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**GEO-SPATIAL APPROACH FOR URBAN GREEN SPACE AND ENVIRONMENTAL QUALITY:
A CASE STUDY OF ADDIS ABABA**

*Thesis submitted for Partial Fulfillment of the Requirements for the
Award of the Degree of
MASTER OF SCIENCE*

In

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(Remote Sensing and Geographical Information Systems (GIS))

Addis Ababa University, Addis Ababa, Ethiopia.

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June 2015

ADDIS ABABA UNIVERSITY

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DECLARATION

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CERTIFICATE

This is certified that the thesis entitled “Geospatial Approach for Urban Green space and Environmental Quality” is on a field work carried out by Roza Assaye under my guidance and supervision. This is the actual work done by Roza Assaye for the partial fulfillment of the award of the Degree of Master of Science in Earth Sciences (Remote Sensing and GIS) from Addis Ababa University. Addis Ababa.

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Finally I would like to be memorial thesis for my Dad Assaye Yismaw who is uneducated but belongs to the literate

Roza Assaye

ACRONYMS

AMA	Addis Ababa Meteorological Agency
AEPA	Addis Ababa Environmental protection Authority
CR	Consistency Ratio
CSA	Central Statistics Agency
EMA	Ethiopian Mapping Agency
ERDAS	Earth Resources Data Analysis System
ETM	Enhancement Thematic Mapper
GSA	Geospatial Approach
GIS	Geographic Information System
GPS	Global Positioning System
ILIC	Integrated Land Information Center
LULC	Land-use and Land-cover
MCE	Multi-criteria Evaluation
NDVI	Normalized Deference Vegetation Index
NMS	National Meteorological Agency
POS	Parks and Open spaces
UEQ	Urban Environmental Quality
UGS	Urban Green Space

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Cities have become more stressful due to poor environmental conditions triggered by anthropogenic pressure on the environment in an unsustainable manner. Because urban environment is not being utilized in a sustainable way, the quality of its environment is being compromised leading to deterioration in several environmental variables such as natural vegetation, climates, wetlands, and wildlife among many others. Depending on the rapid growth in structural developments, along with the increasing of human population, the natural appearance and quality of, cultural and social structures of the cities are being changed drastically. Timely and regular information on urban environmental quality (UEQ) is essential for urban planning. This thesis presents the potential application of urban green as an indicator of urban environmental quality changes in the city of Addis Ababa based on the indicators of natural parameters extracted from remotely sensed images and socioeconomic variables derived from census data. Physical environmental variables such as land-use/land-cover data, surface temperature, normalized difference vegetation index, and other transformed remote sensing variables were derived from the three Landsat images of 1986, 2000, and 2015. Socio-economic variables including population density of Addis Ababa Central Statistical Agency and greenhouse gas emission of 2012 data were used. Regression analysis, factor analysis and overlay analysis were performed after the two groups of variables were integrated, four factors were identified such as greenness, crowdedness, heat island, and greenhouse gas emission for interpretation. By assigning different weights to each of these factors, risk map was generated and the proportion to overall greenness based on UEQ indexes map was generated. The goal was to extract greenness as a measure of environmental quality change and these results point towards a deterioration in environmental quality in Addis Ababa Sub City of Addis_Ketema order between very high risk and high risk, Arada and Lideta high risk and risk, Kirkose within risk and marginal Gulele among moderate and least risk, Kolfe, Yeka, Nifas_Silke , Bole and Akaki_Kality sub cities belong to are very low risk during this period of evaluation (1986–2015). It is recommended that future studies should include more parameters to provide a holistic view of the changes in greenness of the city and to try to mitigate the adverse effects of development activities leading to crowdedness and depletion of greenness in the city.

Keywords: NDVI, GIS, landsat, urban green space, spatiotemporal distribution

1.1 Research overview

The urban environment quality is deteriorating day by day with the largest cities reaching saturation points and unable to cope with the increasing pressure on their infrastructure (Asadi et al., 2007). Greenery is one of the important ingredients for urban planning with a sustainable environmental quality. Yet urban environmental quality is an abstract concept that is based on both human and natural factors operating at different spatial scales. However, urban environmental quality is based on planning process with emphasis on social, economic, cultural, physical and emotional indices in both mental and visible forms (Opeyemiet al., 2014).

While environmental planners have assessed the cities, the urban green spaces and vegetation cover areas play a great role in balancing the human biophysical interconnections and keeping environmental quality. Green space is a basic infrastructure of the city that makes tremendous contributions aesthetically and ecologically to the city, as well as to community pride, public health, and quality of life (Low et al., 2007).

Urban greenery is defined as the overall extent of planted outdoor spaces (with trees, bushes, ornamental plants, or grass). Examples of such spaces are squares, parks, rows of trees in roads, groves, planted spaces in yards of public or private buildings (schools, residential complexes) (Aravadinouet and Evmorphopoulou, 1999). Parks and open spaces (POS) provide greater diversity of green spaces with substantial impacts on environmental quality in many mega cities around the world.

The existence of urban green spaces in a contemporary urban environment is expected to improve air quality, reduce noise, air pollution and enhance its aesthetic quality. Specifically, urban greenery is a key factor for the overall city planning, as its benefits have a direct impact on the environment as well as on quality of life of its residents. Urban green space is an indicator of urban environmental quality (Faryadi and Taheri, 2008). Nevertheless, due to its multi-dimensional, multifaceted and multidisciplinary nature, only one indicator alone cannot measure environmental quality. It requires the integration of a variety of elements. Thus, the most important variables that measure urban environmental quality are urban greenery, built up area, carbon emission, temperature, humidity, waste disposal, accessibility to major roads and population density (Liang and Weng., 2011) with great contribution in order to affecting environmental quality. However, a major challenge in urban environmental quality is that here

is no simple way to model and to predict the interaction of all these aspects and variables of urban environmental quality.

Therefore, in this research suitable distribution of urban green space and vegetation density have been emphasized as the major index of air freshening, which will generally improve the urban environmental quality. Building density, population density, temperature, humidity, waste disposal, accessibility to major road and carbon emission are considered as the major indications of degrading city environment. Understanding the causal factors is a prerequisite to assess and maintain sustainable urban environmental quality. To assess the degradation of the environment, effective Geospatial approach is required. This method takes into account location, specifically location on the earth subsequently locations are explicit in geospatial methods. As the result provide the key to understanding how results change when the locations of the phenomena being analyzed change. Because of broad range of numerical methods fall under the general heading of geospatial methods. (Cromley, 2013)

Based on this hypothesis the main aim of research is to assess the environmental quality of Addis Ababa using the natural and social parameters and address the critical area using GIS and Remote sensing techniques.

1.2 Statement of the problem

Rapid urbanization brings with it many problems as it places huge demands on land, water, housing, transport, health, and education. Depending on the rapid growth in science and technology, the economical, cultural and social structures of cities and so their natural appearances change continuously. Unfortunately as urban cities grow due to increased population, adequate development planning is usually not well undertaken. Cities have become more stressful due to poor environmental conditions triggered by anthropogenic pressure on the environment in an unsustainable manner. Because urban environment is not being utilized in a sustainable way, the quality of its environment is being compromised leading to deterioration in several environmental variables such as natural vegetation, climates, wetlands, and wildlife among many others. There rises the need to develop a means to indicate changes in the state of the urban environment. Indicators are used in qualifying and simplifying phenomena and to help us understand complex realities. They usually tell us something about changes in a system. They usually quantify and aggregate data that can be measured and monitored to determine

whether change is taking place. The urban environment is a complex system and only with the aid of indicators can change in the urban environmental quality be measured. The majority of the natural indicators such as LULC, NDVI and urban heat have been derived from the classification of satellite imagery the social indicator is explored from census data and greenhouse gas emission (GHG). The information obtained from these often serves as the basis for which environmental variables that will show the condition of the natural environment in question are derived.

Systematic assessment of each of these environmental variables is necessary for a proper understanding of urban environmental quality (Opeyemi and Trina, 2014). Also, many of the socio economic variables needed for an understanding of urban environmental quality can be derived from census data. However, attention in this paper will be devoted to extracting greenness through the assessment of land use land cover change, suitable distribution of urban green space, vegetation density using NDVI urban heat island carbon emission building density and population density will serve as a preliminary means of investigating urban environmental quality change in the study area.

1.3 Research objectives

1.3.1 General Objective

- ❖ The general objective of this study was, to map the urban environmental quality of the ten sub-sites of Addis Ababa using natural and social parameters, derived from remote sensing satellite imagery and secondary data.

1.3.2 Specific objectives

Specific objective of this study was the following

- ❖ To assess the changing pattern of environmental quality of Addis Ababa city using land-use/land-cover pattern.
- ❖ To estimate the percentage of urban greenery using NDVI in the study area.
- ❖ To evaluate the urban environment both qualitatively and quantitatively using weighted overlay method
- ❖ To recognize the factors leading to such conditions and evaluate the possibilities of improvement of urban environment by public participation in Addis Ababa.
- ❖ To generate different thematic maps of the study area measuring environmental quality

1.4 Significance of the research

In this dynamic world nothing is static, especially in relation to environmental aspects. In relation to these environmental changes it is necessary to take care of our urban environment by creating bellows, living areas through this follows:

- ❖ Enhance the environmental quality of polluted area by developing of urban greener.
- ❖ This research will support for environmental planers, policy makers in improving and maintain the environmental quality of urban cities.
- ❖ Give additional information's for supporting previous studies.
- ❖ Used as base line data for further studies.

1.5 Scope of the study

The scope of the study is spatially limited within the ten sub-city of Addis Ababa. Urban greenery map, greenhouse gas emission map, population density, building density urban thermal heat map land-use/land-cover map, finally environmental quality map are expected to be develop during this investigation. All efforts were made to perform the present study in a systematic and logical manner.

2.1 Environmental quality

Environmental quality is an urban planning process with attention to social, economic, cultural, physical and emotional indices in both mental and visible forms. Due to its multi-dimensional, multifaceted and multidisciplinary nature, it is a difficult concept to define. However, urban environmental quality is that which is based on both human and natural factors operating at different spatial scales (Opeyemi and Trina, 2014). Several studies on urban environmental quality have been carried out using one or more parameters, which quantify the quality of the environment. Accordingly, suitable distribution of urban green space and vegetation density has been emphasized as a major index of air freshening which will generally improve the urban environmental quality (Faryadi and Taheri, 2008). Also, extracting greenness through the assessment of land-use/land-cover, urban thermal comfort, high levels of population density and greenhouse gas concentration in each city region have been considered, as indices for low quality of urban environments serve as a preliminary means of investigating urban environmental quality where mentioned by (Opeyemi and Trina, 2014). Numerous environmental challenges fuelled partly by the pressures caused by human activities such as housing development and road construction, economic development and demographic changes (Twumasi and Merem, 2006). The other approach is spatiotemporal and qualitative study which is an index that is often used to evaluate the sufficiency of urban greenery is the fraction of the square meters of green spaces by the number of a city's inhabitants (m^2 green spaces / inhabitants) and density of building block (m^2 green spaces / building density) taken as an indicator (Tsouchlaraki et al. 2010).

During the past millennium, humans have taken an increasingly large role in the modification of the global environment. With increasing human population and development of technologies, man has emerged as the most powerful, and universal instrument of environmental changes in the biosphere (Saied et al., 2004). Overall housing density is a more important negative predictor of extent of green space and tree-cover (Richard et al., 2008). Many of these studies have used quantitative methods, qualitative description, attitudinal explanations and landscape. Despite these studies, urban environmental quality is still very vague and elusive and still requires complete understanding. So, it requires the integration of a variety of elements because only one or few indicator(s) alone cannot measure environmental quality. Many studies have therefore advocated for an integrated approach on the subject. Some have even opined that different viewpoints, which consider local knowledge about aspects of their neighborhood and its conditions, should be integrated with environmental assessment. However, according to Liang

and Weng (2011) major challenge in urban environmental quality is that there is no simple way to model and to predict the interaction of all these aspects and variables of urban environmental quality.

2.2 Urban greenery

According to Aravadinouet and Evmorphopoulou (1999) urban greenery is the overall extent of planted outdoor spaces (with trees, bushes, ornamental plants, or grass). Examples of such spaces are squares, parks, rows of trees in, groves, planted spaces in yards of public or private buildings (schools, residential complexes).

2.3 Geospatial Approach

Geospatial approach is a method, which takes into account the location, specifically location on the earth. Locations are explicit in geospatial methods. As the result provides the key to understanding how change results when the locations of the phenomena being analyzed change. A broad range of numerical methods fall under the general heading of geospatial methods (Cromley, 2013).

2.3.1 Spatiotemporal Approach

The other approach is spatiotemporal and qualitative study, which is an index that is often used to evaluate the sufficiency of urban greenery is the fraction of the square meters of green spaces by the number of a city's inhabitants and density of building (m^2 green spaces / inhabitants) and building (m^2 green spaces / density of building block), respectively (Tsouchlaraki et al., 2010).

2.3.2 Geographic Information System

A geographic information system (GIS) is a computer-based tool for mapping and analyzing geographic phenomenon that exist, and events that occur, on earth. Geographic Information System technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps. These abilities distinguish GIS from other information systems and make it valuable for a wide range of public and private enterprises for explaining events, predicting outcomes, and planning strategies. Map making and geographic analysis are not new, but a GIS perform faster and with more

sophistication than do traditional manual methods. (Buckley, 1997). Geographic information system is technology as a tool used by geographers, archaeologists, geologists and other scientists in the social and natural sciences is provide opportunities for storage, manipulation and mapping of data with a spatial reference(Rashmin, 2004).

2.3.3 Weighted Overlay Approach

Ian McHarg first explained the necessity of overlay methods for environmental sensitive planning in his design with nature in (McHarg, 1969). Weighted Overlay is one of the mostly used approaches for overlay analysis to solve multi-criteria problems such as optimal site selection and suitability models (Esri, 2013). To identify the most preferred locations for a specific phenomenon and for applying a common scale of values to diverse and dissimilar inputs to create an integrated analysis. One major part of the GIS is the ability to overlay various layers of spatially referenced data (Akanbi et al., 2013). Use of Weighted Overlay Method, Various factors assessed for suitability for a particular phenomenon do not allow for direct addition as they do have different value scales, in suitability models various factors may have different importance.

2.3.3.1 The Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making approach which was introduced by Saaty (1980). The AHP has attracted the interest of many researchers mainly due to the nice mathematical properties of the method and the fact that the required input data are rather easy to obtain(Triantaphyllou and Mann, 1995). The AHP is a decision support tool which can be used to solve complex decision making problems. It uses a multi-level hierarchical structure of objectives, criteria, sub-criteria and alternatives. The pertinent data are derived by using a set of pair-wise comparisons. These comparisons are used to obtain the weights of importance of the decision criteria, and the relative performance measures of the alternatives in terms of each individual decision criterion. If the comparisons are not perfectly consistent, then it provides a mechanism for improving consistency. The AHP and its use of pair-wise comparisons which was instrument in the creation of many other decision-making methods.

2.3.3.2 Pairwise Comparison

One of the most crucial steps in many decision-making methods is the accurate estimation of the pertinent data. This is a problem not bound in the AHP method only, but it is crucial in many other methods which need to elicit qualitative information from the decision maker. An approach based on pairwise comparisons which was proposed by Saaty (1980) has long attracted the interest of many researchers. Pairwise comparisons are used to determine the relative importance of each alternative in terms of each criterion, in this approach allow the decision-maker has to express his opinion about the value of one single pairwise comparison at a time, these comparisons are used to obtain the weights of importance of the decision criteria, and the relative performance measures of the alternatives in terms of each individual decision criterion

The main problem with the pair-wise comparisons is how to quantify the choices selected by the decision maker during their evaluation. All the methods, which use the pair-wise comparisons approach eventually express the qualitative answers of a decision maker into some numbers which, most of the time, are ratios of integers. As, pair-wise comparisons are the keystone of these decision making processes, correctly quantifying them is the most crucial step in multi-criteria decision making. Pair-wise comparisons are quantified by using a scale. Such a scale is a one-to-one mapping between the set of discrete choices available to the decision maker and a discrete set of numbers, which represent the importance, or weight, of the previous choice.

