jennings & Bamkole, 2019; Kondo et al., 2018). Additionally, UGSs are associated with a sense of safety and security, while enclosed spaces tend to be perceived as less safe (Lorson & Hipp, 2022; Holtan et al., 2015).

2.3.2 Physical (Health) Benefits of UGS

The ecological services provided by green spaces contribute to the physical, emotional, and social well-being of users. Research indicates a positive correlation between green space availability and survival rates among older adults (Wood et al., 2017), as well as a reduction in stroke mortality rates in greener environments. Green spaces can also mitigate the negative health impacts of stressful life events. Natural outdoor settings are beneficial to mental health due to the physiological changes they induce in the body. For example, a Japanese study found that being in or walking through forests can lower cortisol levels, pulse rates, and blood pressure compared to urban environments (Park et al., 2010). During the COVID-19 lockdowns, individuals with views of nature from their homes reported lower levels of psychological distress and stress (Ribeiro et al., 2021).

2.3.3 Environmental Benefits of UGS

Green and open spaces are essential in urban areas as they enhance health, well-being, and the environment. These spaces, which include parks, gardens, and green infrastructure such as plant walls and green roofs, naturally cool urban areas and aid in water management (Rakhshandehroo et al., 2017). The vegetation in these spaces absorbs carbon dioxide, helping to reduce greenhouse gas emissions. With climate change intensifying heatwaves, droughts, and storms, urban areas must expand their green spaces to combat these challenges. Creating more green spaces and open areas will enhance the resilience and sustainability of urban environments.

2.4 Urban Green Space Depletion

Urban green spaces are rapidly declining worldwide, with studies indicating that 7.3−41% of land designated for green spaces in 25 European cities has been repurposed for other uses (Essel, 2017). Similarly, research on land use changes in 274 U.S. metropolitan areas found that nearly 1.4 million hectares of urban green space were lost to development between 1990 and 2000 (McDonald et al., 2010). Consequently, many countries now enforce green space standards that exceed the World Health Organization and United Nations Food and Agriculture Organization's minimum recommendation of 9 m² per capita (Wang, 2009). In Africa, the status of urban green spaces varies widely. In South Africa, green areas comprise less than 10% of the total land in some municipalities (McConnachie et al., 2008). The situation is particularly concerning in Lagos, where green space accounts for just 3% of the city’s total area (Oduwaye, 2013). In Alexandria, Cairo, and Luanda, the per capita green space is below 1 m² (Mensah, 2014).

Although Ethiopia is among the least urbanized nations in Sub-Saharan Africa, rapid urbanization is expected, with 60% of the population projected to reside in cities by 2040, up from 7.1% in 1994 (United Nations, 2014; Lamson-Hall et al., 2018). Thus, integrating green spaces into urban planning is crucial to meeting future needs and preserving ecosystems.

2.5 Vegetation and Built-up Indices

Spectral indices play a vital role in analyzing, modeling, and forecasting surface dynamics. These indices, derived from various satellite spectral band combinations, have been applied in numerous fields, including agriculture, water resources, urban planning, forest ecology, geology, and soil sciences. Landsat-8, Sentinel-2, and other spectral indices have been widely used over time to address complex environmental challenges.

2.5.1 Normalized Difference Vegetation Index (NDVI)

Vegetation indices, such as the Normalized Difference Vegetation Index (NDVI), are crucial for analyzing land cover changes and monitoring trends. NDVI values range from 0 to 1, with higher values indicating denser vegetation. This index is particularly useful for distinguishing vegetated from non-vegetated areas, and it remains unaffected by factors such as slope, seasons, and illumination (Meera et al., 2015). In this study, NDVI was employed to assess the current vegetation cover in Addis Ababa.

2.5.2 Normalized Difference Built-up Index (NDBI)

The Normalized Difference Built-up Index (NDBI), introduced in 2003, is a method used to map built-up areas automatically. Initially applied in Nanjing, China, the NDBI was effective in distinguishing built-up areas from vegetated or green and wet surroundings (Chunyang et al., 2010). This index, calculated using the difference and sum of reflectance from the shortwave-infrared (SWIR) and near-infrared (NIR) bands, has applications in watershed runoff predictions and land-use planning (Yasin et al., 2020). In this study, NDBI was used to explore urban expansion in Addis Ababa.

2.6 Remote Sensing and GIS for UGS Mapping

Accurate and up-to-date spatial data on green spaces are essential for urban land use planning and management. Traditional methods of landscape surveys have become increasingly challenging due to the rapid transformation and fragmentation of green spaces caused by urbanization. Given the time and labor-intensive nature of field data collection, there is a need for modern automated approaches to survey green spaces (Mengistu & Salami, 2007). This study integrates accessibility analysis with remote sensing image classification, using spectral indices, GIS network analysis tools, and unsupervised classification algorithms to estimate the distribution and accessibility of urban green spaces.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Geographic Location and Area Coverage

Ethiopia is recognized for its rapid economic growth, both in Africa and globally, with Addis Ababa as its capital and the diplomatic center of Africa. The city spans an area of 526.47 km², located between 38°39′03″ – 38°54′19″ E longitude and 8°50′10″ – 9°06′01″ N latitude. Figure 3.1 illustrates the geographic location and shape of the study area.

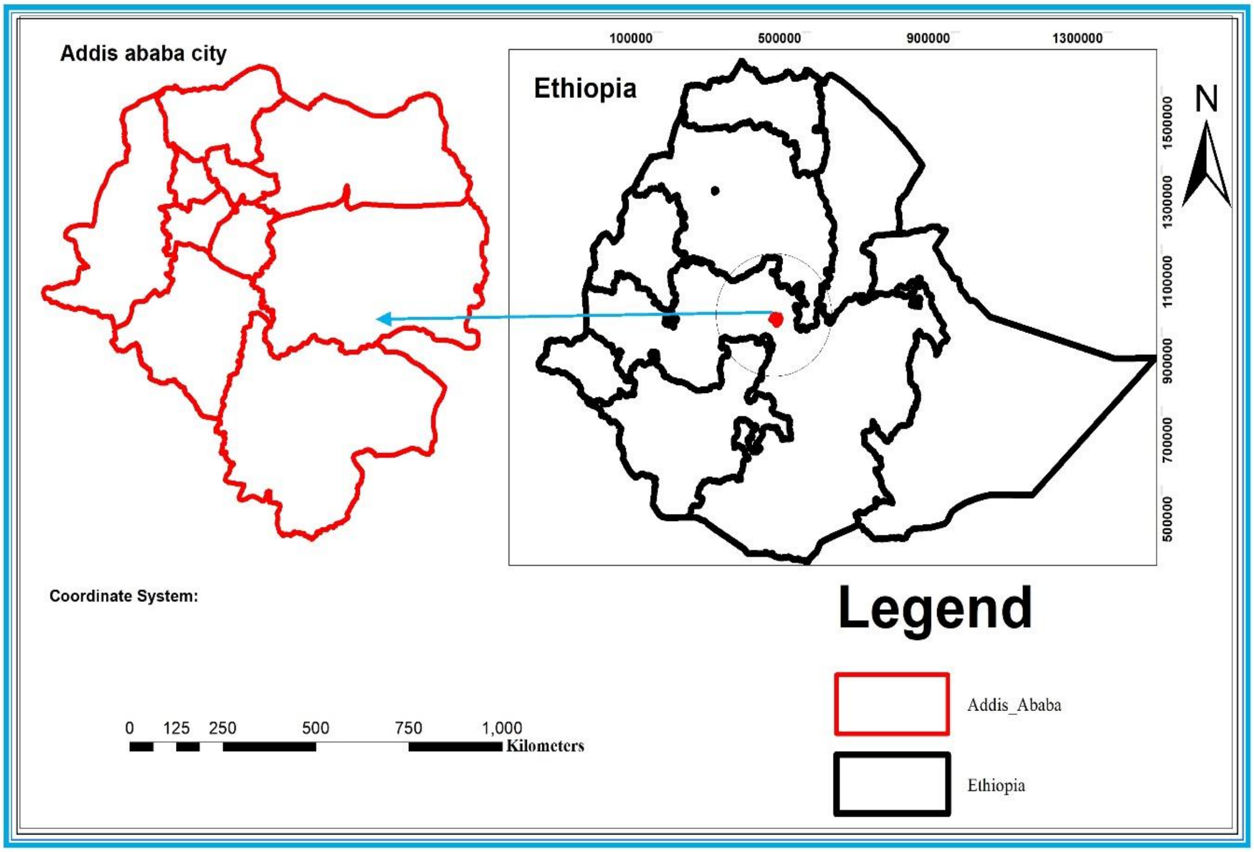

Figure 3.1 Geographic locations and shape of the study area

3.2 Topography

Situated on a well-watered plateau, Addis Ababa is surrounded by hills and mountains, lying at the base of Mount Entoto. The city’s elevation ranges from 2,326 meters in the southern region near Bole to 3,000 meters at its highest point on Entoto Mountain in the north.

3.3 Temperature

The average annual temperature in Addis Ababa ranges between 16 and 30°C (60-63°F). The warmest period, with temperatures reaching about 29/30°C (84/86°F), occurs from February to May, prior to the rainy season. May is typically the warmest month, averaging 18°C (64.4°F). The cool season extends from July 7 to September 6, with daily high temperatures generally below 67°F, and August being the coldest month, with lows around 54°F and highs around 66°F. Temperature variations across the city are influenced by altitude and location.

3.4 Rainfall

Addis Ababa experiences a subtropical highland climate with two rainy seasons: one from February to April and the other from June to September. The city receives an average of 1,200 mm of rainfall annually, with the heaviest rains occurring in July and August. This precipitation is essential for agriculture, supporting crops like coffee, a key Ethiopian export. However, heavy rains can also cause flooding, especially in lower-lying areas. The dry season, from October to January, brings warm and sunny weather, with temperatures ranging between 15°C and 25°C.

3.5 Population

As Ethiopia's largest city, Addis Ababa is home to over 5 million people, accounting for approximately 60% of the nation's urban population. The city is ethnically diverse, with groups such as the Oromo, Amhara, and Tigray well represented. The population has grown steadily, driven by urbanization, migration from rural areas, and a high birth rate. According to United Nations estimates, Addis Ababa's population reached 5,461,000 in 2023, with an annual growth rate of 4.46%. The distribution of the population across the city's sub-cities is presented in Table 3.1.

Table 3.1 Addis Ababa Sub city Population number in 2023

No	Sub city	Total population	Population Density
1	Arada	298,043	29,804
2	Addis Ketema	359,735	17,130
3	Akaki-Kality	255,349	2,027
4	Lideta	284.208	18,948
5	Gulele	377,032	10,190
6	Kirkos	311,765	20,784
7	Yeka	459,225	7,918
8	Nifas-silk	445,683	8,739
9	Kolfe-keranio	604,226	11,847
10	Bole	378,816	5,740
11	Lemi-Kura	85,918	965

3.6 Data collection methods

This study utilizes both satellite and ancillary data. Ancillary data include shape files of the study area, population data, and ground truth information for extracting public park facilities. Ground truth data were gathered using a handheld GPS to validate land-use and land-cover classes, aiding in the accuracy assessment of classification results. Supervised Object-Based Image Analysis (OBIA) will be used to map urban green spaces.