2. 4 Parameters to Measure Environmental Quality

2.4.1 Land use and land cover

The assessment of land-use/land-cover serve as a preliminary means of investigating urban environmental quality change (Opeyemi and Trina, 2014) because land cover/ land use changes associated with urbanization are important drivers of local geological, hydrological, ecological, and climatic change.

2.4.2 Urban green space and vegetation density

Green space is an important part of complex urban ecosystems that give environmental, esthetic, recreational and economic benefits to the urban dwellers. Vegetation provides cooling through shading and enhanced evapo transpiration (Christian and Ugoyibo, 2013). In spite of this, urban green space and vegetation density had been emphasized as the major index of air

freshening, which will generally improve the urban environmental quality (Faryadi and Taheri, 2008).

2.4.3 Temperature

Temperature and quality of environment had direct relationships, as temperature is an indicator of degradation of urban environment. With rising urban temperature increase social and environmental injustices may commonly present in cities. High thermal levels in the city region has been considered as an index for low quality of urban environment which is an important parameter of urban environmental quality (Opeyemi and Trina 2014).

2.4.4 Population density

High levels of population density in the city has been considered as human index for low quality of urban environment because unbalanced and uncontrolled urbanization lead to environmental degradation in the quality of urban life which is associated with sound, air, and water, created by disposal of hazardous waste. During the past millennium, humans have taken an increasingly large role in the modification of the global environment. With increasing numbers and developing technologies, man has emerged as the major powerful and universal instrument of environmental changes in the biosphere (Saied et al, 2004).

2.4.5 Greenhouse Gas Emission

High amount of carbon monoxide concentration in the sub-city have been considered as human index for low quality of urban environment which is an important parameter of urban environmental quality (Opeyemi and Trina, 2014).

2.4.6 Density of built-up area

Rapid urbanization brings with it many problems as it places huge demands on land, water, housing, transport, health and education. Several environmental challenges fuelled partly by the pressures caused by human activities such, as housing development, road construction for transportation, economic development and demographic changes (Twumasi and Merem, 2006). This implies that urban development increased the temperature by replacing natural environment (forest, water and pasture) with non-evaporating, non-transpiration surfaces such

as stone, metal and concrete surface. Overall housing density is a more important negative predictor of the extent of green space and tree cover (Davies et.al, 2008).

2.5 Remote Sensing and GIS Application

The integrated framework of RS techniques and GIS framework greatly reduces time, effort and expenses in using geographical data. Remote sensing with its advantages of spatial, spectral and temporal availability of data coverage large and inaccessible areas within short time has become a handy tool in assessing, monitoring and conserving urban greenery. Satellite Remote Sensing, with its repetitive coverage together with multi-spectral (MSS) capabilities is a powerful tool to map and monitor the emerging changes in the urban core as well as in the peripheral areas of any urban areas (Akanbi et al., 2013).

Satellite images enable us to better understand some of the intrinsic components of the ecosystems and the interactions within the whole environment. The relevance of remote sensing in urban environmental quality is further enhanced by geographic information system (GIS) which makes it possible to integrate remote sensing data with socio-economic variables and in situ data. (Opeyemi and Trina, 2014). The use of a GIS system in this research, is gives the opportunity to combine a set of data, dissimilar to each other, to find relations and differences and to classify the urban greenery into different categories and for overlay analysis and for this preparation the concerned map.

2.5.1 Measuring Green area using Normalized difference vegetation index (NDVI)

Information about green space is important for urban environmental quality analysis. Remote Sensing and GIS are providing new tools for advanced natural resources evaluation, mapping and prediction of the greenery in terms of percentage available in (Saied et al., 2004). The previous system of estimating or extracting green percentage mostly taking more time and inaccuracy so it is difficult for large area so it is tedious, consume more time and costly but now remote sensing technique is very crucial in order to differentiate qualitative and quantitative measuring of urban green by the mechanism of NDVI which is part of remote sensing technique.

Measurement of NDVI, using remote sensing techniques, shows all existing vegetation in green land uses (Faryadi and Taheri, 2008). The Normalized Difference Vegetation Index (NDVI) gives a measure of the vegetative cover on the land surface over wide areas. Dense vegetation shows up very strongly in the imagery, and areas with little or no vegetation can also clearly identified. NDVI also identifies water surface area. Vegetation differs from other land surfaces because it tends to absorb strongly the red wavelengths of sunlight and reflect in the near-infrared wavelengths. NDVI takes values between -1 and 1, with values 0.5 indicating dense vegetation and values <0 indicating no vegetation. As shown in Figure 1.1 healthy vegetation absorbs most of the visible light that hits it, and reflects a large portion of the near infrared light and unhealthy or sparse vegetation reflects more visible light and less near infrared light.

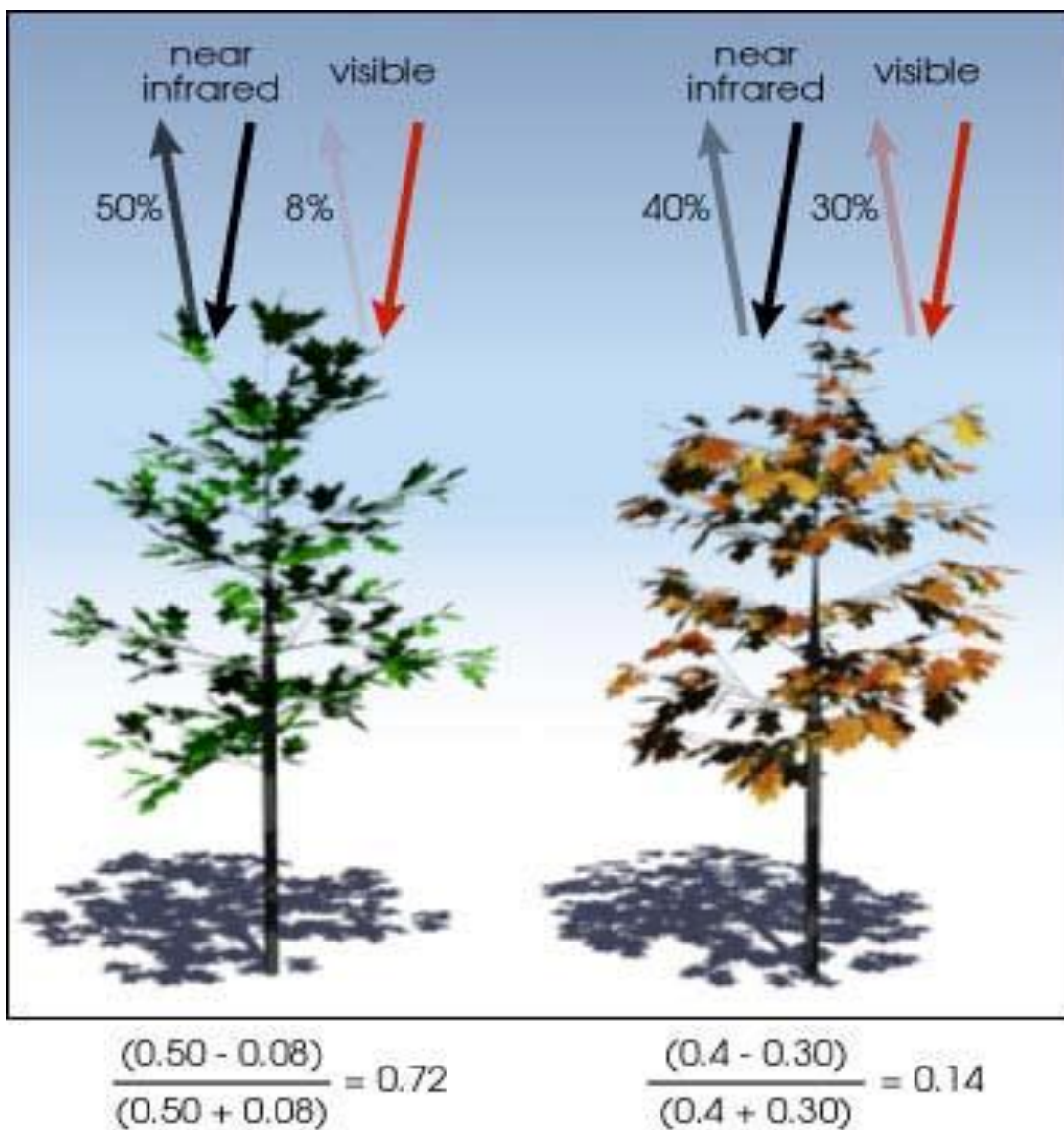


Figure 2.0.1 Normalized Difference Vegetation Index (NDVI)

(Source by Robert Simon 1980)

2.6 Urban Greeneries and Sustainable Quality of Life

Urban greenery play a vital role in improving the quality of life of urban community in which it contributes to public health as well as to the urban environment. Several environmental challenges fuelled partly by the pressures caused by human activities such as housing development, road construction, transportation, economic development and demographic changes (Twumasi and Merem , 2006). As a result, park and open green space (POS) are one of the most important spaces in the urban environment that should be considered during the Strategic Environmental Assessment (SEA) process of urban planning. Another important feature for a sustainable development in urban regions is the conservation of open spaces, mostly green areas (Thomson, 2002).Vegetation is very useful in filtering air, water and sunlight cooling urban heat, recycling pollutants, moderating local urban climate, providing shelter to animals and recreational areas for people.

Conservation and improvement of existing green areas in urban area and the creation of new spaces to ameliorate the urban heat effect is important and can have a number of additional benefits such as creating areas for recreation, biodiversity conservation, filtering air and draining and storing water.

3.1 Study Area

Addis Ababa, the capital city of Ethiopia, is one of the largest urban centers in Sub-Saharan Africa. It is located between latitude, 8°49'–9°5' N and longitude, 38°38'–38°54' E covering a total area of 51957.92ha as show in (Fig 3.1).The city altitudinal zones of Addis Ababa range from 2054 to 3023 masl. It situated in the foothills of the 3000 m Entoto Mountains spreads across many wooded hillsides and gullies, cut through with fast flowing streams ([Atlas of Addis Ababa, 2013](#)).Addis Ababa was founded during the reign of Emperor Menelik II in 1886. Under the Italian occupation, the first city plan was designed in 1936 with defined functional and ethnically segregated zones for most parts of the city ([Atlas of Addis Ababa, 2013](#)). At present, the whole city is divided in to ten sub-cities and 116 district or weredas.

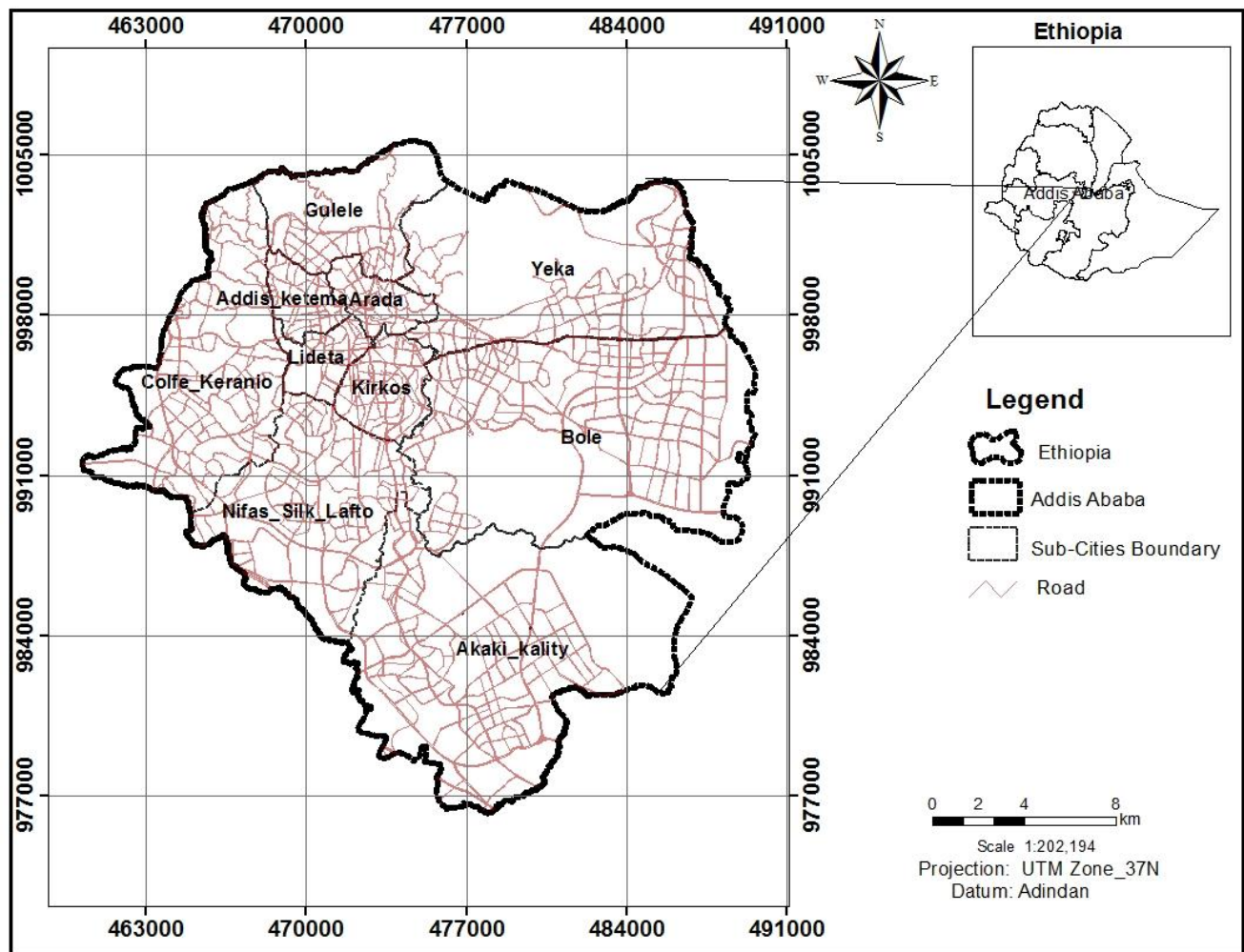


Figure 3.1 Location map of Addis Ababa

3.2 Population

According to the (CSA, 2015) Census Addis Ababa City has a total population of 3,275,348 which is about 60% of the total urban population of Ethiopia. Among this the number of female population was 1,723,235 (53%) and the remaining was male 1,552,113 (48%). which shown in (Table 3.1 and Fig 3.2).