3.7 Data Acquisition

Sentinel-2A imagery was employed for Normalized Difference Vegetation Index (NDVI) analysis. Data were acquired during the dry season (January-February 2024) from the European Space Agency (ESA) to classify urban green spaces. These data, provided through the European Copernicus program, include 13 spectral bands with a swath width of 290 km and spatial resolutions of 10 m, 20 m, and 60 m (Jian & David, 2017). The mission supports monitoring vegetation changes during the growing season (Simonetti et al., 2017). Detailed data acquisition information is listed in Table 3.2.

Table 3.2 data source

Year	Date of Image Acquisition (dd/mm/yyyy)	Sensor	Cloud cover (%)	Spatial resolution	Source
2017	19/01/2017	Sentinel L2A	6	10	https://scihub.copernicus.eu
2024	27/02/2024	Sentinel L2A	6	10	https://scihub.copernicus.eu

3.8 Material and Software

Remote sensing and GIS software were crucial for data collection, processing, and analysis. ArcGIS Pro 2.81 was used for mosaicking and NDVI analysis, while land-use/land-cover classification and accuracy assessment were conducted using both ArcGIS Pro and ArcGIS 10.5. Ground truth data were collected using a handheld GPS and Google satellite imagery.

3.9 Data pre-processing for Sentinel 2A

Sentinel-2A data are delivered in the SAFE format as zip-compressed files. The imagery, atmospherically and radio metrically corrected by ESA, was selected with less than 6% cloud cover. Three different geometric resolutions (10 m, 20 m, and 60 m) were used to store the spectral bands. The images were combined into a single 10 m-wide GeoTIFF file and the study area was subset during pre-processing. Data processing and classification were performed using ERDAS Imagine 2014 and ArcGIS Pro 2.81. The band wavelengths and resolutions are provided in Table 3.3.

Table 3.3 band wavelength and resolution

Band	Type	Wavelength (µm)	Resolution (m)
1	Coastal aerosol	0.443	60
2	Blue	0.490	10
3	Green	0.560	10
4	Red	0.665	10
5	Near infrared	0.705	20
6	Near infrared	0.740	20
7	Near infrared	0.783	20
8	Near infrared	0.842	10
8A	Near infrared	0.865	20
9	Water vapour	0.945	60
10	Cirrus	1.375	60
11	Shortwave infrared	1.610	20
12	Shortwave infrared	2.190	20

3.10 Data Analysis

3.10.1 Satellite indices

3.10.1.1 Normalized Difference Vegetation Index (NDVI)

NDVI is calculated by dividing the difference between the near-infrared (NIR) and red values by their sum. For Sentinel-2A, NDVI is computed as (Band 8 – Band 4) / (Band 8 + Band 4). The 2024 NDVI image was classified using ArcGIS Pro to evaluate vegetation cover in the study area.

3.10.1.2 Normalized Difference Built-up Index (NDBI)

NDBI, used for mapping built-up areas, was first implemented in Nanjing, China (Chunyang et al., 2010). The index is calculated as (ρSWIR-ρNIR) / (ρSWIR+ρNIR), where SWIR refers to the shortwave infrared band and NIR to the near-infrared band. In this study, NDBI was applied to examine urban expansion in Addis Ababa.

3.11 Support Vector Machine Algorithm

Remote sensing is a key tool for extracting land cover information through classification analysis. Image segmentation is performed before feature selection to train the Support Vector Machine (SVM) classifier for land-use and land-cover classification (Cortes & Vapnik, 1995). Ground data were gathered using a handheld GPS in 2024 and Google Earth imagery from 2017, corresponding with the time of satellite data acquisition.

3.12 Object-based Classification

Object based image classification is based on the spectral information in each pixel, object-based classification is based on information from a set of similar pixels called objects or image objects. Image objects or features are groups of pixels that are similar to one another based on the spectral properties such as size, shape, and texture, as well as context from a neighborhood surrounding the pixels. Object-based classification is a two-step process, first the image is segmented or broken into discrete objects or features with and then each object is classified. This type of classification attempts to mimic the type of analysis done by humans during visual interpretation. Object-based classification methods were developed relatively recently compared to traditional pixel based classification techniques.

3.13 Development of classification scheme

Designing a classification scheme for mapping land use that meets diverse needs for land-use maps (Yu, L., & Liu, Y. 2003).Based on the prior knowledge of the study area, a brief reconnaissance survey was carried out using Subset image (based on the shape of the study area) and a classification scheme was developed and are used to produce the final land use/land cover map of the study area. Accordingly five classes were identified namely urban areas, Barren Land, sparse vegetation, Shrub and Grassland, Dense and healthy vegetation (in Table 3.2) and table 3.3 for the year 2017 and 2024

Table 3.4 classes of land use land cover change for the year 2017

Class	**Description**
Urban Areas	Areas with buildings, roads, pavements, and other urban infrastructure, including artificial water features such as canals.
Barren Land	Areas with construction sites, vacant lots, degraded areas, or exposed soil or rock.
Shrub and Grassland	Natural grasslands, shrublands, savannas, open woodlands, parks, and artificial grass.
Sparse Vegetation	Areas with semi-natural habitats, peri-urban forests, and vegetated corridors.
Dense Vegetation	Areas with urban forests, protected areas, botanical gardens, large parks with mature trees

Table 3.5 classes of land use land cover change for the year 2017 and 2024

3.14 Accuracy assessment

Accuracy assessment is a crucial aspect of any classification project. It involves comparing the classified image to a reference data source considered accurate, often referred to as ground truth data. While ground truth can be collected through fieldwork, this method can be both time-consuming and costly. Alternatively, ground truth data can be obtained from high-resolution satellite imagery. The most common method for evaluating the accuracy of a classified map is by generating a set of random points from the ground truth data and comparing these with the classified data using a confusion matrix. In this study, Google satellite imagery and GPS data collected in the field were used as ground truth to assess classification accuracy. To validate the classifications for 2017 and 2024, a total of 351 and 333 randomly selected points, respectively, were used across five land use and land cover classes. According to Anderson et al. (1976), for a reliable land cover classification, the minimum overall accuracy derived from an error matrix should be 85%.

3.15 General methodology flow chart

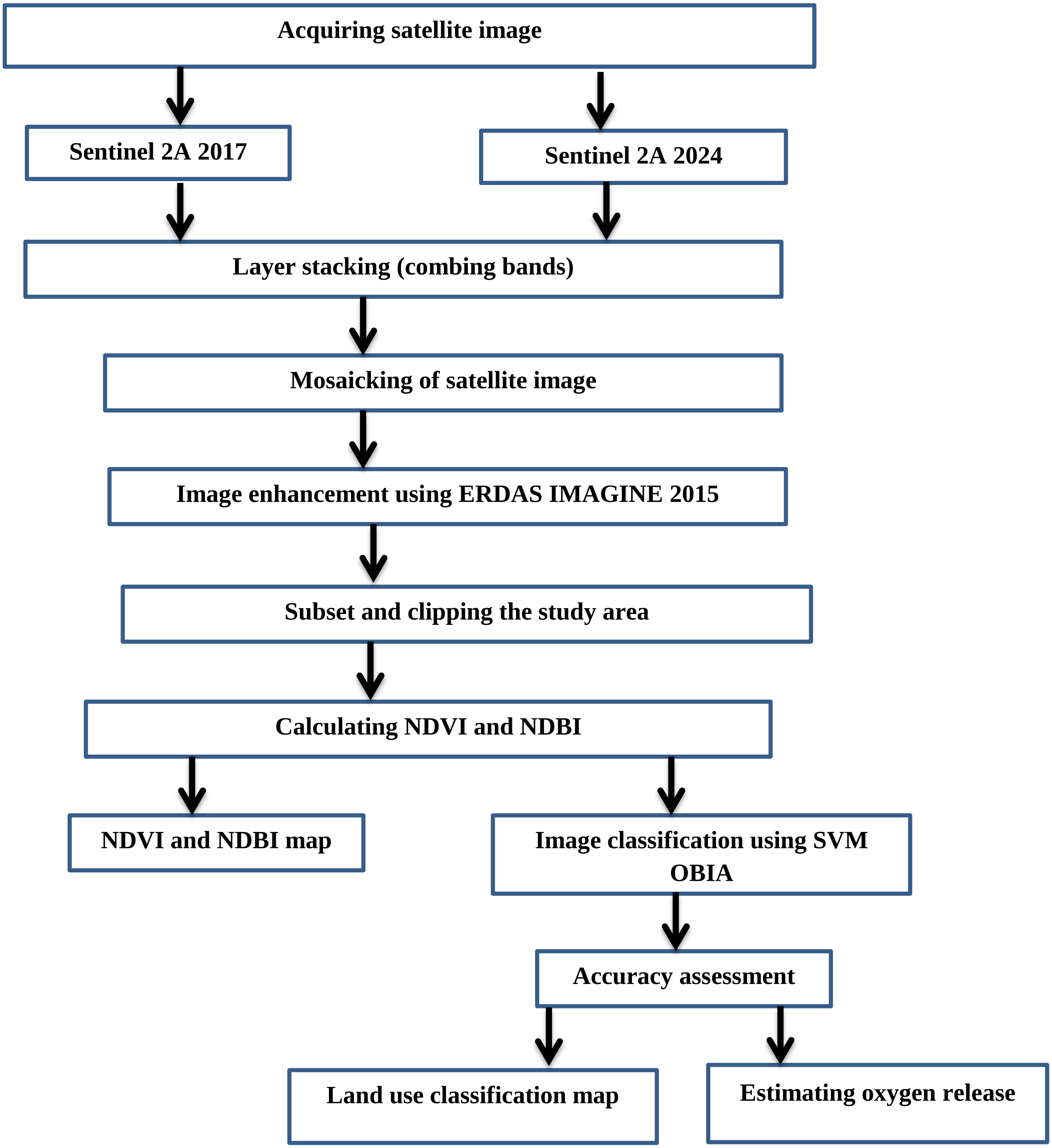

Figure 3.2 flow chart

CHAPTER FOUR

RESULTS

4.1 NDVI, NDBI and Land-use and land-cover status of UGS

4.1.1 Accuracy assessment of 2017

4.1.1.1 Confusion matrix for 2017

Producer's accuracy of urban areas 92.9%, Sparse Vegetation 84.3%, Shrub and Grass land 92.6% and Barren Land 87.4% and user's accuracy urban areas 95.1%, Sparse Vegetation 89.7%, Shrub and Grassland 82.4% and Barren Land 90.0%. The overall accuracies in the study period 2017 is 89.2%. As shown this result the highest user's and producer's accuracies were observed in urban areas the lowest user's and producer's accuracy were Shrub and Grassland and Sparse Vegetation respectively. The lowest values of class accuracies were misclassified due to spectral property similarities among other land cover classes. The results are shown in table4.1 below.

Table 4.1 Confusion matrix of 2017 land use classes

Classified data	urban areas	sparse vegetation	Shrub and Grassland	Barren Land	Total	User accuracy (100%)
urban areas	78	1	1	2	82	95.1
Sparse Vegetation	2	70	3	3	78	89.7
Shrub and Grassland	3	5	75	8	91	82.4
Barren Land	1	7	2	90	100	90.0
Total	84	83	81	103	351	
	92.9	84.3	92.6	87.4		
	Producer accuracy (100%)					
	Over all accuracy		89.2			

4.1.2 NDVI of 2017

A sentinel2A image was used to assign Normalized difference vegetation index map (NDVI) range from -0.28 to 0.75 which shows non vegetation areas dense vegetation areas respectively based on the result the northern part of the city is manly covered by dense vegetation where the remaining and most part of the city is covered by built up areas figure below shows NDVI values of the year 2017.

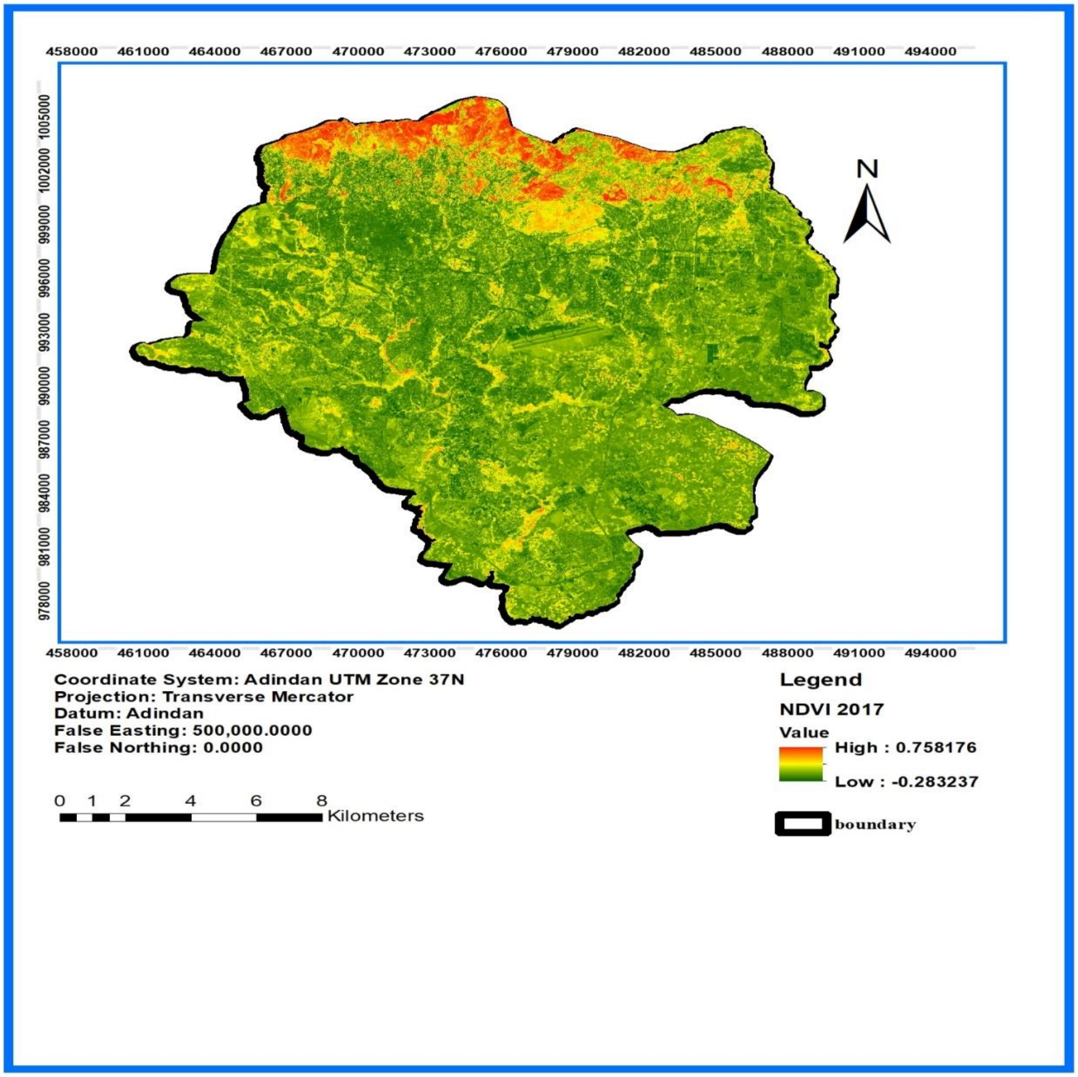

Fig 4.1 Normalized difference vegetation index map 2017

4.1.3 NDBI of 2017

The built-up index in the figure 4.4 indicates that, the positive values are referred to the area dominated by built-up is large. As it is presented in the map most of the study area is occupied by built-up area. The positive value from the Fig.4.2 illustrates the land-cover area under built-up.

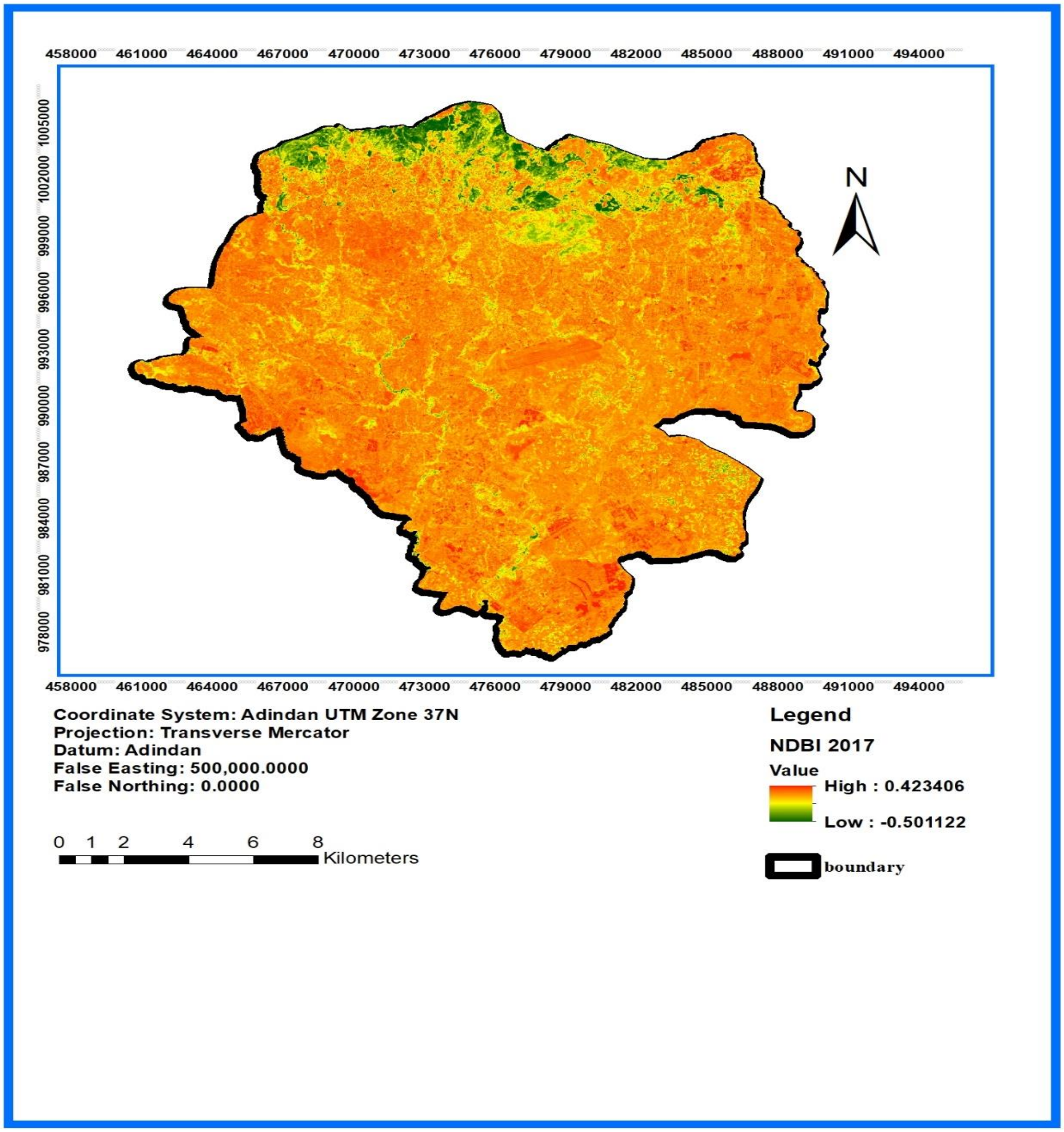

Fig 4.2 Normalized Differences Built-up Index map

4.1. 4 Land-use and land-cover status of UGS of 2017

The result of supervised SVM classification algorithm is presented in (Fig 4.3, Fig 4.10and Table 4.2). The study classified Sentinel 2A satellite imagery acquired from ESA (European Space Agency). The land-use and land-cover map was generated using supervised SVM (Support Vector Machine) algorithm. The land-use and land-cover map is shown below along with the area coverage table. Five land-use and land-cover classes were identified based on the NDVI range shown (in figure) and table these are urban areas, sparse vegetation, and dense vegetation cover Shrub and Grassland, and dense and Barren Land

As table 4.2 shows most part of Addis Ababa city is covered by Barren Land (44.25) and urban areas (19.39) which contributes less to oxygen production, dense vegetation covers only 5.12% which contributes most for oxygen production and sparse vegetation covers 10.06% and Shrub and Grassland covers 21.16 % which also contributes to oxygen production

Table 4.2 Land-use and land-cover status of UGS of 2017

Class name	NDVI range	Area (ha)	Area (%)
Dense Vegetation	0.419207 to 0.758176	**2663.39**	5.12
Sparse Vegetation	0.259932 to 0.419206	**5227.44**	10.06
Shrub and Grassland	0.157833 to 0.259931	**10997.4**	21.16
Barren Land	0.0843206 to 0.157832	**22987.2**	44.25
Urban areas	-0.283237 to 0.0843205	10073.7	19.39
Total		51949.13	100

4.1.5Accuracy assessment of 2024

4.1.5.1 Confusion matrix for of 2024

the percentage of correctly classified pixels in each class (category) divided by the total number of pixels in the reference data that were assigned to that category (column total are classified) is known as the producer's accuracy .Producer’s accuracy of urban areas 90.0%, Sparse Vegetation 86.1%, Shrub and Grassland 89.4% and Barren Land 98% whereas user’s accuracy of urban areas 88.9%, Sparse Vegetation 91.9%, Shrub and Grassland 86.4% and Barren Land 84.4%. The overall accuracies in the study period 2024 is 87.7%. The highest user’s and producer’s accuracies were Sparse Vegetation and urban areas and the lowest users and spectral producer’s accuracies were observed in Barren Land and Sparse Vegetation The lowest values of class accuracies were misclassified due to property similarities among other land cover classes the result is shown in the table 4.3 below.