Table 3.1 Population in the sub cities of Addis Ababa

Sub City	2015		
	Male	Female	Total
ADDIS KETEMA	148,504	156,772	305,277
AKAKI KALITI	105,481	111,212	216,693
ARADA	117,908	134,979	252,886
BOLE	172,673	196,780	369,453
GULELE	153,853	166,089	319,942
KIRKOS	123,062	141,465	264,527
KOLFE KERANIYO	246,886	265,850	512,736
LIDETA	114,468	126,694	241,162
NEFAS SILK-LAFTO	177,143	201,020	378,163
YEKA	192,134	222,375	414,509
TOTAL POPULATION	1,552,113	1,723,235	3,275,348

Source: Addis Ababa Central Statistics (CSA, 2015)

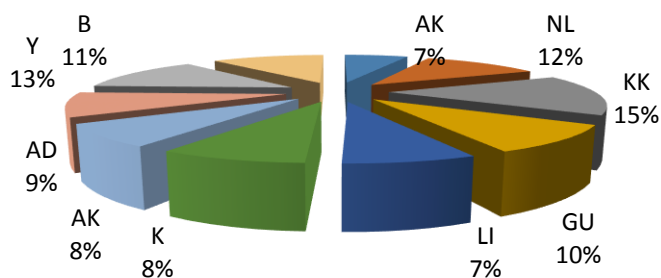


Figure 3.2 Population distribution of sub cities in Addis Ababa

3.3 Temperature

The temperature Addis Ababa fluctuates from January to December. The monthly mean maximum and minimum temperature recorded during the years between 1984 and 2014 indicates that the highest mean monthly maximum temperature occurs in the month of March, which is about 24.4°C and the lowest is in the months of August, which is about 20.2°C While the mean monthly minimum temperature ranges for the lowest from 7.2°C in December to the highest 10.9°C in the month of May. Long term mean annual maximum and minimum temperature of the city administration is 24.4°C and 7.2°C, respectively (Fig 3.3). (Addis Ababa meteorological Agency)

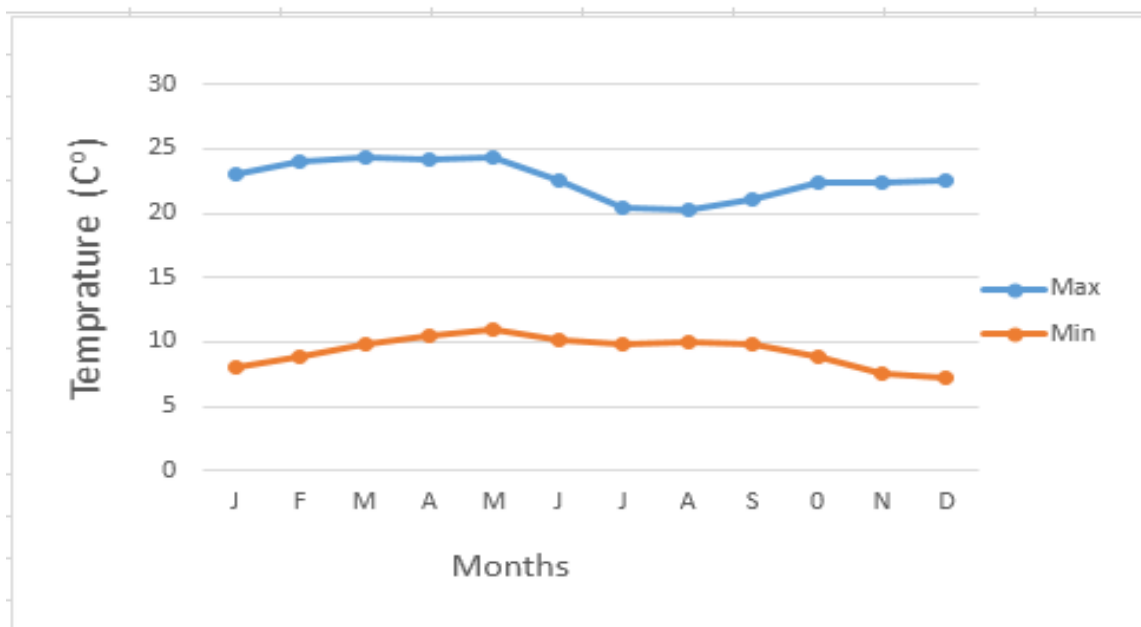


Figure 3.3 Monthly average temperature of Addis Ababa (AMA)

3.3.1 Precipitation

According to the mean annual precipitation recorded at Addis Ababa Meteorological Station during 30 year period from 1984 to 2014 was about 1143.3mm. There is a significant seasonal variation in the amount of rainfall. Almost 50% of the mean annual rainfall occurred in two rainy months of July and August with the maximum mean value of 287.7mm and 274.7mm, respectively (Fig 3.4). (Addis Ababa meteorological Agency)

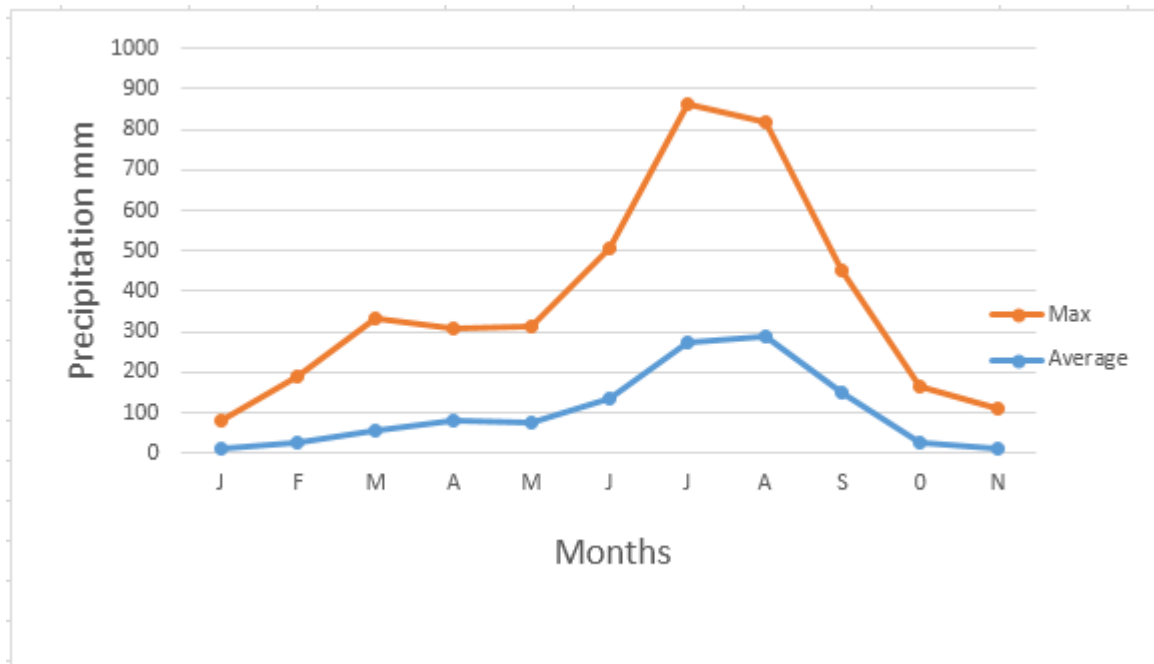


Figure 3.4 Mean Annual precipitation of Addis Ababa (AMA)

3.4 Soil

Soil is the end product of the influence of the climate, relief (elevation, orientation and slope of terrain), biotic activities (organisms), and parental materials (original rocks) interacting over time. According to FAO soil classification, Addis Ababa has three types of soils. These are chromic luvisols with an area of 6854.3201, eutricvertisols with an area of 28767.8008, humicnitosols with an area of 16329.6932 ha (FAO, 2014).

3.5 Topography

3.5.1 Elevation

Elevation is an indicator that enables a simple understanding of topography (relief) for a given area. It is mapped using DEM. Conversion of raster to contour map and creates an elevation surface data providing the altitude value of any space measured on small size square or pixels. From the Elevation map, Addis Ababa that city is characterized by vigorous type of topography with noticeable elevation difference and steepy landscape, especially in the northern part. Generally, in the sub city, the altitude ranged from 2050 to 3020 m above sea level which has a range of 957 m. The highly elevated land exists in the north while relatively lower elevation exists in the South. The highest peak of the city exists in city at Entoto Mountain at an altitude value of 3016 m.

3.5.2 Slope

Slope is another means of describing topography for a given area. It is a measure of terrain steepness that i.e., the degree to which land is not horizontal. A flat surface is 0%, and as the surface becomes more vertical, the percent rise becomes increasingly larger. The categorization of an area in different slope classes can be used for different civic works such as for planning of drainage, road construction, housing. Slope is measured as percentage rise classified in to 7 different ranges. Gulele is highly steepy sub city in which 49.57% of its land area comprising greater than 15% (8.53°) slope. Like the altitude mentioned before, larger slopes exist in northern part while lower slopes with relatively gentle grounds exist in the south west part of the sub city.

3.6 Land-use/land-cover

The main land-use/land-cover of the city is dominated by residential and vegetation which, include riverine, vegetable farm, mixed forest, plantation and field crop, which include in the category of vegetation as shown in Table 3.2.

Table 3.2 Existing land-use/land cover

Land-use/land-cover	Area in (ha)	Area in (%)
Built-up area	20441.28	39
Vegetation	19786.76	38
Open space	4405.92	9
Recreational	113.66	0
River	1090.69	2
Road network	5773.88	11
Restricted Area	345.73	1
Total	51957.92	100

Source: Addis Ababa Integrated Land Information Center (ILIC)

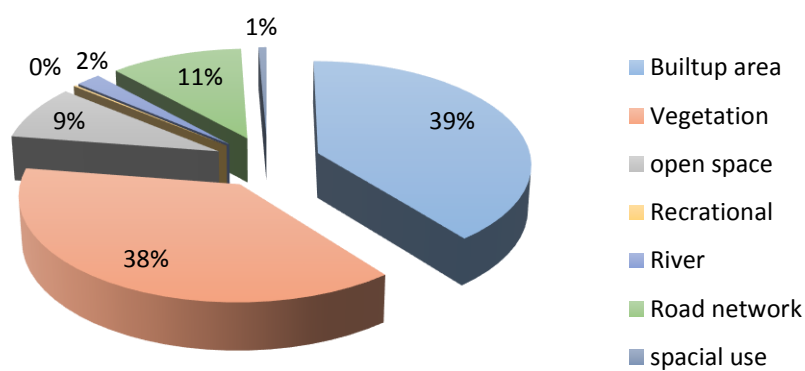


Figure 3.5 Land-use/land-cover distribution in Addis Ababa

3.6.1 Urban Attractions

3.6.1.1 Parks

A park is a tract of land that often includes lawns, woodland and pastures attached to a country house and are used for recreation. Parks are recreational places that are mostly more of gardens, open area and structure and space for structures. Urban parks can be developed through partnership with business community, Hotels, regional or city transport Company, airlines, tourist commissions, tour operations. There are about eleven public parks in Addis Ababa. These recreational parks are not only few in number to satisfy the need of the population but also lack the necessary facilities. On top of this, the spatial distribution of these facilities is uneven. In addition to this there is no plot available for future expansion of the services. The total area coverage of public parks in the city almost 109 hectare that cover 0.4 percent of the total built-up area in Addis Ababa.

3.6.1.2 Botanical garden

Botanic garden is a place where collections of living plants are maintained and studied, and hence it is a living museum of plants. Botanic gardens have a role to play in the conservation of plant species which otherwise might become lost or extinct. Urban garden areas may also strengthen the resilience of urban areas by decreasing vulnerability to food crises ([Akanbiet.al, 2013](#))

Gulelle Botanical Garden, the first of its kind in Ethiopia, came in to being in after almost thirty years covering 705 hectares of land situated at an elevation of 3000 meters, is located in the northwestern part of Addis Ababa, about 4.3 km away from the center of the city within Gulelle and Kolfe-Keranyosub-cities. Geographically, it belongs to the central plateau of Ethiopia. In the garden, there are over 240 plant species (trees, shrubs, herbs and climbers). Among these plant species 71 are medicinal and 28 are endemic to Ethiopia and Eritrea, as shown in (Plate 3.1 to 3.4).

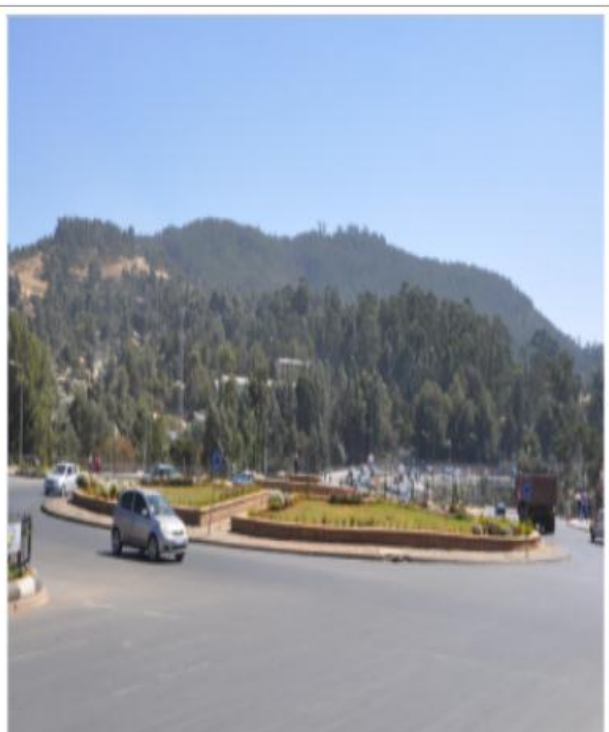


Plate 3.1 Ethiopian Korea War veteran memorial park Plate 3.2 Urban green area at Yeka square



Plate 3.3 Debabe Park in Arada sub-cities



Plate 3.4 Gulele Botanic Garden

4.1 Data source and acquisition

To realize the designed objectives reliable data are necessary. The study was based on both primary and secondary data. Spatial data were analyzed with descriptive statistics and remote sensing technology. In addition to this, field observation was used with the hand held GPS readings to check the ground truth of satellite images to generate primary information and to collect data on urban green spaces. (Table 4.1) shows the data sources and their descriptions.

Table 4.1 Data sources used for the study

Item No	Data Type	Data Sources	Description
1.	Top Map of Addis Ababa	EMA	1:50,000
2.	Boundary of the study Area	ILIC	Shape file
3.	Existing road	Master plan	Shape file
4.	GPS reading data	Field data	Longitude & Latitude value
5.	Socio economic data	ILIC	Textual information
6.	Atlas of the study area	ILIC	Textual information
7.	Landsat image	USGS	TM,ETM ,ETM+
8.	Greenhouse gas emission	AEPA	Textual information
9.	population	CSA	Excel file
10.	Temperature and Rain fall	AMA	Excel file
11.	Waste disposal	ILIC	Shape file
12.	Industrial area	ILIC	Shape file
13.	Line map	ILIC	CAD file

4.2 Material and software

Hand held Global Positioning System instrument (garment GPS) was used to collect information on training sites for land-use/land-cover classification, ERDAS Imagine 2013 software was used for image processing activities on satellite images and to compute change detection analysis on land-use/land-cover of classified images and to do accuracy assessment. The variables development were carried out using ArcGIS10.2.2 software package. Maps of variables that were input for multi-criteria analysis were preprocessed in accordance with the criteria set to assess urban environmental quality. Using spatial analyst extension, relevant GIS analyses were undertaken to convert the collected shape files. Eigen vector for the selected variables were computed using weight module in IDRISI 17 software.

4.3 Datasets and Image Pre-Processing

The data sources for this research primarily came from landsat images and secondary data from different organizations used to extract parameters for the environmental variables. The population census data were collected from (CSA, 2015.) The three Landsat images included TM, collected on June 6, 1986, Landsat7 ETM 2000 and ETM+ 2015. All images were first georectified to a common UTM coordinate system using 1:50000-scale topographic maps as reference. For the image, 250 ground control points were selected to generate coefficients for a first-order polynomial, and a nearest-neighbor method was applied to resample the image according to their original theoretical spatial resolution.

4.4 Extraction of Environmental parameters From Image Data and Secondary Data

This research aims to assess environmental quality for evaluating the environmental quality of the study. First the distribution and quantity of following indices, land-use/land-cover, distribution and density of vegetation cover (NDVI), surface temperature, greenhouse gas emission, built up density, population density were measured, evaluated and compared for each sub-city in Addis Ababa.

4.4.1 Land use/ Land cover

The first task is to develop a scheme for classification. In order to provide a complete representation of the UEQ condition in the natural environmental aspect for the study area, three LULC maps of 1986, 2000 and 2015 were first derived from Landsat images with different classifiers. The land cover (LC) map are given by performing the supervised classification.

4.4.2 Distribution and Density of Vegetation Cover (NDVI indices)

Normalized Difference Vegetation Index (NDVI) has been applied for measurement of vegetation distribution and density in this research. Vegetation has a high reflectance in the Near Infrared Red (NIR) bands of a sensor system because of the internal reflectance by the spongy mesophyll tissue of a green leaf (Campbell, 1987). The NDVI separates the soil vegetation from other ground cover materials. Then its ratio is calculated through the difference of near infra-red

(NIR) and red band (RED) which would be normalized by summing up these two bands in the following equation (1) (Lillesand and Keifer, 1994)

$$NDVI = \frac{NIR - Red}{NIR + Red} \dots\dots\dots (1)$$

Where, NDVI → Normalized Difference Vegetation Index

RED → Stand for the spectral reflectance measurements acquired in the red

NIR → Stand for the spectral reflectance measurements acquired in the near-infrared regions.

4.4.3 Surface Temperature Extraction

In this study the approach was used by converting the thermal band of Landsat 8 band 10 and 11 to radiance followed by calculating the satellite temperature. Then, the satellite temperature is corrected using the emissivity values, which computed from the Normalized difference vegetative index, to find the corrected at satellite temperature. Finally that corrected at satellite temperature was changed in to surface temperature. Basically, three steps were involved in the procedure: first, converting the digital number (DN) values of the thermal band into spectral radiance; second, converting the spectral radiance to at-satellite brightness temperature, namely, blackbody temperature; and third, adjusting the blackbody temperature to land surface temperature by incorporating emissivity biases due to land cover differences.

1. Conversion of DN Values to Radiance

OLI and TIRS band data was converted to TOA special radiance rescaling factors provided in the metadata file. The first step is that conversion of the Digital Number (DN) value of the image which was converted to the radiance units using equation... (2)

$$L_{\lambda} = [M_L * Q_{CALMAX} + A_L] \dots\dots\dots (2)$$

Where: L_{λ} = TOA special Radiance (watts/(m²*srad*μm))

M_L = Band specific multiplicative rescaling factor from metadata
(RADIANCE_MULT_BAND_X where x is band number)

A_L = Band specific additive rescaling factor from metadata
(RADIANCE_ADDT_BAND_X where x is band number)

Q_{CAL} =quantized and calibrated standard product pixel value (DN)

2. Conversion of Radiance to at Satellite Temperature

The second step during quantitative analysis is that conversion of radiance to temperature. The satellite temperature was calculated under an assumption of unity emissivity and using the pre-launch calibration constants K_1 and K_2 (LANDSAT Project Science office, 2015), presented in (Table 4.2).

Table 4.2 ETM+ Thermal band Calibration Constant (USGS)

ETM+ Thermal band calibration Constants		
Constant	Band 10	Band 11
K_2	1321.08	1201.14
K_1	774.89	480.89

$$T = \frac{K_2}{\ln\left[\frac{K_1+1}{L_\lambda}\right]} \dots\dots\dots (3)$$

Where, T → Effective at –satellite temperture in kelvin

K_2 =Band specific thermal conversionconstant from metadata
($K_2_CONSTANT_MULT_BAND_X$ where x is band number 10 or 11)

K_1 =Band specific thermal conversionconstant from metadata
($K_1_CONSTANT_MULT_BAND_X$ where x is band number 10 or 11)

L_λ = TOA special Radiance(watts/(m² *srad *µm))

3. Estimation of Emissivity

The emissivity is a key factor of temperature measurement to measure from the surface, but in this case the remote sensing advantages several method have been developed to measure ϵ from satellite taking into account that every pixel has a fraction cover by vegetation and other fraction cover by soil or rock, the pixel emissivity was obtained as a mix of the emissivity different surface. One of the most powerful model was the Vegetation Cover Method (VCM) (Valor et al, 1996) that gave the following operational equation 4

$$\begin{aligned} \epsilon &= \epsilon_V P_V + \epsilon_g (1 - P_V)(1 - 1.74 P_V) + 1.7372 P_V(1 - P_V) \\ \epsilon &= 0.004P_V + 0.986 \dots\dots\dots (4) \end{aligned}$$

Where, 'v' means vegetation and 'g' ground.

P_V The fraction cover that could be directly obtained from the NDVI vegetation index that is obtained from satellite measurement.

$$P_V = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \right)^2 \dots\dots\dots (5)$$

Where, P_V = proportion of vegetation

3. Land Surface Temperature

Land surface temperature then is computed from calculated emissivity values and calculated temperature at satellite using equation 6, which gives an emissivity corrected image as follows

$$T_{LST} = \frac{T_B}{1 + W * (T_B / \rho) * \ln \epsilon} \dots\dots\dots (6)$$

Where, T_{LST} → Surface temperature (K)

T_B = At satellite temprature

W = wavelength of emitted radianc(11.5 μ m)

$\rho = hc/k$ (1.438 x10⁻²mk)

h = plank's constant (6.26 x10⁻³⁴J-sec)

c = velocity of light (2.998 x10⁸m/sec)

k = stefan Boltzmann's constant (1.38 x10⁻²³J/K)

4.4.4 Population Density

Human population data for each the sub cities was obtained from the 2015 data of Addis Ababa (CSA, 2015) and converted to compatible shape file. Population factor was classified by density of settlement size which is high population density was marked as poor environmental quality.

4.4.5 Greenhouse Gas emission

Data in row carbon monoxide pollutant has been obtained from measured sample data of Addis Ababa Environmental Protection Agency which was taken as baseline for the greenhouse gas (GHG) inventory cover carbon dioxide (CO₂) methane (CH₄) and nitrous oxide (N₂O).The inventory emissions sources was from five emission sectors: stationary energy, transportation, waste, industrial processes and product use and agriculture, forestry and other land-use. The obtained raw data was digitalized based on existing land-use/Land-cover map then processed using interpolation method and reclassify based on the value high GHG emission was mentioned environmentally critical.

4.4.6 Built-up Density

Rapid urbanization brings with it many problems as it places huge demands on land, water, housing, transport, health and education. Several environmental challenges partly by the pressures caused by human activities such as housing development, (Twumasi1 and Mermen, 2006).From Addis Ababa city of Integrated Land Information Center, 2003 built up shape files were acquired and building density was calculated using raster calculator an extension of spatial analyst of Arc GIS and high building density was mentioned (Fig4.1)on the general methodology.

Risk: is the degree of total loss of a particular phenomenon due to different factors.

Environmentally Critical Areas (ECA):Are those areas ranging from national parks to areas frequently exposed to hazards or areas relating to or being state in which or a measurement or point at which some quality, property or phenomena suffers a definite change .

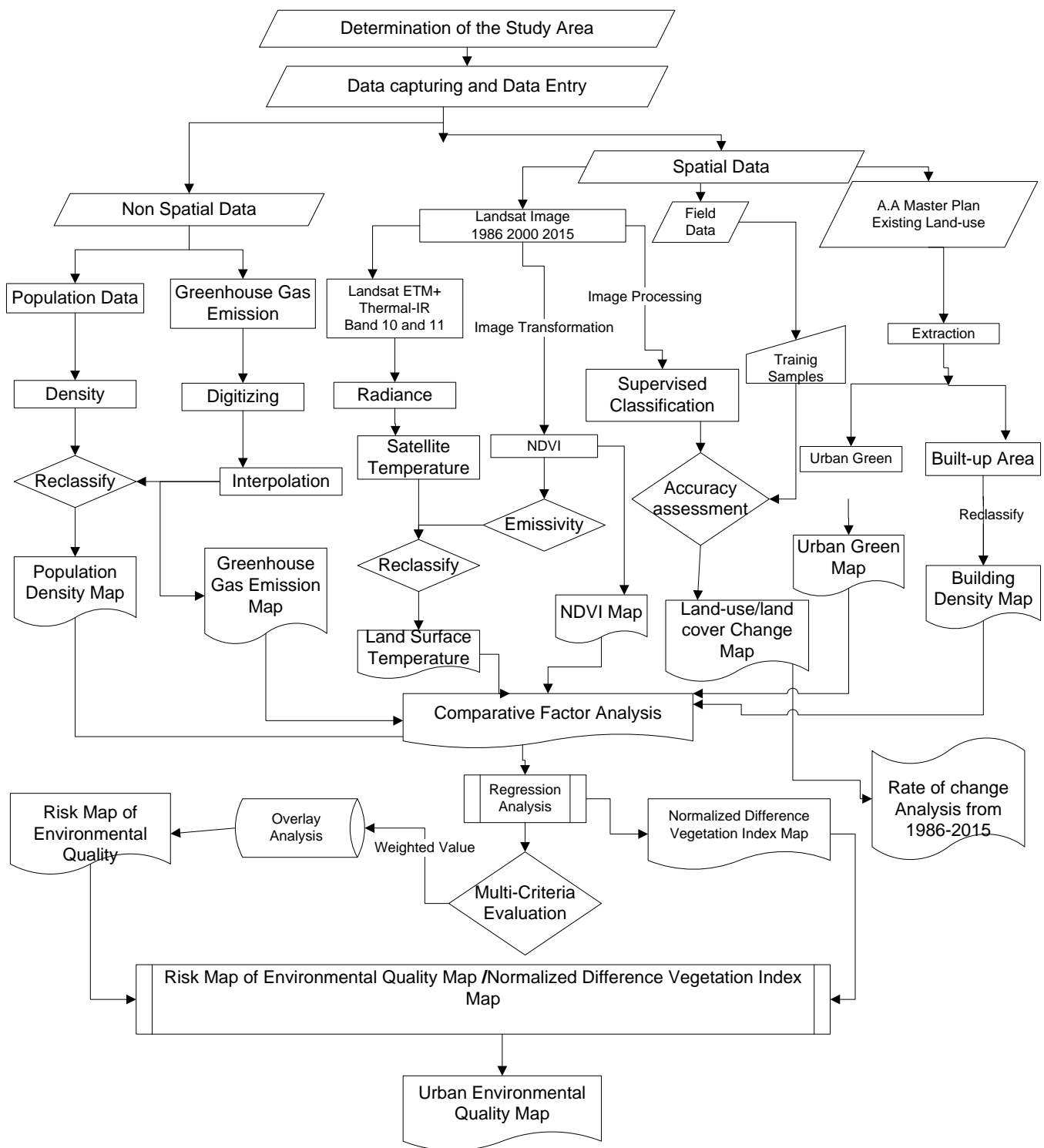


Figure 4.1 Flow chart of general methodology

4.5 Parameter Criteria Classification and Map Generation

The next stage of the study was to determine the priority classes and influence for the weighted overlay operation. This study identified the following parameters (Table 4.3) as indicators of Urban Environmental Quality in the city of Addis Ababa. The evaluation for UEQ was conducted based on the six chosen parameters viz land-use/land-cover, NDVI, surface temperature, building density, population density and greenhouse gas emission.

Table 4.3 Reclassification for parameters value

Parameters	Criteria	Unit	Urban Environmental Quality Indicator Rating				
			High	Moderate	Marginal	Not Suitable	
Land Cover	LULC	Class	Forest/ vegetation Land	Crop/land/grass Land	Water Body	Bare Land	Settlement
	NDVI	Value	0.22-0.52	0.15-0.22	0.09-0.15	-0.15--0.01	
Existing LULC	Built up Area	Density	0.05-0.08	0.08-0.09	0.09-0.14	>0.14	
Urban Heat	Surface Temperature	Value°C	17-24	24-27	27-29	>29	
Population	Population size	p/ha	<50	50-150	150-250	>250	
Green House GHG	Carbon emission	Per ton	0.02-0.03	0.03-0.14	0.14-0.23	>0.23	

4.5.1 Urban Environmental Quality Index Development and Validation

The resultant Land Cover categories included forest/vegetation, cropland/grass land, water body, settlement, and bare lands and risk variables include population density, building density, thermal heat and greenhouse gas components were used to develop UEQ index after weighted by the percentage of variance that each component explained.

4.5.1.1 Model Validation Using Multi Regression Method

Accuracy assessment is needed for validating the effectiveness of the developed UEQ index. The overall accuracy obtained from these three maps was 88.80% for TM 85% for ETM+00 and 84.00% for OLI_TIR. The land use (LU) map was produced using a supervised maximum likelihood classifier. A few approaches have been proposed by using regression modeling in this study, the Multi regression method was performed to validate the model by using Ordinary least square regression model an extension of spatial analysis tool of GIS the original variables that showed correlation with the considered components as predictors and residual map was produced with adjusted $R^2 = 92$ and Coefficient values also generated. A coefficient of determination was calculated to examine the effectiveness of the developed regression models with the following formula.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n + \varepsilon \dots \dots \dots (7)$$

Where, Y → Dependent variable what you are trying to model or predict

X → Explanatory variables you believe cause or explain the dependent variable

β → Coefficients Values, computed by the regression tool, reflecting the relationship between explanatory variables and the dependent variable.

ε → Residuals the portion of the dependent variable that isn't explained by the model; under- and over-predictions.

4.5.1.2 Determination of Weight Value for Each Criteria Using AHP

Analytic Hierarchy Process is an effective, flexible and simple method to be used in certain cases on which many contradictory criteria make decision making process very difficult. This multi- criteria evaluation method was propose by Saaty in 1980 and since then had several applications in different sciences. A principal method to test AHP method is calculated using (eq.8) which is a binary comparison method. This method considerably reduces the conceptual complexity of decision making process because of simultaneous evaluating of two components by using IDRISI 17 software and the weight Consistency ratio = 0.02. Therefore Consistency law acceptable (eq 8). The criteria set up where choosen according to Multi regreition experiances, experts'opinions and information from various sources.knowledge acquisition has been accomplished throuhg discssion with students of related fields of study and surveying of authenticated literatures.

$$CR = \frac{CI}{RI} \dots\dots\dots (8)$$

Where CI →consistency index

$$CI = \frac{\lambda^{-n}max}{n - 1}$$

$\lambda^{-n}max$ →is the principal Eigen value of the matrix, n is the order of the matrix

RI →is the average of the resulting consistency index depending on the order of matrix

The following percentages of influence (weights) as shown in Table 4.4 were given for each layer by using IDRISI17 software and the weight Consistency ratio = 0.02 therefore consistency is acceptable.

Table 4.4 Weighting Value

No	Criteria	Weight %
1	Land-use/land-cover	24
2	Built up Density	17
3	Surface Temperature	16
4	Population Density	21
5	Green House Gas emission	22

4.6 Data Integration of Environmental and Secondary Data Variables

Correlation analysis factor analysis and Overlay analysis were the major approaches to integrate environmental parameters derived from remotely sensed images and secondary data variables extracted from census data. To illustrate the critical area of urban environment, geospatial approach, was carried out using ERDAS Imagine, ArcGIS and IDRISI environment.

4.6.1 Regression Analysis

All the 5 parameters extracted from the physical and secondary datasets were first entered to run ordinary list square correlation analysis. Tables 5.1, list the computed by variables later proved to be important for the research. To shed some light on their qualification on the study, Coefficients have the expected sign, statistically significant, no redundancy among explanatory variables, residuals are normally distributed, residuals are not spatially auto-correlated and strong Adjusted R-Squared value summarizes their correlation with all the variables that have been evaluated.

4.6.2 Factor Analysis

For land-use/land-cover, the following methods of data analysis were adopted for the study using Maximum Likelihood Classification, accuracy Assessment with 250 reference points Calculation of the Area in hectares of the land use/land cover types obtained for each study year and subsequently comparing the results and finally Annual Rate of Change (ha/year) = (% of recent land-use/land-cover change - % of previous land-use/land-cover change) / 100 * # of Study years (15 years).