Table 4.3 confusion matric of 2024

Classified data	urban areas	sparse vegetation	Shrub and Grassland	Barren Land	Total	User accuracy (100%)
urban areas	72	2	3	4	81	88.9
Sparse Vegetation	1	68	3	2	74	91.9
Shrub and Grassland	2	3	76	7	88	86.4
Barren Land	5	6	3	76	90	84.4
Total	80	79	85	89	333	
	90.0	86.1	89.4	85.4		
	Producer accuracy (100%)					
	Over all accuracy		87.7			

4.1.6NDVI of 2024

Sentinel 2A image from Copernicus hub were used for NDVI classification. The normalized vegetation index is used to assess the greenness of a study area. The NDVI map (Fig 4.3) shows vegetation cover of Addis Ababa for the year of 2024. The value ranges from −0.3 to 0.7. The highest value (0.7) depicts vegetated surfaces whereas the lowest value (−0.3) indicates non-vegetated areas. As shown in figure vegetated areas are found in northern part of Addis Ababa. However, riverine vegetation is classified and displayed slightly buffering the river streams. The NDVI illustrates that the study area has very little vegetation cover and most of the areas are populated by built up and other land uses.

As figure 4.1 Shows The NDVI values ranges from_0.3 to 0.716, higher NDVI values (0.716) are detected in the northern part of the town which shows dense vegetation whereas lower NDVI values (-0.3) are detected in non-vegetation areas like built up areas and other land uses.

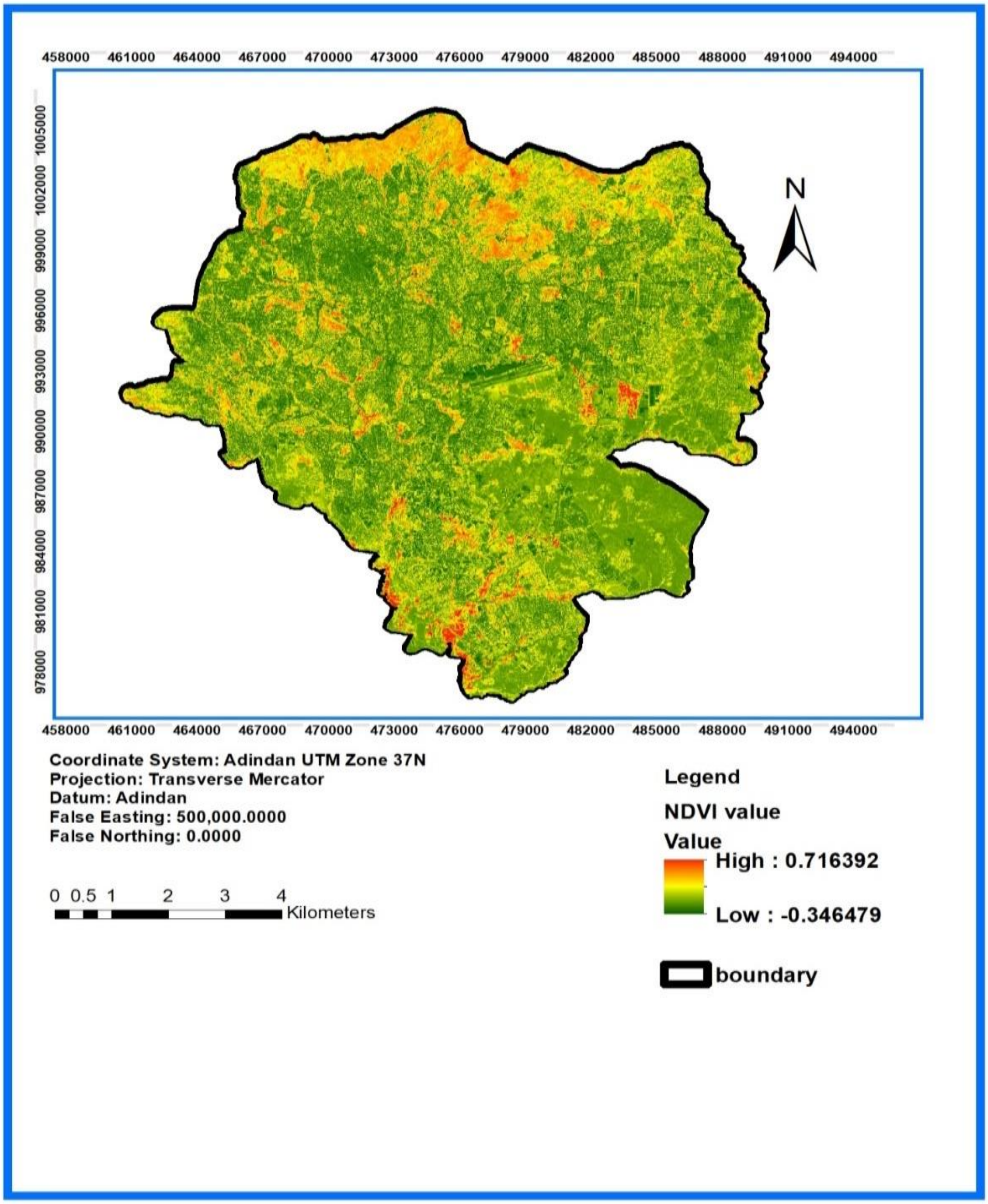

Fig 4.3 Normalized difference vegetation index map

4.1.7 NDBI of 2024

In order to show the extent of built up and non-built areas calculating Normalized Difference Built-up Index(NDBI) is required therefore as figure below shows most of Addis Ababa towns is covered by built up areas and the positive values indicates the distribution of built up areas and the negative shows non built up areas like vegetation's and UGS.

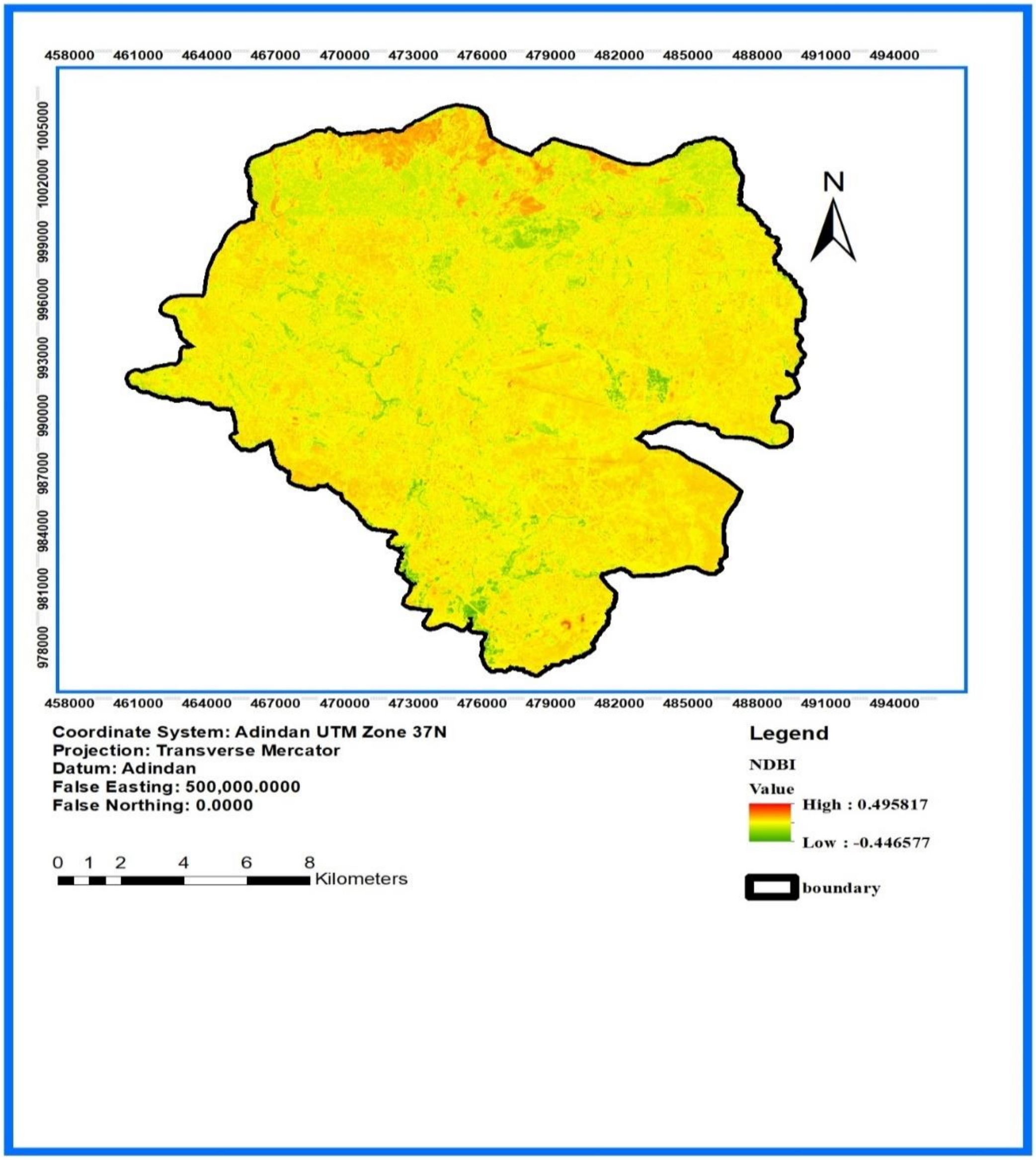

Figure 4.4 Normalized Differences Built-up Index

4.1.7 Land-use and land-cover status of UGS of 2024

The result of supervised SVM (Support Vector Machine) algorism classification algorithm is presented in (Fig 4.5, Fig 4.6 and Table 4.4). The study classified Sentinel 2A satellite imagery acquired from ESA (European Space Agency). The land-use and land-cover map was generated using supervised SVM algorithm. The land-use and land-cover map is shown below along with the area coverage table. Five land-use and land-cover classes were identified based on the NDVI range shown (in figure 4.7) and table 4.4. These are urban areas, sparse vegetation, and dense vegetation cover Shrub and Grassland, and dense and Barren Land

As table 4.4 shows most part of Addis Ababa city is covered by Barren Land (36.88) and urban areas (30.58) which contributes less to oxygen production, dense vegetation covers only 5.51% which contributes most for oxygen production and sparse vegetation covers 11.62% and Shrub and Grassland covers 15.41% which also contributes to oxygen production

Table 4.4 each land use NDVI range and area coverage 2024

Class name	NDVI range	Area (ha)	Area (%)
Dense Vegetation	0.353765491 to 0.71639204	2862.129	5.51
Sparse Vegetation	0.237058096 to 0.353765491	6035.921	11.62
Shrub and Grassland	0.195376884 to 0.28290743	8007.931	15.41
Barren Land	0.066165125 to 0.141191307	19157.92	36.88
Urban areas	-0.34647888 to 0.066165125	15885.75	30.58
Total		51949.651	100