4.6.3 Overlay Analysis

Overlay Analysis tools included in the Spatial Analyst extension commonly used to solve multi-criteria problems such as optimal site selection or suitability modeling. Further more, it is a technique for applying a common scale of values to diverse and dissimilar inputs to create an integrated analysis (Esri, 2013) used to address which locations are most exposed to environmental degrading. The first step was to model the operators using ordinary least squares linear regression to generate prediction to model a dependent variable in terms of its relationships to a set of explanatory variable. Then generate risk map of Environmental Quality map, parameter layers were computed by reclassifying as population density, building density, urban heat, greenhouse gas density and Land-use/ Land-cover Classification. The layer classified into classes, assigning values to classes overlaying the parameters. Table 4.3 summarizes the data groups, priority classes, points and influence (weight) values used for weighted overlay to come

up with the final environmental risk map of the study area, all these will be integrated together to show the level of environmental quality in the study area; which is the function of all these factors. Which in the weighted overlay, Overlays environmental parameter layers using a common measurement scale and weights each according to its importance each cell in a single layer was given a point value, which was calculated with the multiplication of the priority class point of the cell with the influence factor of the related secondary data group. The influence factors of the secondary data groups and the new values of the cells in each secondary data layer under the same primary data group were then again multiplied to get risk map of UEQ. Besides the weighted overlay technique, AHP is an import application for creating geographical analysis, to the model by performing pair-wise and multi criteria decision support to determine the weighting factor as summarized in table4.4for the risk map of urban environmental quality selection. There is a need to have a holistic integration of many more indicators to reach a logical conclusion using deductive indices the proportion of the vegetation cover area (NDVI index) to Risk map of Environmental Quality were also weighted overlaid using map algebra raster calculation then the proportion of risk map to obtain Urban Environmental Quality result map in Fig 4. According to this index the regions with high greenhouse gas density, overpopulated, high building density, high heat density and low vegetation cover area would get the lowest values thus, they will be considered as critical area. And sparsely populated area, low heat, less built up area, low greenhouse gas emission and high vegetation cover and density area consider as suitable environmental quality

5.1 Regression Analysis Result

For the sake of evaluating the effectiveness of the developed urban environmental quality models, regression analyses were performed with the original variables that had loading with the corresponding factors as the independent variables and dependent variables and the result are given in Table 5.1. This table summarizes the correlation with all the variables that have been evaluated. Coefficient represents the strength and type of relationships between each explanatory variable and the dependent variable. In general, the correlation coefficients relatively inversely correlated with the dependent variable for most the tested data. Probability and Robust Probability (Robust-Pr): Asterisk (*) indicates a coefficient is statistically significant ($p < 0.01$). Large Variance Inflation Factor (VIF) values (> 7.5) indicate redundancy among explanatory variables. Clearly, while there was variance inflation factor between Populations (14) and building (17) variable with a VIF greater than 7.5 should have been removed one by one. The R-Squared measures of model fit/performance values showed 92% (Appendix)

Table 5.1 Summary of urban environmental quality regression analysis result

Variable	Coefficient	t-Statistic	Probability	Robust-t	Robust-Pr [b]	VIF [c]
Intercept	0.31966	4.195808	0.005943*	7.353267	0.000393*	-----
population	-3.038025	-8.255098	0.000132*	-10.294585	0.000002*	1.923088
Temperature	-0.006742	-2.649933	0.037747	-4.367938	0.004997	1.463664
Greenhouse gas emission	0.000027	2.722399	0.034257	4.62643	0.003897	2.416063

Note: * (Asterisk) indicate probability (b) and Robust-pr (b) variable Correlation is significant ($P < 0.01$)

5.2 Factor Analysis Results

The results of 1986, 2000, and 2015 classified images are presented in and Figure 5.1 was assessed for accuracy by comparing represents the static land-use/land-cover category of thick vegetation/forest land, urban crop /grass land, settlement, water body and bare land available information from the area Figure 5.1 shows thick vegetation and, crop land and bare land decline with the increasing of settlement.

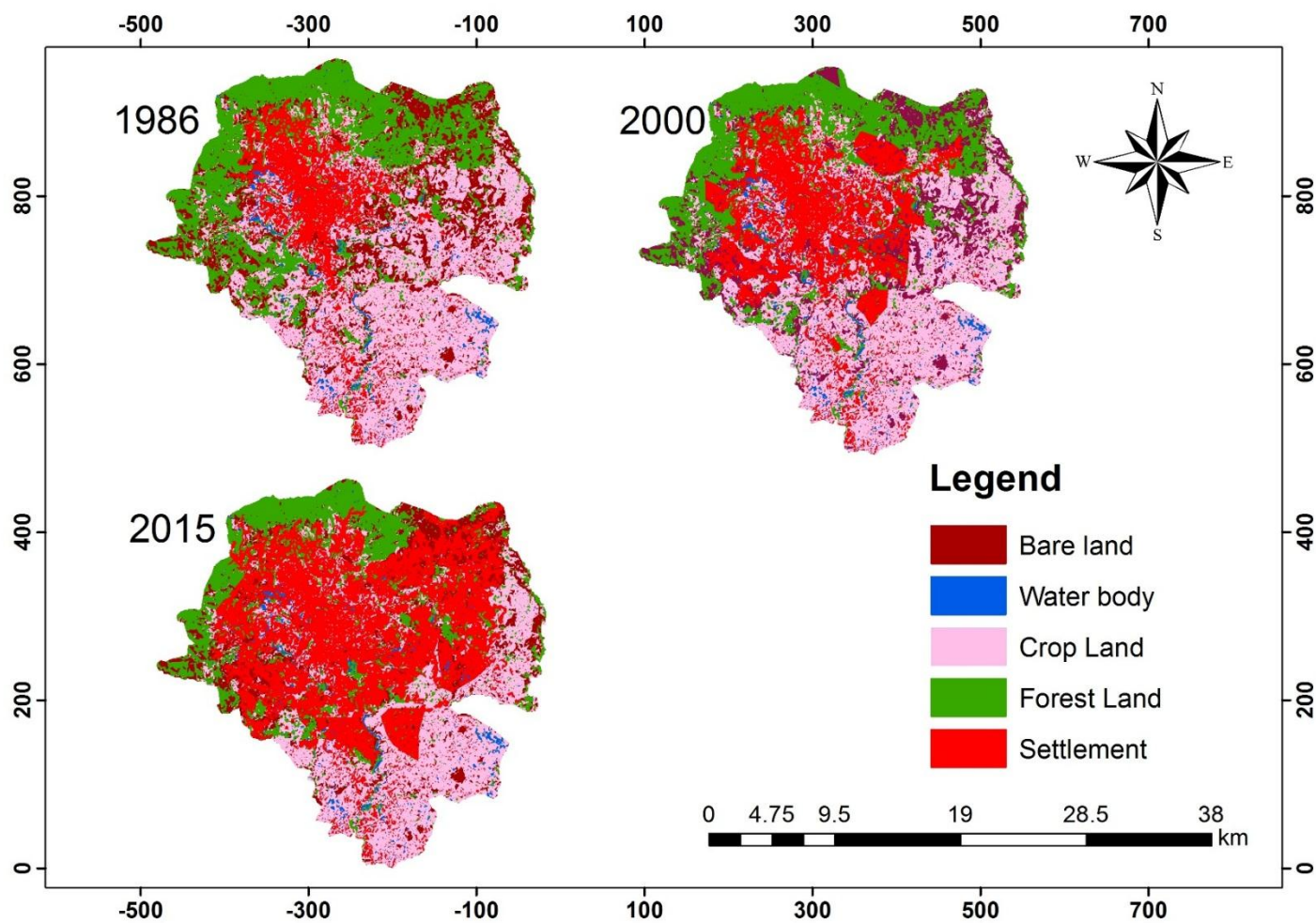


Fig 5.1 Land-use/land-cover change map of 1986, 2000 and 2015 the study area

The overall accuracy for land-use land-cover change (Table 5.2) 1986 image classification is 88.80% for 2000 is 85% while for 2015 is 84.00%.

Table 5.2 Land-use/land-cover accuracy assessment

Land use land cover Category	1986		2000		2015	
	PA	UA	PA	UA	PA	UA
Thick vegetation/forest land	77.7	78.5	82.4	85	80	88.4
Urban crop land	70	75.9	89	80	78	86.7
Settlement	80	74.7	85	82	85	75
Open water	85	78	90	73.7	77	79
Bare Land	73.5	80	79.2	72	85	77
Overall Accuracy	88.80%		85%		84.00%	

PA =Producer Accuracy

UA=User Accuracy

Note: Producer's accuracy is the probability of a reference pixel being correctly classified and is a measure of omission error while User's accuracy describes the probability of a pixel classified on the map actually representing that category on the ground (Commission error).

From Land-use/land-cover distribution of the year 1986, 2000 and 2015 the area a total of 519.5792km² of the area of interest Table 4.3 thick vegetation/forest land decline from an initial estimate of 110.405km², in 1985 to 5,238.90 ha in 2000 and 27.3042km² in 2015. Urban cropland/grassland had 207.0540km² 1986 and decline to 188.3510km² and 107.567km² in 2000 and 2015 respectively while water body had just increased from 44.1684km² in 1986 to 58.701km² in 2000 and to 68.366km² in 2015. Settlement areas had the highest increase in the area. For example, from the initial estimate of 70.0560km² in 1986, it increased to 140.376km² in 2000 and to 257.15km² in 2015, this is the most dynamic land-cover which extend it self every year. Bare land slight decline 87.8958km² 79.7622km² and 59.192km² of the total area of interest under classification of the year 1986, 2000 and 2015 respectively.

Table 5.3 Land-use/land-cover distribution of the year 1986, 2000 and 2015

Land-use/land cover category	1986		2000		2015	
	Area (km ²)	Area (%)	Area (km ²)	Area (%)	Area (km ²)	Area (%)
Thick vegetation /forest land	110.4050	21.2	52.3890	10.08	27.3042	5.26
Urban crop land /grass land	207.0540	40	188.35.10	36.25	107.56.70	20.70
Settlement	70.0560	13.4	140.3760	27.02	257.15	49.49
Water body	44.1684	8.5	58.7010	11.30	68.386	13.16
Bare Land	87.8958	16.9	79.7622	15..35	59.1920	11.39
Total	519.5792	100	519.5792	100	519.5792	100

It is true that varieties of land-use/land cover changes spatially in Forest land/vegetation, in crop land settlement, bare land and water body are seen with the area during the period between 1986_2015. overall changes analyses in Table 5.4. The detail land use land cover cause result change describe in discussion

Table 5.4 Assessment of environmental rate of change during 1986-2015

Land-use/land-cover category	1986–2000 change in		Rate of change 2001–2015 (km ² /year)	2001–2015 change in		Rate of change 2001–2015 (km ² /year)
	(km ²)	(%)		(km ²)	(%)	
Thick vegetation /Forest land	-58.016	-11.17	-3.8677	-25.0848	-4.83	-1.6723
Urban crop land /grass land	-18.705	-3.59	-1.2469	-80.784	-15.55	-5.3856
Settlement	70.32	13.53	4.688	116.774	22.47	7.7849
Bare Land	-8.136	-1.57	-0.5422	-20.5702	-3.96	-1.3713
Water body	14.5326	2.80	0.9688	9.665	1.86	0.6443

Note: Annual Rate of Change (km²/year) = (% of recent land-use/land-cover change - % of Previous land-use/land-cover change) /100 * # of Study years (15 years).

Figure 5.2 shows the greenness information derived from the landsat images, generated NDVI images in these images, the shades of white represent man-made surfaces (concrete, roofs, and

roads) and water bodies, light green represents grassy fields of varying health, and dark green represents healthy, tree (forest). The pixel values of 1986 NDVI image ranges from around -0.34 for not very vegetated surfaces to values of 0.63 for vegetated surfaces. For 2000, the pixel values for the NDVI images ranged from -0.52 for not very vegetated surfaces to values of 0.57 for vegetation surfaces. For 2015 the pixel values for the NDVI image ranged from -0.14 for none and not very vegetated surfaces to values of 0.51 for vegetation surfaces.

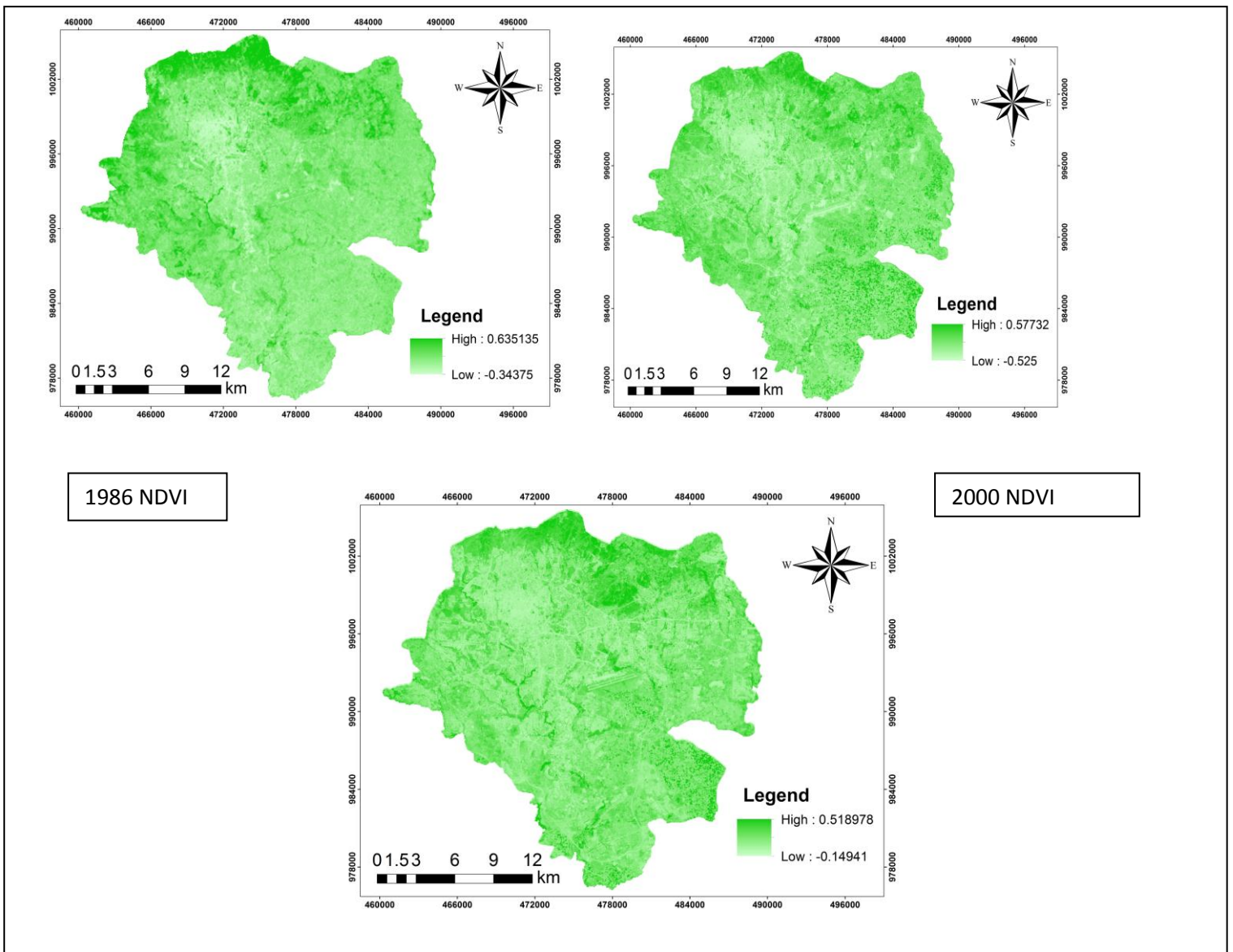


Figure 5.2 Normalized difference vegetation index maps of 1986, 2000 and 2015

contains about 0.005% of green space area, while Kolfe-keranio cover 0.03 % green area coverage and Akaki-Kalitysub-city Nifassilk-Lafto and Bole sub-cities contain less than 0.002% green space per area while other inner area of the city Arada Kirkose and Lideta hold too low green areas and Addis-ketema sub-city contains almost zero or not vegetation cover.

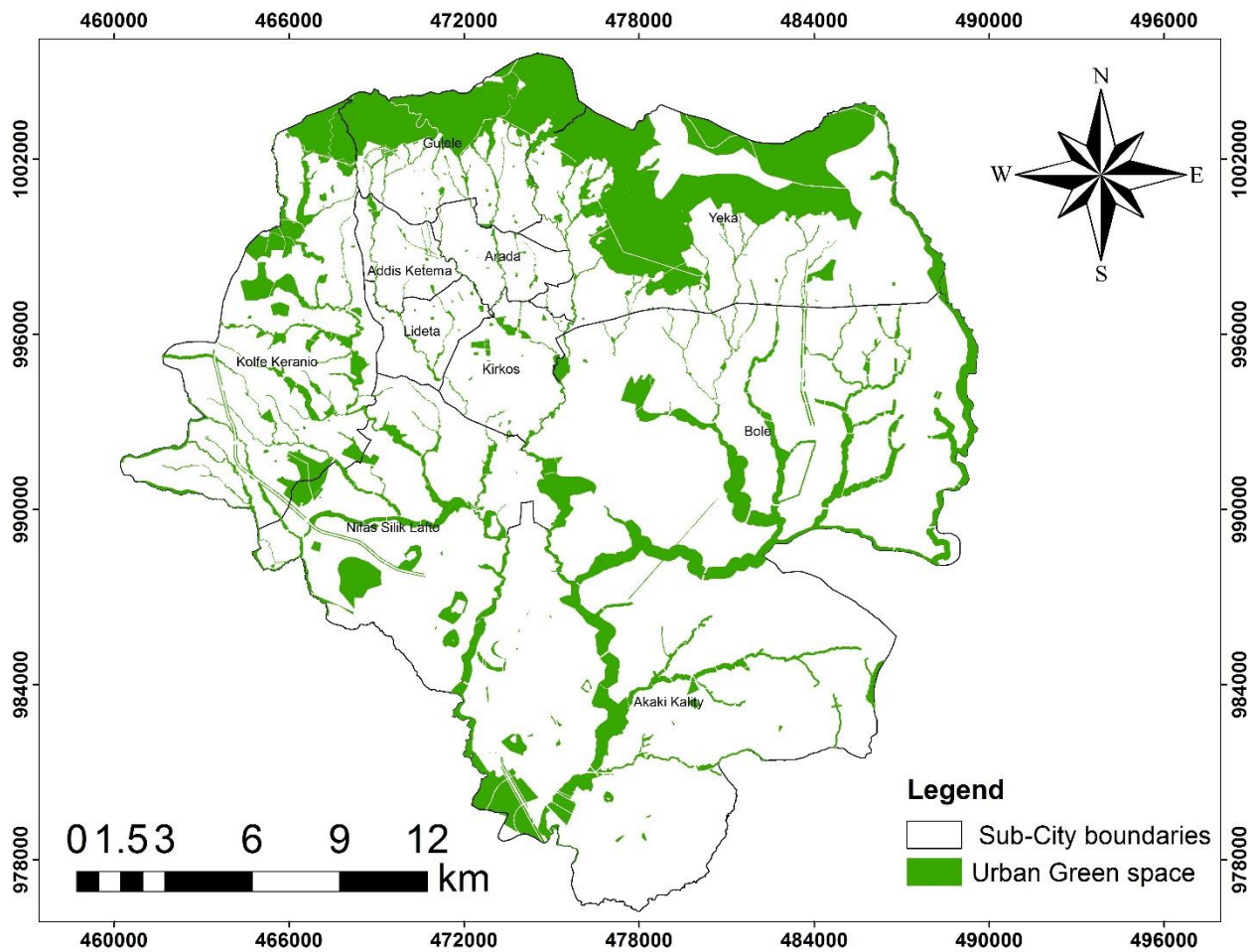


Figure 5.3 Distribution of urban green space map of Addis Ababa in (2015)

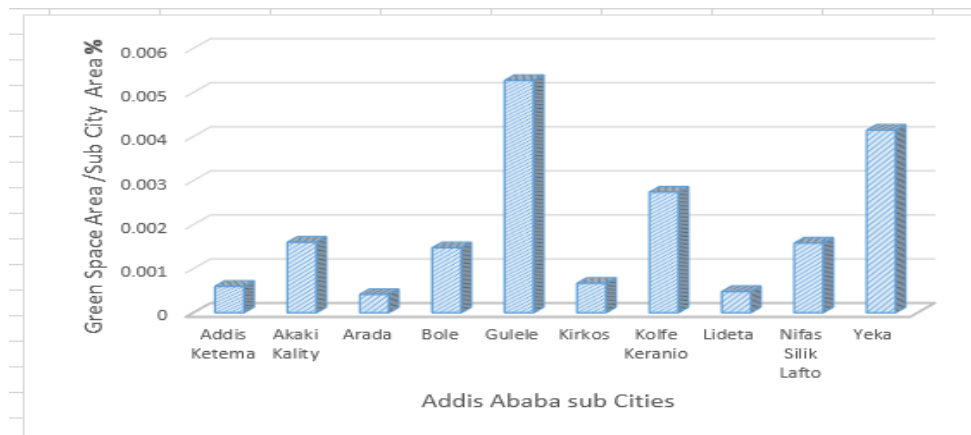


Figure 5.4 Comparison of urban green space in the sub cities of Addis Ababa

Population density in the city of Addis Ababa comparing to the population density of the ten sub cities (Figures 5.5 and 5.6) indicates that central regions with the smallest area are the densest parts. As Addis-Ketema sub-city has greater than 3.50 people/km² which is 35000 people/km² is the most populated district in Addis Ababa and Arada and Lideta sub-city have 30000 people/km² are the second most, while the Akaki-Kality, Yeka and Bole sub cities sparsely populated which is less than 17 people/km² were reached by total sum of the containing neighborhood of each urban sub city.

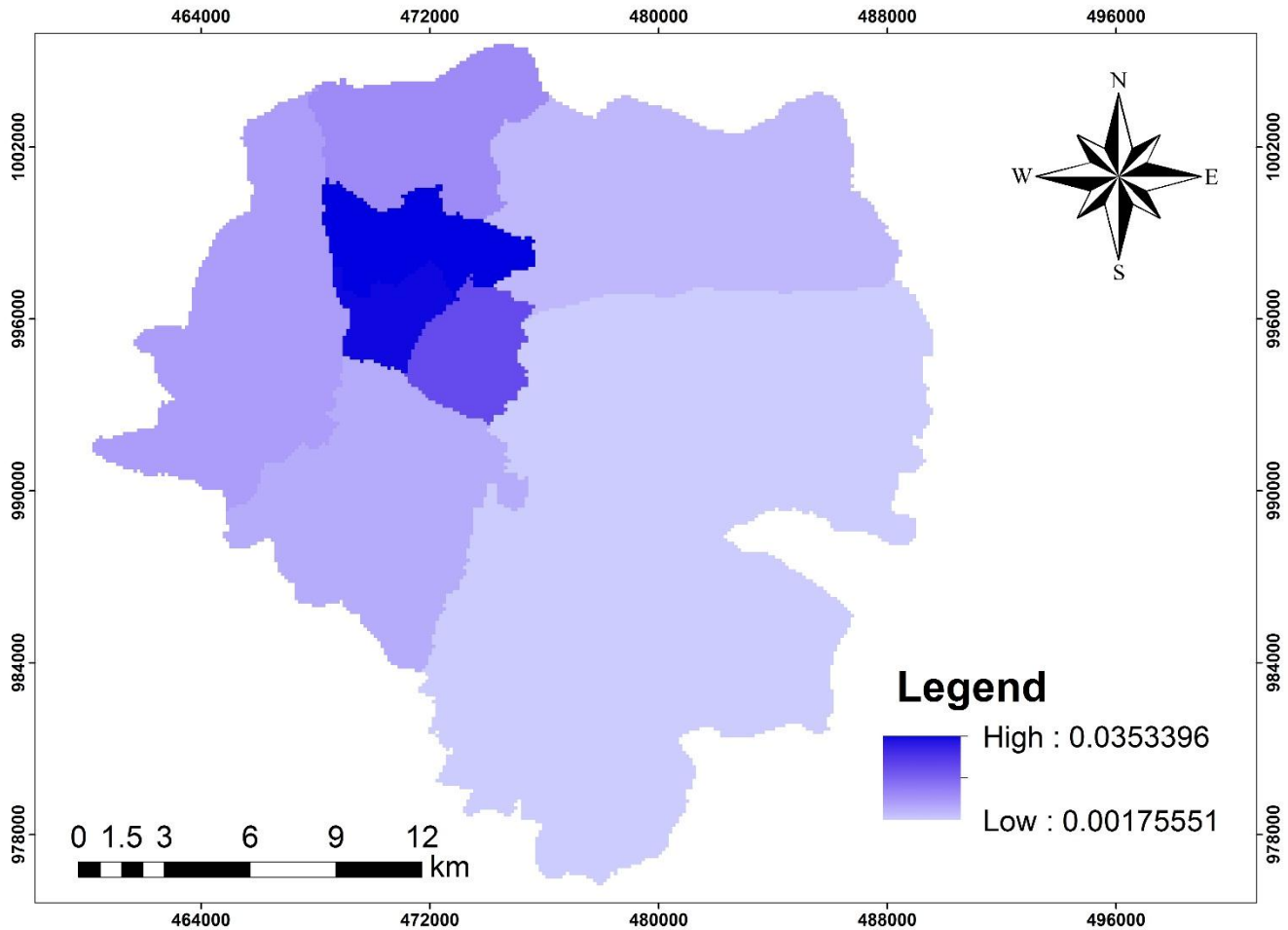


Figure 5.5 Population density distribution map of Addis Ababa sub cities 2015.