Figure 4.5 **shows NDVI range of Addis Ababa town using sentinel 2A of the year 2024**

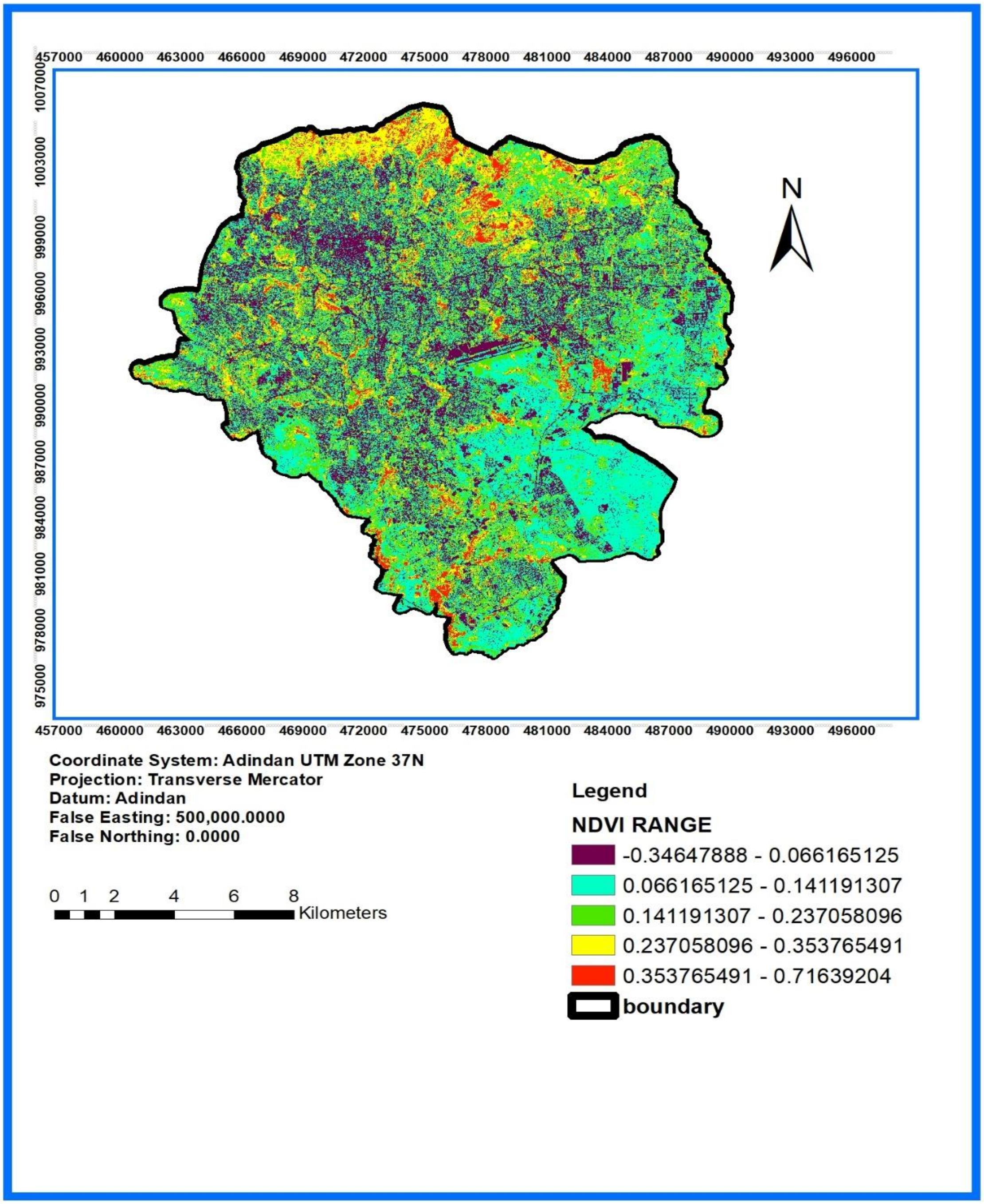

Fig 4.5 NDVI range of 2024

Figure 4.6 below shows SVM image classification based on NDVI ranges.

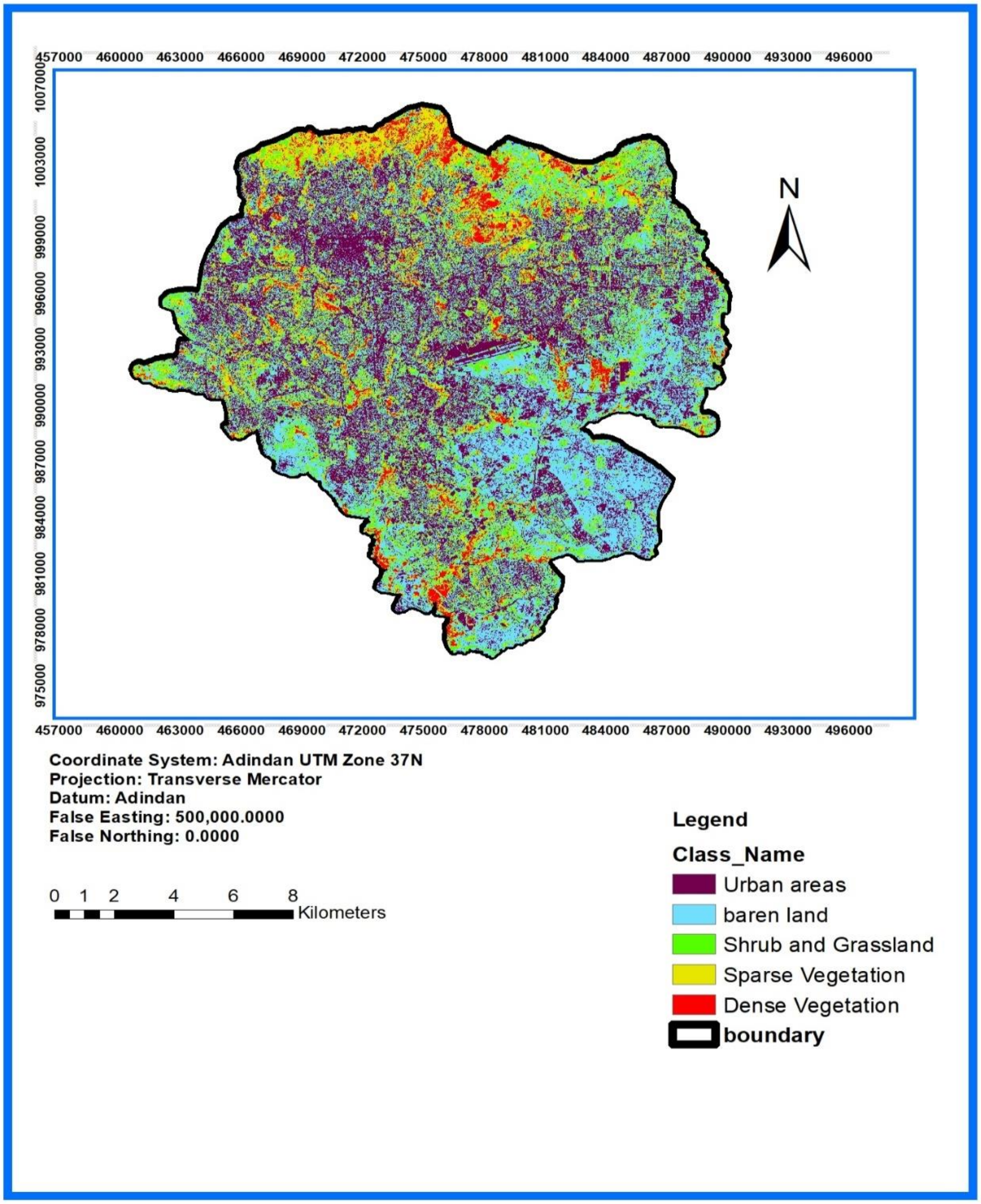

Figure 4.6 SVM image classifications of 2024

4.2 Oxygen production of land use classes of the year 2017

The table 4.5 below shows oxygen production of land use class per kg per hectare per year so based on the literature source urban areas and barren land oxygen production is negligible while shrub and grass land produce 100kg/ha/year up to 500 kg/ha/year oxygen, sparse vegetation produces 300 kg/ha/year - 700 kg/ha/year of oxygen and Dense Vegetation produces 500 kg/ha/year - 1500 kg/ha/year of oxygen

Table 4.5 Oxygen production of land use classes of the year 2017

Class	**NDVI Range**	**Area (ha)**	**Area (%)**	**Oxygen Production Range (kg/ha/year)**	**Estimated Oxygen Production Range (kg/year)**
Dense Vegetation	0.419207 to 0.758176	2663.39	5.12	500 – 1500	1,331,695 - 3,995,085
Sparse Vegetation	0.259932 to 0.419206	5227.44	10.06	300 – 700	1,568,232 - 3,659,208
Shrub and Grassland	0.157833 to 0.259931	10997.4	21.16	100 – 500	1,099,740 - 5,498,700
Barren Land	0.0843206 to 0.157832	22987.2	44.25	Negligible	Negligible
Urban Areas	-0.283237 to 0.0843205	10073.7	19.39	Negligible to very low	Negligible to very low

Table 4.6 average oxygen production of the year 2017

Class	**NDVI Range**	**Area (ha)**	**Area (%)**	**Average Oxygen Production (kg/ha/year)**	**Estimated Oxygen Production (kg/year)**
Dense Vegetation	0.419207 to 0.758176	2663.39	5.12	1000	2,663,390
Sparse Vegetation	0.259932 to 0.419206	5227.44	10.06	500	2,613,720
Shrub and Grassland	0.157833 to 0.259931	10997.4	21.16	300	3,299,220
Barren Land	0.0843206 to 0.157832	22987.2	44.25	Negligible	Negligible
Urban Areas	-0.283237 to 0.0843205	10073.7	19.39	Negligible to very low	Negligible to very low

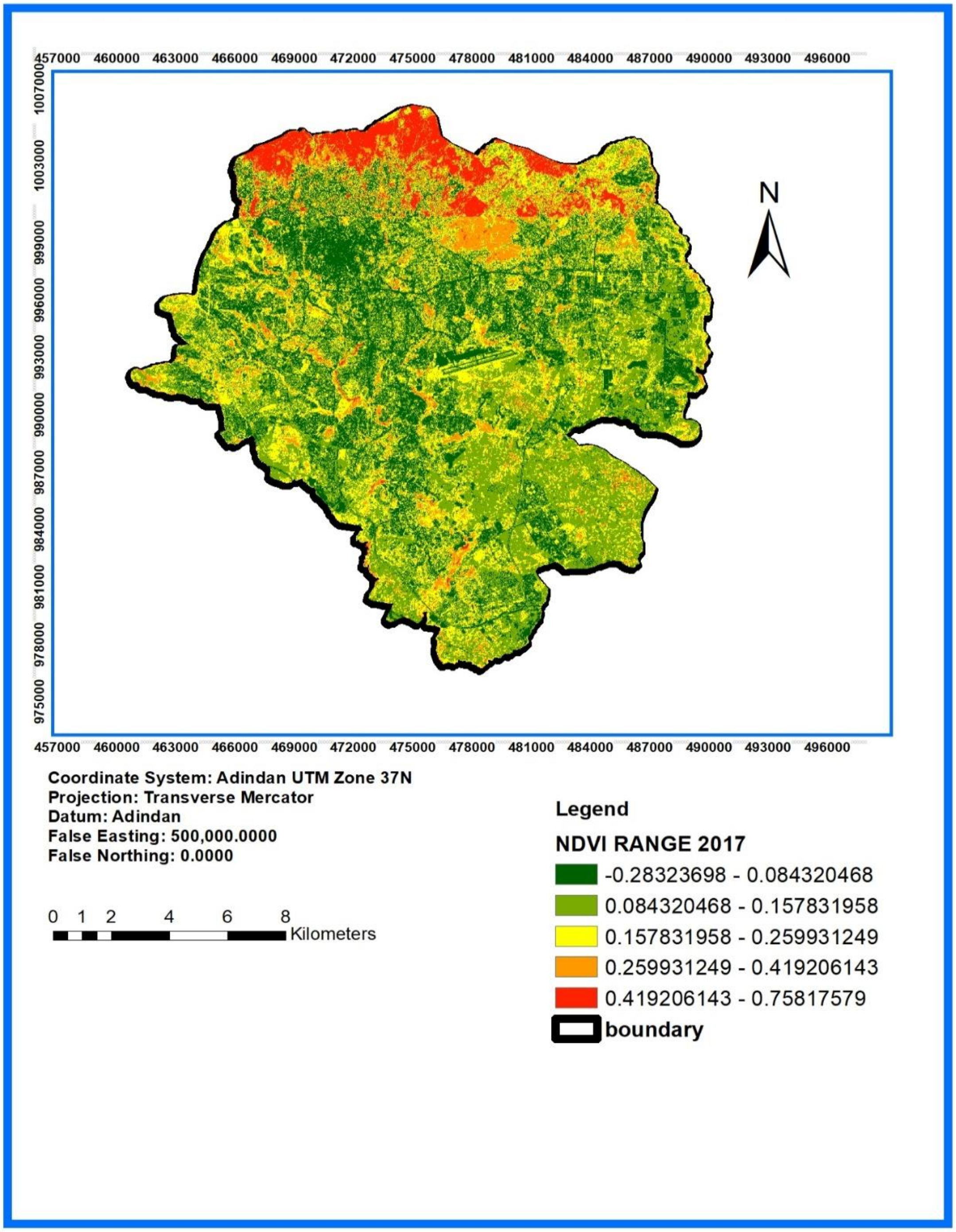

Figure 4.7 NDVI range 2017

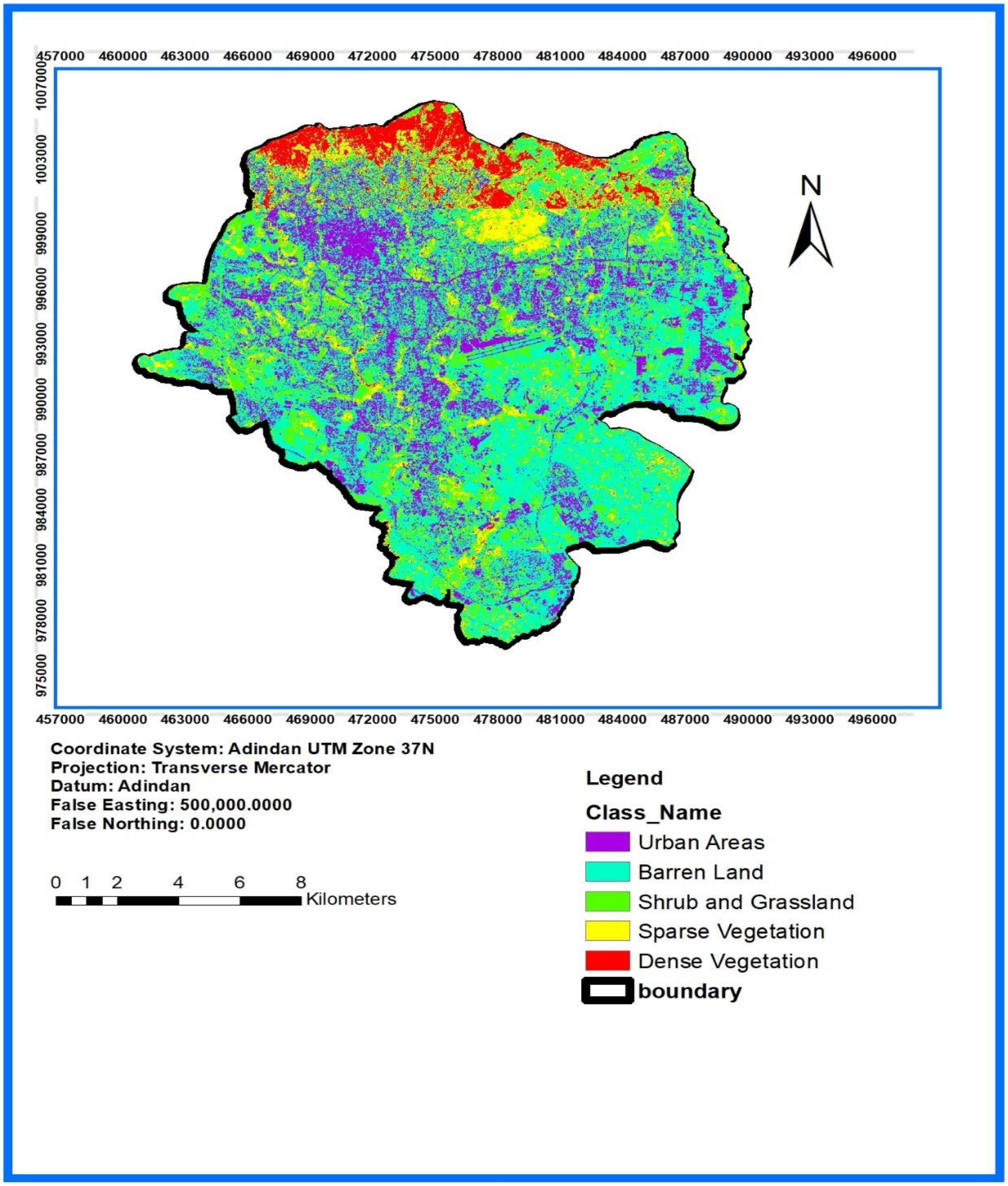

Figure 4.8 LULC classification of 2017

4.3 Estimation of urban green space oxygen production 2017

The urban green space has its own physical components, including urban forest, parks, riverine and street trees. Green space can become so many things like natural play spaces, community gardens, urban agriculture (Farrar, 2009; Rodhead, 2009) according to our study UGS in Addis Ababa city includes Dense Vegetation , Areas with urban forests, protected areas, botanical gardens, large parks with mature trees , Sparse Vegetation, Areas with semi-natural habitats, peri-urban forests, and vegetated corridors Shrub and Grassland, Natural grasslands, shrub lands, savannah, open woodlands, parks, artificial grass. In order to estimate oxygen production the study reclassify the land uses classes as UGS and non UGS so that we can calculate the area covered by UGS and calculate oxygen production.

4.3.1 Reclassifications of land use classes for estimating UGS oxygen production2017

In order to estimate the oxygen production of UGS of the year the study reclassifies areas as UGS and non UGS .based on the result shown in table 4.7. UGS cover a total area of 18818.33(ha) which is 36.22% of the total area. While non UGS covers a total area of 33131.69(ha) this is 63.78% of the total area of the city.

Table 4.7 Reclassification of land uses 2017

Class name	Area(ha)	Area (%)
UGS	18818.33	36.22
NON-UGS	33131.69	63.78
Total	51950.02	100

Source sentinel 2A image reclassification

Figure show map of a reclassified land uses classification done SVM algorithm as UGS and non-UGS.

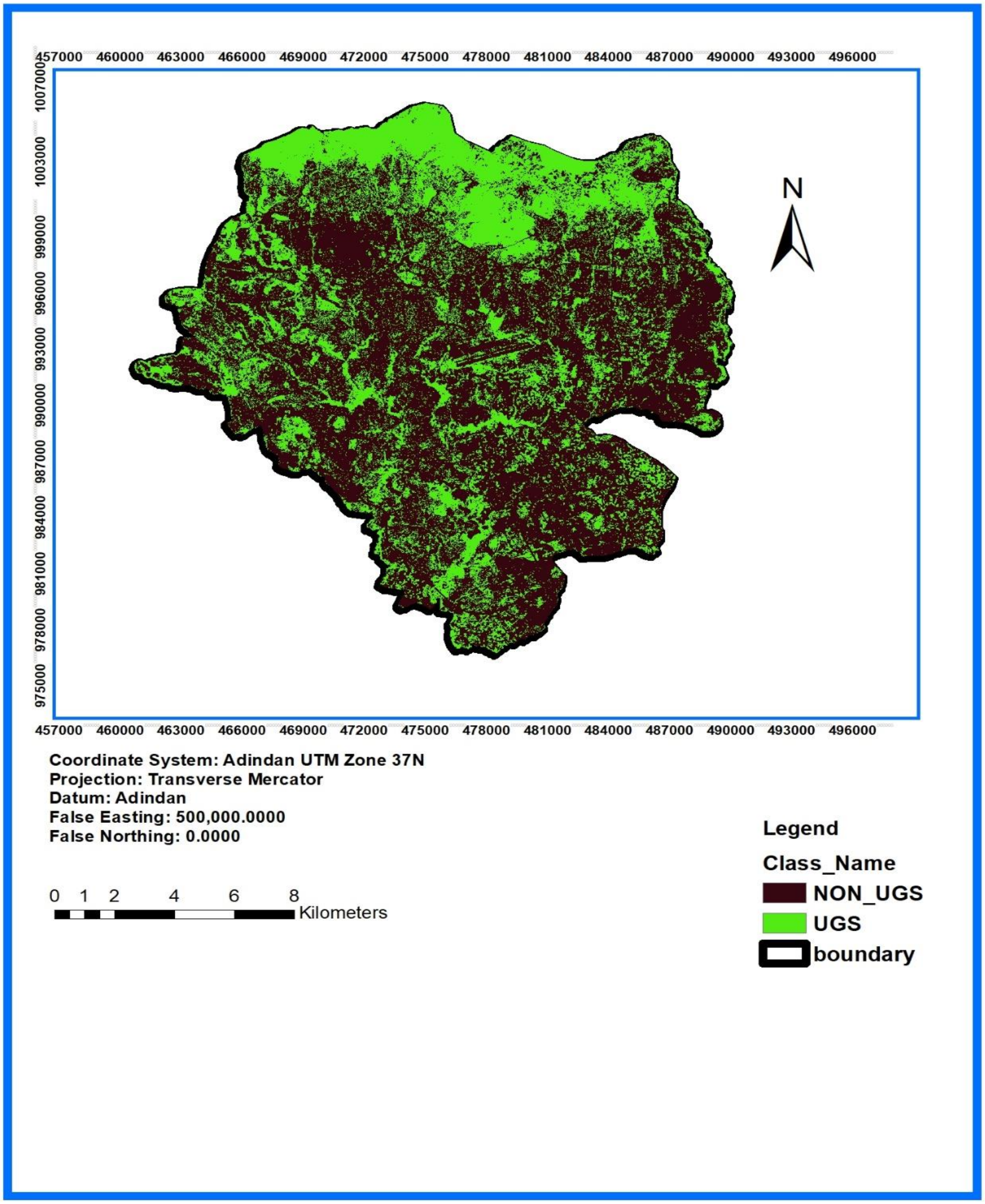

Figure 4.9 reclassified class land use of Addis Ababa 2017

As mentioned from the previous table 4.8The average oxygen production of UGS (dense vegetation (1000 kg/ha/year)) , sparse vegetation (500 kg/ha/year)) ,shrub and grassland (300 kg/ha/year)) when we sum up it becomes a total 1800 kg/ha/year) when estimate the average oxygen production of the year we need to multiply this number by area coverage of the class (UGS) based on the result as shown in the table the average oxygen production of the year 2017 is 33872994 KG.