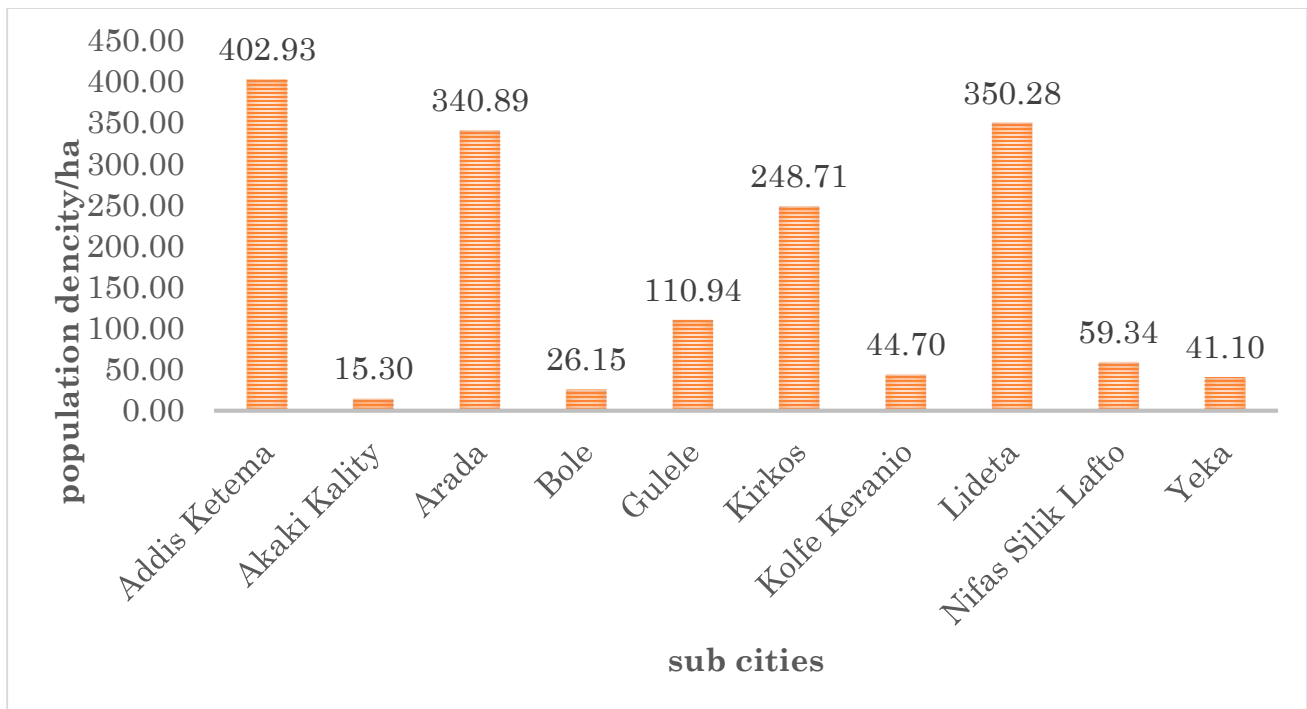


Fig 5.6 Comparison of population density in the sub cities of Addis Ababa

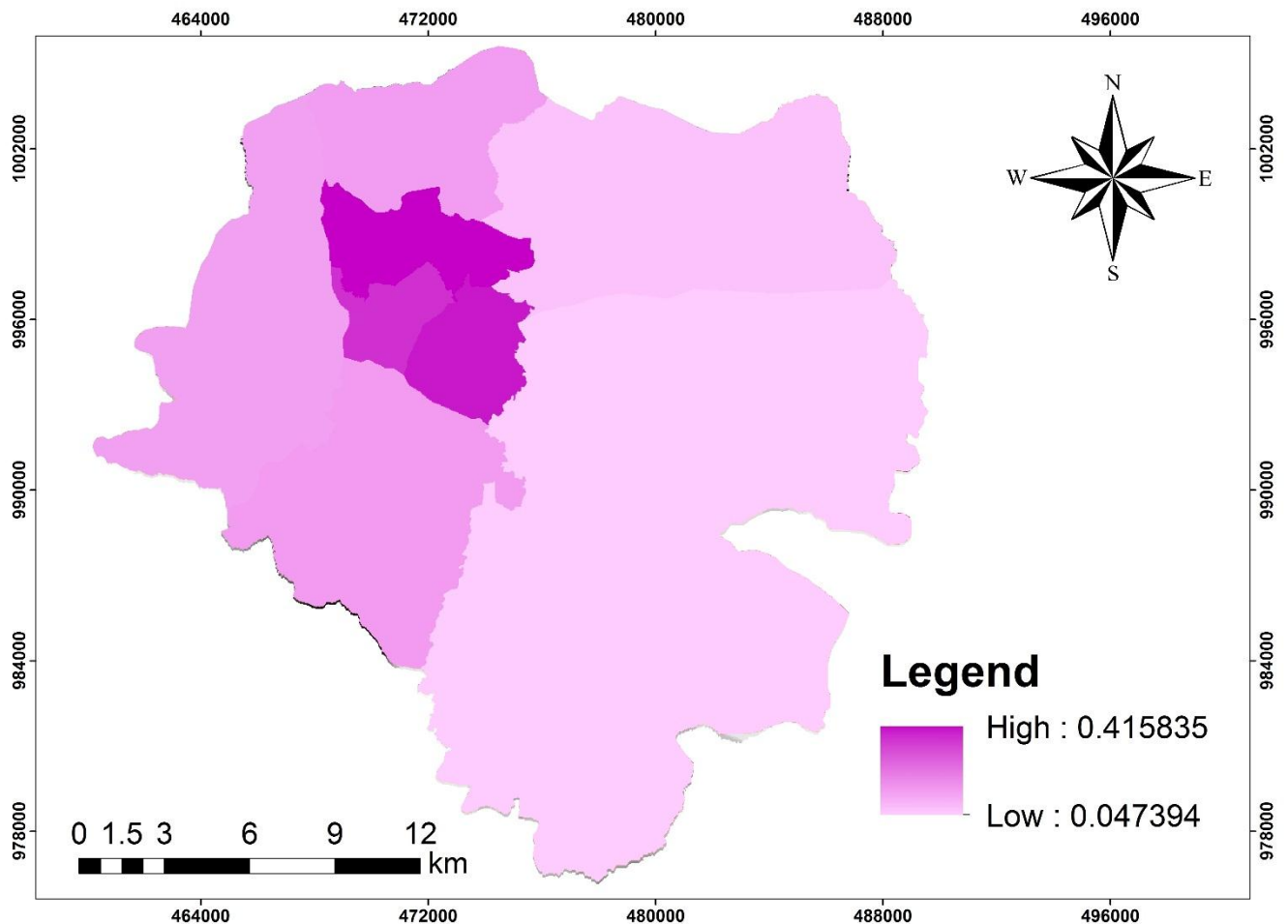


Fig 5.7 Distribution of Built-up Density Map

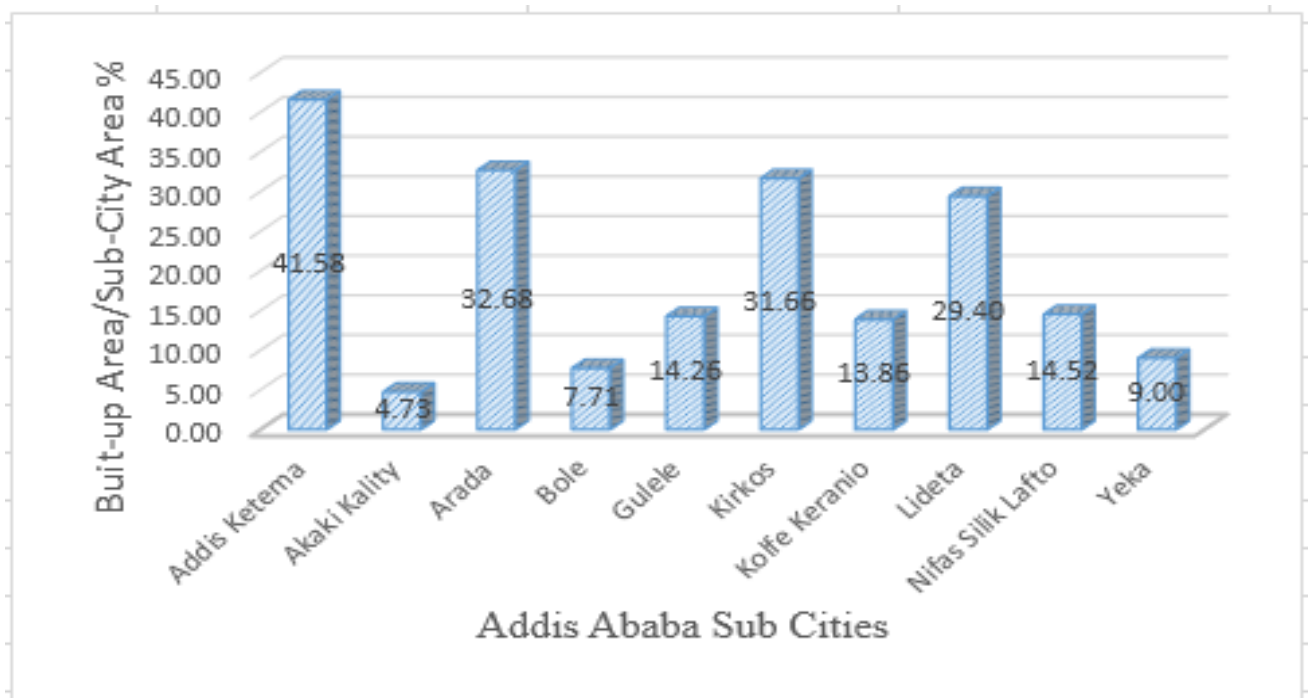


Fig 4.8 Comparison of Building density in the 10 sub city of Addis Ababa

There is a general increase of surface temperature in the impervious surfaces (building concrete and asphalt) rather than vegetated area as shown in Figures 5.9 and 5.10. Maximum average surface temperature recorded was 36.79°C and Minimum 17.40°C. Based on zonal mean statistics the surface temperature in Akaki-Kaliti and Bole sub cities was 29°C, followed by Addis-Ketema, Arada, Kirkose, Liedeta and Nifase-Silke experienced 28°C, Yeka 27°C and Kolfe 26°C respectively, while Gulele sub city experienced the lowest surface temperature which (24°C).

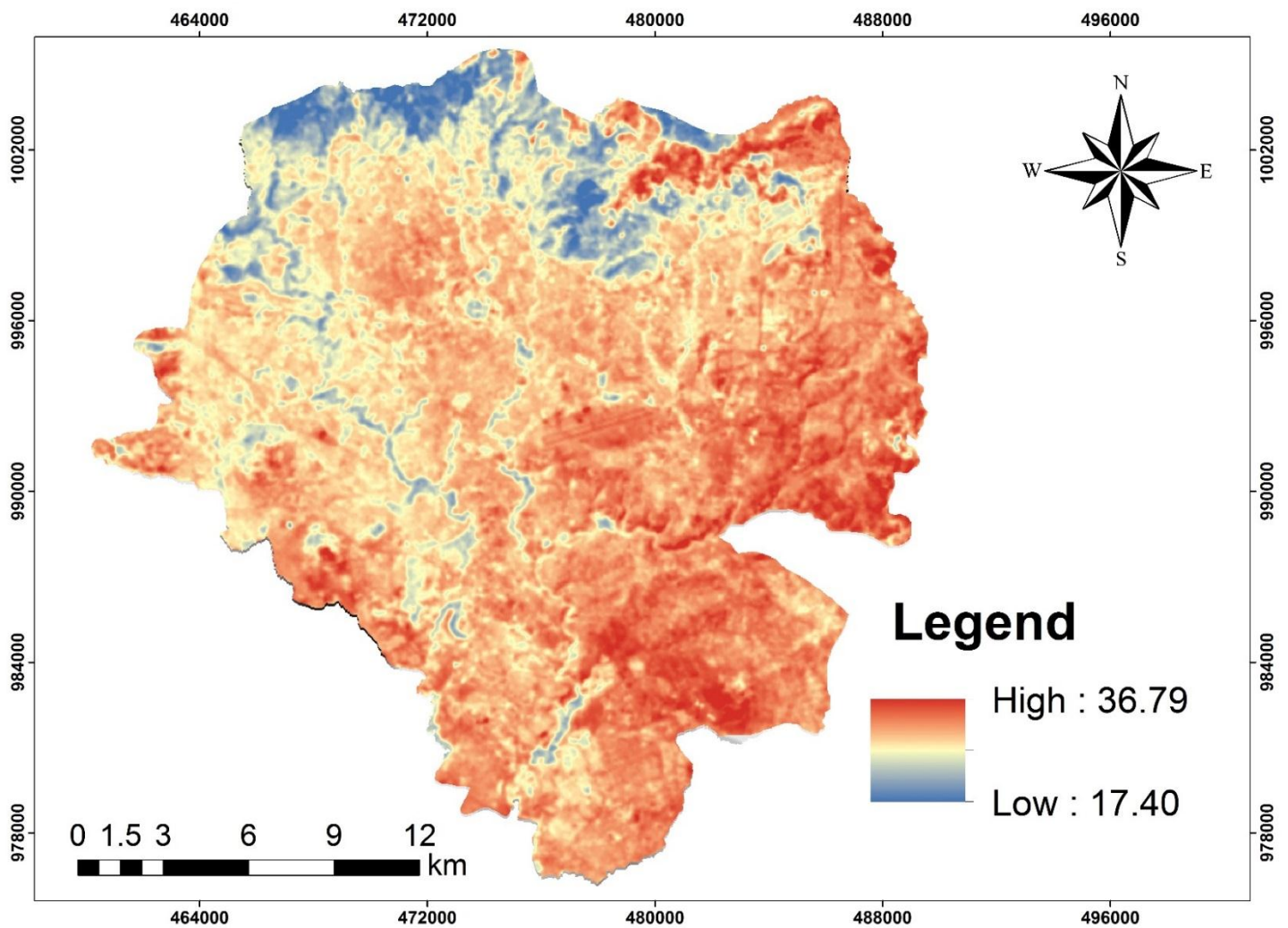


Fig 5.9 Land surface temperature Map of the study area

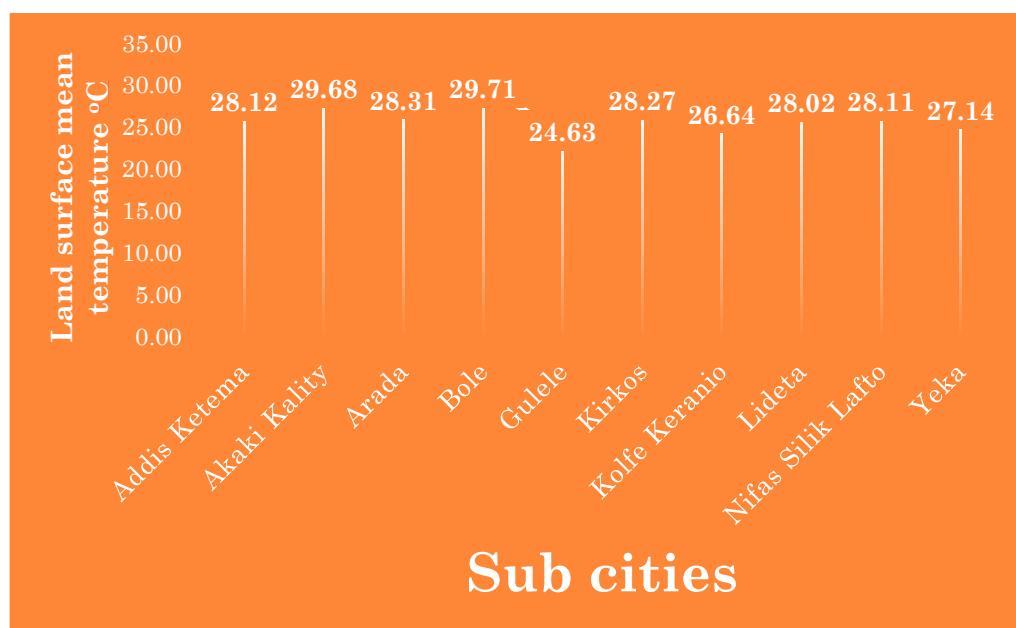


Fig 5.10 Comparison of surface temperature in the sub cities of Addis Ababa

Greenhouse Gas emission sample data which is taken from Environmental protection authority in the year 2012 Fig5.11 and 5.12. The concentration of greenhouse gas emission is high associated in industrial area, residential in and major road spatially based on this the maximum greenhouse gas emission recorded 1.41 mega tone and the minimum is 0.25. Based on zonal mean statistics in Akaki kality sub city is most polluted 0.24 mega ton the first polluted and Addis-Ketema and Lideta 0.21 mega tone the second and Kirkose 0.14 the third critical area Gulele 0.04 mega tone the fourth where kolfe_Keranio and Yeka 0.03 mega tone the fifth Bole, Nifasi-Silke and Akaki-Kality 0.02 mega tone critical areas.

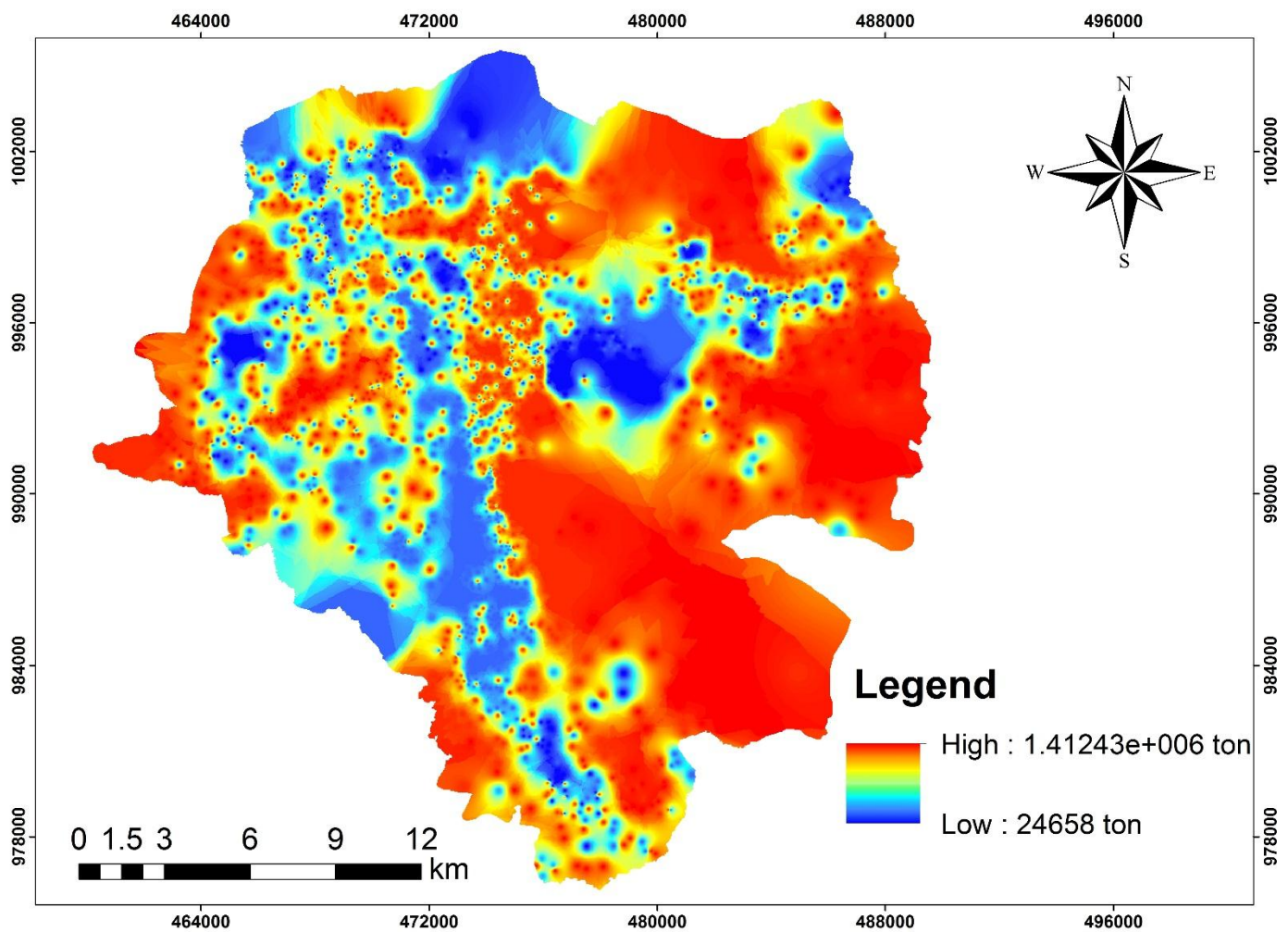


Fig 5.11 Distribution of Green House Gas Emission Map

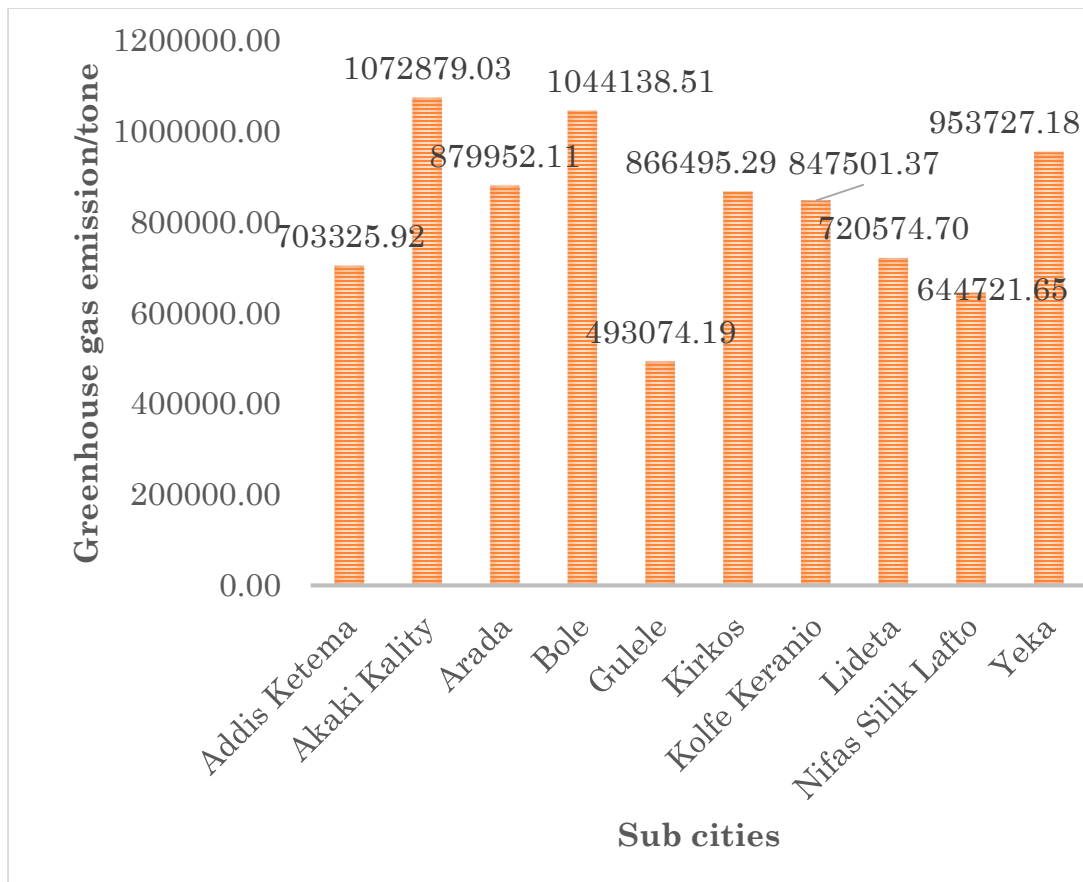


Fig 5.12 Comparison of greenhouse gas emission map of in the ten sub cities of Addis Ababa