Table 4.8 estimated oxygen production of the year 2017

Class name	**Area(ha)**	average oxygen production (kg/ha/year)	Estimated Oxygen Production (kg/year)
UGS	18818.33	1800	33872994
NON_UGS	-	-	
Total	18818.33	1800	33872994

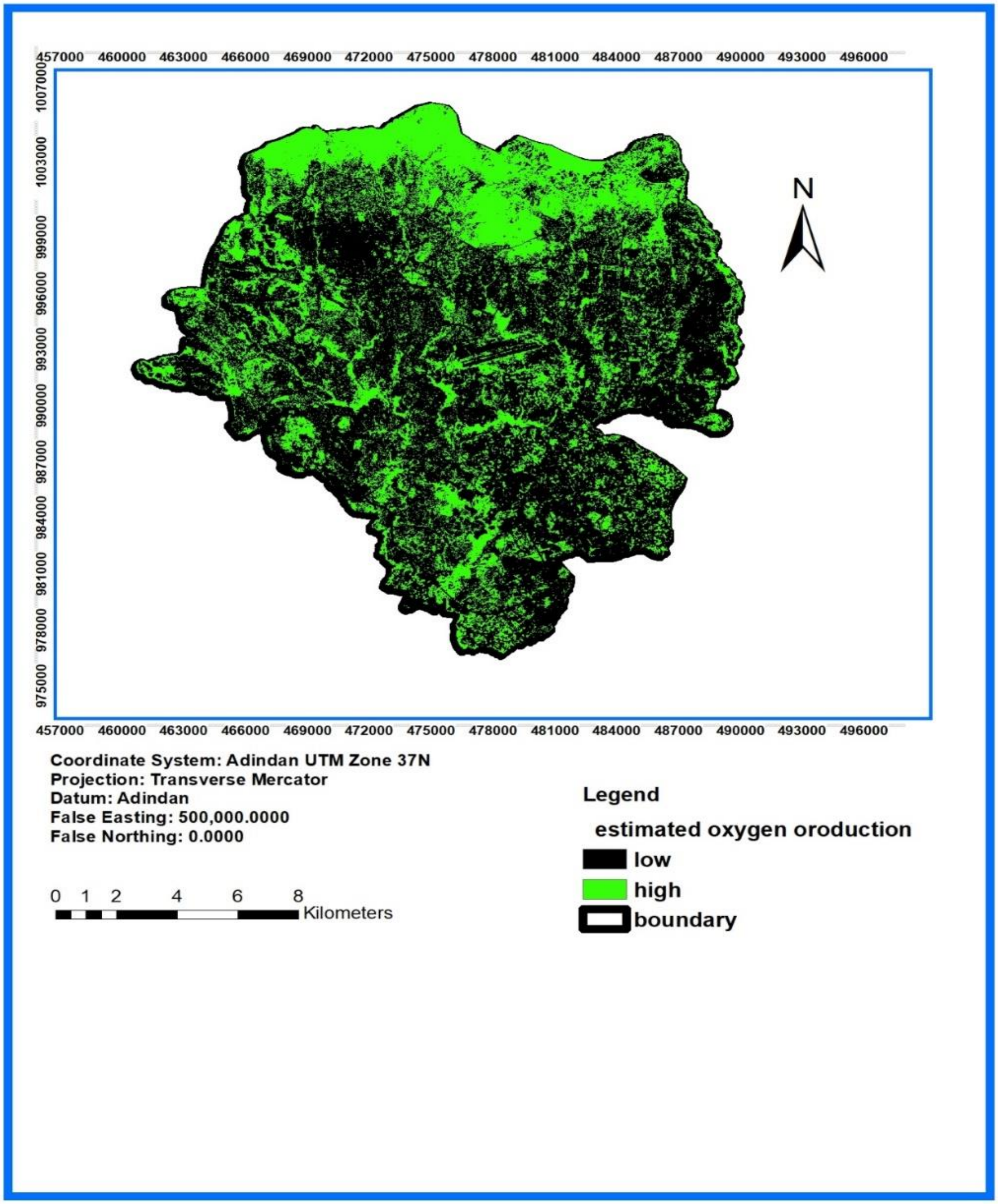

Figure 4.10 the total oxygen estimation of the year 2017

4.4 Oxygen production of land use classes of the year 2024

The table 4.9 below shows oxygen production of land use class per kg per hectare per year so based on the literature source urban areas and barren land oxygen production is negligible while shrub and grass land produce 100kg/ha/year up to 500 kg/ha/year oxygen, sparse vegetation produces 300 kg/ha/year - 700 kg/ha/year of oxygen and Dense Vegetation produces 500 kg/ha/year - 1500 kg/ha/year of oxygen

Table 4.9 Oxygen Production (kg/ha/year)

Class	**Oxygen Production (kg/ha/year)**	**Description**
Urban Areas	Negligible to very low	Urban areas typically have sparse vegetation and minimal green spaces, resulting in low oxygen production rates.
Barren Land	Negligible	Barren land areas, such as deserts or rocky terrain, have minimal vegetation and hence negligible oxygen production.
Shrub and Grassland	100 – 500	Shrublands, grasslands, and open woodlands contribute moderately to oxygen production, ranging from 100 to 500 kg/ha/year.
Sparse Vegetation	300 – 700	Areas with sparse vegetation, such as semi-natural habitats and peri-urban forests, produce moderate to high levels of oxygen, ranging from 300 to 700 kg/ha/year.
Dense Vegetation	500 – 1500	Dense vegetation types, including urban forests, protected areas, and mature parks, contribute significantly to oxygen production, ranging from 500 to 1500 kg/ha/year.

Source Smith, J. A., & Johnson, R. B. (2020)

Table 4.10shows oxygen production of Addis Ababa city based on the above sources table (4.9) dense vegetation produce 1431064 kg/ha/year up to 4293193kg/ha/year, Sparse Vegetation produce 1,810,776 kg/ha/year - 4,225,144 kg/ha/year, Shrub and Grassland800,793 kg/ha/year - 4,003,965 kg/ha/year and barren and urban areas produce negligible and very low oxygen.

Table 4.10 Estimated Oxygen Production (kg/year) of 2024

Class	**Oxygen Production (kg/ha/year)**	**Area (ha)**	**Estimated Oxygen Production (kg/year)**
Dense Vegetation	500 – 1500	2862.129	1,431,064 - 4,293,193
Sparse Vegetation	300 – 700	6035.921	1,810,776 - 4,225,144
Shrub and Grassland	100 – 500	8007.931	800,793 - 4,003,965
Barren Land	Negligible	19157.92	Negligible
Urban Areas	Negligible to very low	15885.75	Negligible to very low

Table 4.11 below shows Average oxgen production and based on the result Dense Vegetation produces 2,862,129kg per year, Sparse Vegetation, 3,017,960kg per year Shrub and Grassland2, 402,379kg per year

Table 4.11 Estimated Oxygen Production (kg/year) of 2024

Lass	**Average Oxygen Production (kg/ha/year)**	**Area (ha)**	**Estimated Oxygen Production (kg/year)**
Dense Vegetation	1000	2862.129	2,862,129
Sparse Vegetation	500	6035.921	3,017,960
Shrub and Grassland	300	8007.931	2,402,379
Barren Land	Negligible	19157.92	Negligible
Urban Areas	Negligible to very low	15885.75	Negligible to very low

4.4.1 Reclassifications of land use classes for estimating UGS oxygen production 2024

In order to estimate the oxygen production of UGS of the year the study reclassify areas as UGS and non UGS .based on the result shown in table 4.10 UGS cover a total area of 16842.17 (ha) which is 32.50% of the total area. While non UGS covers a total area of 35108.38 (ha) which is 67.50% of the total area of the city

Table4.12 Reclassification of land uses 2024

Class name	Area(ha)	Area (%)
UGS	16842.17	32.50
NON-UGS	35108.38	67.50
Total	51950.55	100

Figure 4.11 show map of a reclassified land uses classification done SVM algorithm as UGS and non-UGS.

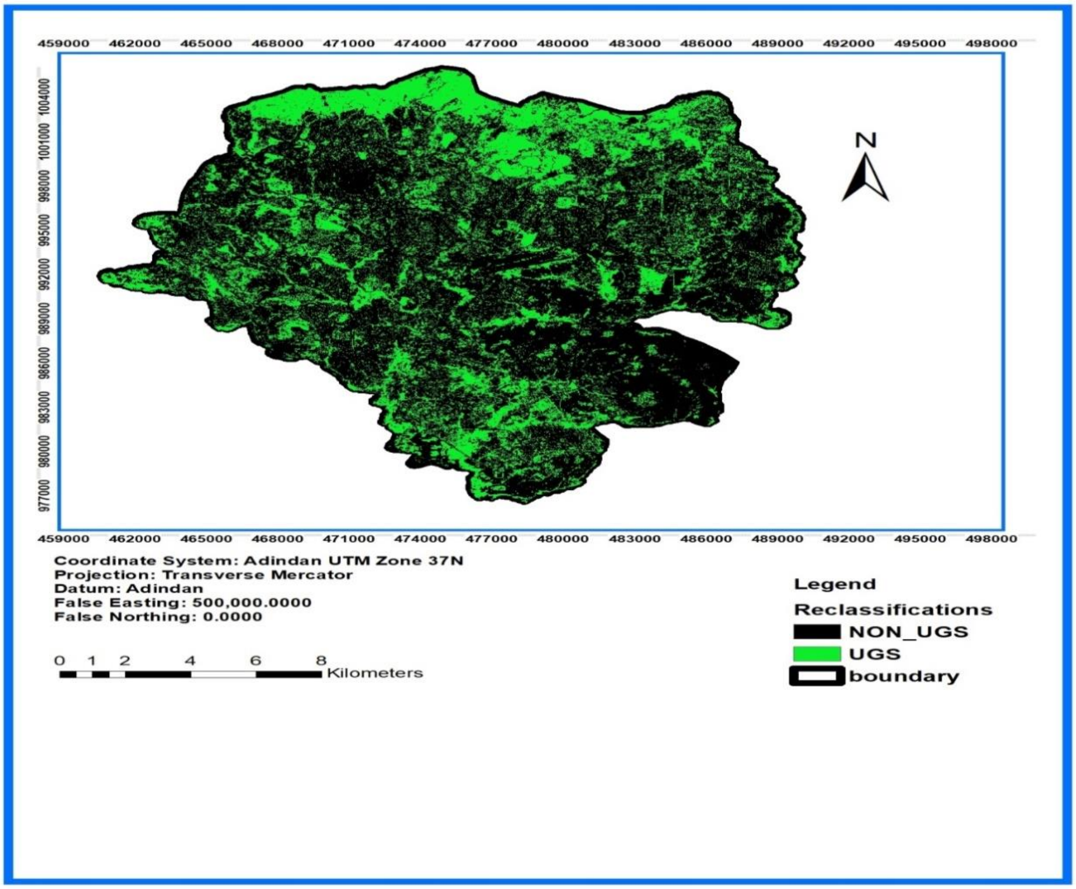

Figure 4.11 reclassified land use classification done SVM algorithm as UGS and non-UGS 2024

As mentioned from the previous table 4.12. The average oxygen production of UGS (dense vegetation (100 kg/ha/year)) , sparse vegetation(500 kg/ha/year)) ,shrub and grassland(300 kg/ha/year)) when we sum up it becomes a total 1800(kg/ha/year) when estimate the average oxygen production of the year we need to multiply this number by area coverage of the class (UGS) based on the result as shown in the table the average oxygen production of the year 2024 is 30315906 KG

Table 4.13 estimated oxygen production of the year 2024

Class name	**Area(ha)**	average oxygen production (kg/ha/year)	Estimated Oxygen Production (kg/year)
UGS	16842.17	1800	30315906
NON_UGS	-	-	
Total	30315906	1800	30315906

Figure 4.12 also shows the total oxygen estimation of the year 2024

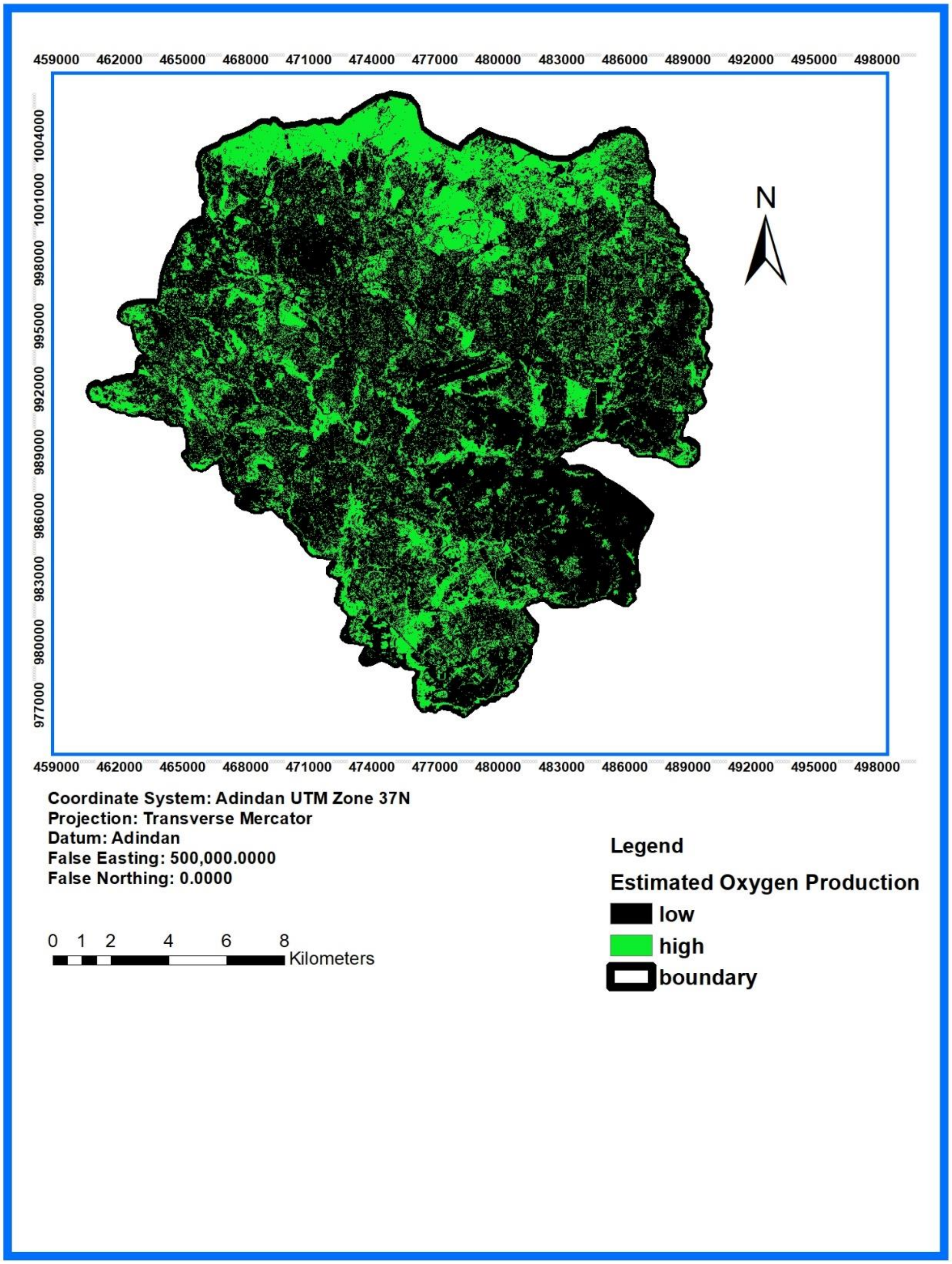

Figure 4.12Total oxygen estimation of 2024

4.5 Discussion

The study reveals a significant impact of urbanization on agricultural land in Motta Town, Ethiopia, as evidenced by the substantial decrease in agricultural land over the years. This finding aligns with previous research indicating that urban expansion often comes at the expense of agricultural land, particularly in rapidly growing urban areas (Seto et al., 2011). The analysis using Geographic Information Systems (GIS) and remote sensing techniques showed a marked increase in built-up areas, which supports the hypothesis that urban growth is a primary driver of land use change in the region.

The decline in agricultural land is consistent with the patterns observed in other studies conducted in similar contexts. For instance, studies in other Ethiopian cities, such as Addis Ababa, have reported similar trends where agricultural lands are being converted to urban uses due to the increasing demand for housing and infrastructure (Meshesha et al., 2014). This pattern is not unique to Ethiopia; research in other developing countries also highlights the conflict between urban growth and agricultural land preservation (Deng et al., 2015).

The study's findings also reflect the broader global trend where urbanization leads to the loss of agricultural land, raising concerns about food security and sustainable development (Angel et al., 2011). The observed land use changes in Motta Town underscore the need for more effective land management policies that balance urban growth with the preservation of agricultural land. Similar recommendations have been made in other studies that advocate for integrated land use planning to mitigate the adverse effects of urbanization on agricultural land (Verburg et al., 2019).

In summary, the results of this study contribute to the growing body of evidence on the negative impacts of urbanization on agricultural land. The findings are supported by similar research from both local and international contexts, reinforcing the need for policies that address the challenges posed by rapid urban expansion.

Chapter Five

Conclusion and Recommendations

5.1. Conclusion

Addis Ababa has experienced significant expansion of urban and built-up areas, leading to a sharp decline in green spaces. The City's new Development Plan (2001-2010) reveals that over 75% of its land has already been utilized for development, and the remaining potential expansion area of 10,000 hectares within the city's boundaries may be fully utilized by 2010. This rapid growth surpasses the city's current socio-economic, physical, and administrative capacity. Compounding these issues are the growth of informal settlements, increased traffic congestion, elevated pollution levels, insufficient green spaces, and inadequate water supply and sanitation. The study highlights that rapid, unplanned urban expansion and commercial development, coupled with population pressure, have significantly harmed green spaces in Addis Ababa, particularly in the study area. Presently, much of the city's green space has been converted into urban development. The historical characterization of Addis Ababa as a "forest city" is no longer accurate. Many neighborhoods are experiencing increased heat due to urban heat island effects. Consequently, estimated oxygen production has dropped from 338,729,945 kg/year in 2017 to just 30, 15,906 kg/year in 2024. Contributing to these issues are unsustainable land use practices, disorganized urban development, and an unstable land tenure system. Additionally, factors such as lack of public awareness, minimal community engagement, poor policy implementation, insufficient funding, shortage of skilled personnel, land scarcity, illegal settlements, inadequate monitoring, pollution from various sources, and lack of inter-stakeholder cooperation have exacerbated the reduction of green spaces in the city. The analysis indicates that the rapid urbanization in Addis Ababa has left little opportunity for green space development.

5.2. Recommendations

To address the critical decline in green spaces and the associated reduction in oxygen production in Addis Ababa, several key actions are recommended. First, the city administration, alongside the departments of beautification, parks, and sustainable development, should adhere strictly to national standards for urban green space coverage as specified in the master plan. This will ensure that green spaces are adequately incorporated into urban development plans.

Second, it is essential to update land use and land cover (LULC) data regularly using advanced remote sensing and GIS technologies. This will provide accurate and up-to-date information on green space distribution, facilitating informed decision-making and effective urban management.

Third, comprehensive guidelines for the development and management of urban green spaces should be developed and implemented using the GIS-based multi-criteria analysis (GIS-MCA) process. These guidelines will help optimize the allocation and maintenance of green areas, thereby enhancing their ecological benefits.

Additionally, the city administration should promote community involvement in creating and managing community gardens and green spaces. Engaging local stakeholders and aligning efforts with the master plan and local development plans will foster a collaborative approach to green space management.

Finally, continuous monitoring of green space coverage is crucial. Regular assessments using high-resolution satellite imagery and updated parameter tables will help track changes and implement appropriate measures to address any reductions in green space

5.3. Future work

Due to the use of Sentinel-2A imagery with a 20-meter resolution in this study, some land use and land cover (LULC) types were generalized and there were classification errors in the images. To address these issues, future research should consider employing higher-resolution imagery such as IKONOS and QuickBird, which provide more detailed and accurate mapping results. Furthermore, incorporating Esri City Engine into the planning process can improve urban planning, architecture, and design by offering enhanced 3D visualization. This tool facilitates a better understanding of relationships, evaluates project feasibility, and supports effective project planning, ultimately leading to higher-quality decisions that benefit the community.

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