5.3 Overlay Result

However assessing of environmental quality is multi-disciplined and multi-faced overlay analysis gives a direction of what we are likely to expect with a more holistic work. Based on Weighted overlay analysis result, there is a need to have a universal integration result of five summing up(land-use/land-cover, population density, surface temperature, greenhouse gas emission and built-up density) parameters based on the weighting value in eq(8) and Table4.4 isolate the hot spot areas of environmental deteriorate and Risk map generated(Figure 5.13) and reclassify as very high risk, high risk, risk, moderate risk, low risk and very low risk, based on this classification Addis_Ketema order between very high risk and high risk, Arada and Lideta high risk and moderate risk, Kirkose within moderate risk and low risk Gulele among low risk 1 and very low risk, Kolfe, , Yeka, Nifas_Silke , Bole and Akaki_Kality sub cities belong to are very low risk.

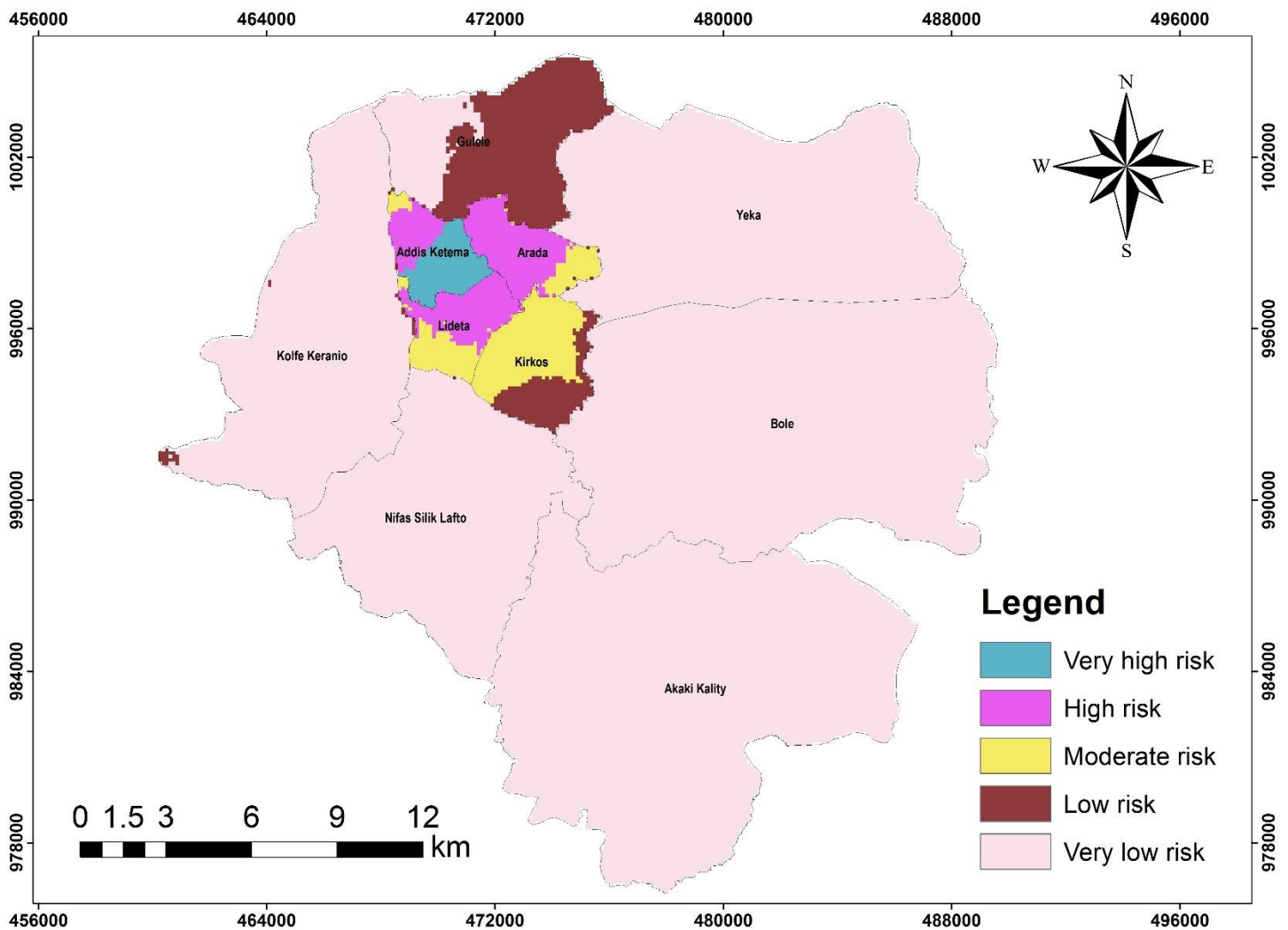


Fig 5.13 Enviromental Quality Risk Map of the study area

Finally using map algebra raster calculation proportion of risk map to overall green produced urban environmental quality map. Based on urban environmental quality indicator rating (Table 4.3) sub-cities with fewer green spaces, over polluted, high heat accumulation, high Greenhouse gas emission and dense built-up areas where identified as critical regions and the area with high vegetation density and distribution, low greenhouse gas emission, low heat island, low built up area and sparsely populated sub cities mentioned environmentally least critical (Fig 5.14).Based on these results the Sub City Arada, and Addis_Ketema are in the category in between very high and high critical areas Kirkose and Lideta sub city were within the critical and moderate, Kolfe, Gulele, Yeka, Nifas_Silke , Bole and Akaki_Kaliti are very low critical.

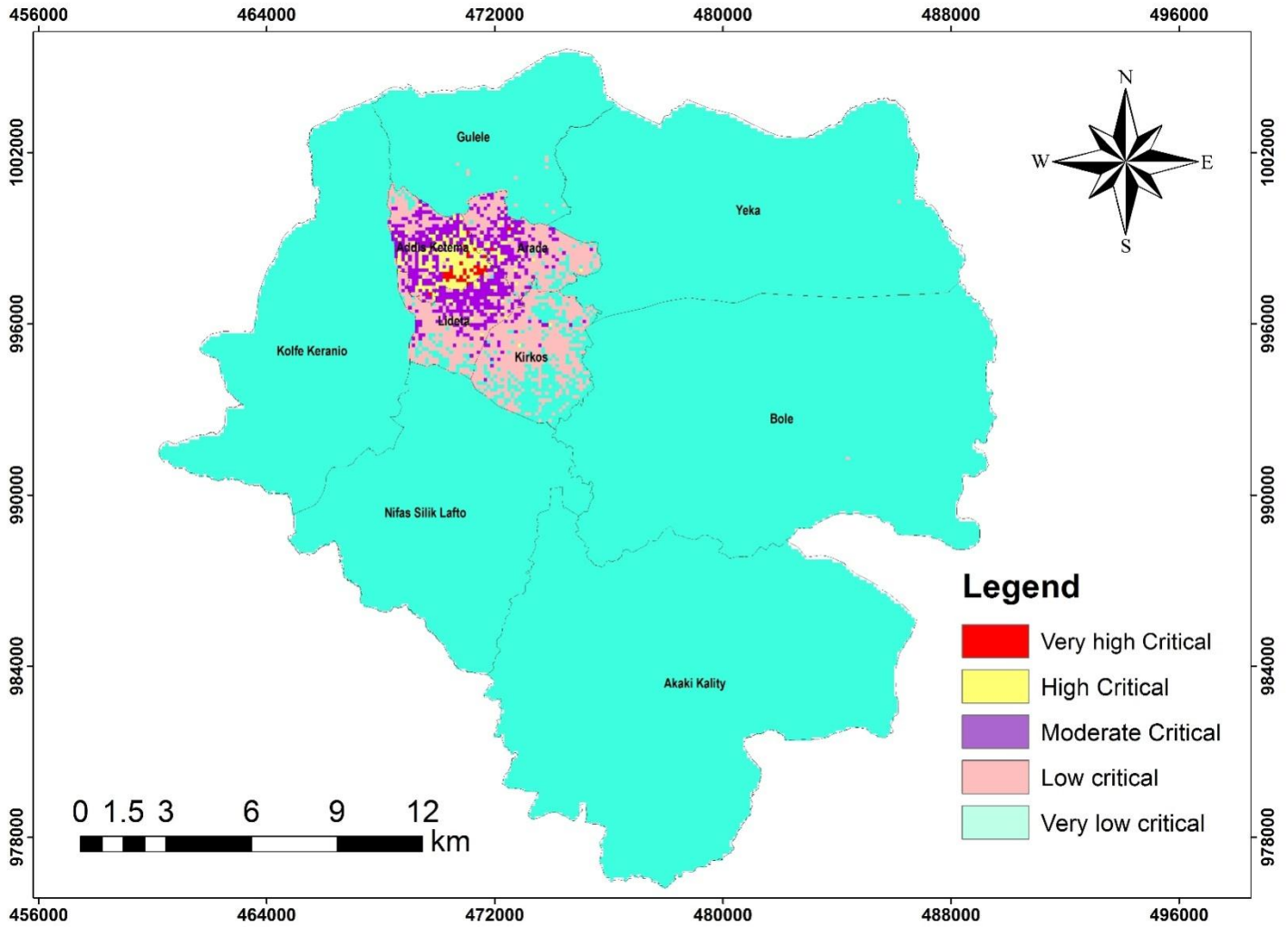


Fig 5.14 Environmental Quality Map of Addis Ababa city

Table 5.5 Area and level of environmental quality Risk Map and Environmental Quality Map

sub-city	Environmental Quality Risk Map			Environmental Quality Map		
	Area in (km ²)	Area in (%)	Risk level	Area in (km ²)	Area in (%)	Critical level
Addis-ketema	5.15	59.56	Very high Risk	0.50	5.84	Very high Critical
	3.00	34.72	high Risk	2.75	31.89	high Critical
	0.45	5.18	Moderate Risk	3.10	35.89	Moderate critical
	0.04	0.50	Low Risk	2.06	23.87	Low critical
	0.00	0.00	Very low Risk	0.22	2.50	Very low Critical
Arada	0.00	0.00	Very high Risk	0.03	0.00	Very high Critical
	7.08	74.58	high Risk	0.51	5.00	high Critical
	2.09	21.95	Moderate Risk	2.34	25.00	Moderate critical
	0.13	1.35	Low Risk	5.67	60.00	Low critical
	0.20	2.11	Very low Risk	0.94	10.00	Very low Critical
Lideta	0.13	1.42	most Risk	0.00	0.00	Very high Critical
	5.81	63.29	high Risk	0.36	3.96	high Critical
	3.24	35.28	Moderate Risk	3.02	32.91	Moderate critical
	0.00	0.00	Low Risk	4.98	54.27	Low critical
	0.00	0.00	Very low Risk	0.81	8.86	Very low Critical
Kirkose	0.06	0.39	high Risk	0.04	0.29	high Critical
	9.23	63.04	Moderate Risk	0.36	2.45	Moderate critical
	5.31	36.27	Low Risk	8.49	57.94	Low critical
	0.04	0.29	Very low Risk	5.76	39.31	Very low Critical
Gulele	0.06	0.19	high Risk	0.00	0.00	high Critical
	0.01	0.05	Moderate Risk	0.01	0.05	Moderate critical
	21.65	69.43	Low Risk	0.24	0.77	Low critical
	9.46	30.33	Very low Risk	30.94	99.18	Very low Critical
Kolfe_Keranio	0.50	0.78	LowRisk	0.03	0.05	Low critical
	62.99	99.22	Very low Risk	63.46	99.95	Very low Critical
Yeka	0.01	0.02	Moderate Risk	0.00	0.00	Moderate critical
	0.31	0.37	Low Risk	0.01	0.00	Low critical
	81.51	99.61	Very lowRisk	82.12	100.00	Very low Critical
Bole	0.07	0.06	LowRisk	0.03	0.24	Low critical
	118.42	99.93	Very low Risk	118.46	99.97	Very low Critical
Akaki-Kality	123.44	100.00	Very low Risk	123.44	100.00	Very low Critical
Nifassilk-Lafto	58.76	100.00	Very low Risk	58.76	100.00	Very low Critical

This thesis provides an insight into the likely result of a holistic study of urban environmental quality in the city of Addis Ababa from classified maps extracted land-use/land-cover and the vegetation classes analyzed. Accordingly Extracting greenness through the assessment of land-use/land-cover serve as a preliminary means of investigating Urban Environmental Quality (Opeyemiand Trina, 2014). Information on green space in urban area is important for maintaining urban environmental quality. Vegetation is very useful in filtering air, water and sunlight, cooling urban heat, recycling pollutants, moderating local urban climate and providing recreational areas for people. Consequently, the ecological function of vegetation cover in urban Parks may filter up to 85 % of the air pollutants (Bolund and Hunhamma, 1999).

The comparison between the percentage increases in impervious surface as against the reduction in greenness might signify that there is a deterioration in the quality of environmental (Liang and Weng, 2011) Forest land/vegetation, crop land/grass land, bare land, settlement and water body (Fig5.1 and Table 5.2) are the five land-use classes where identified but different land use either increase or decrease in size at different rate of change compare to 1986_2015 of land cover.

Thick vegetation/forest land decline from an initial estimate of with the change rate of $3.8677\text{km}^2/\text{year}$ and $1.6723\text{km}^2/\text{year}$ seen in the area in the period between 1986–2000 and 2001–2015 respectively because vegetation are used for house conception and urban expansion. Urban cropland/grassland had reduced with the change rate of $1.2469\text{km}^2/\text{year}$ and $5.3856\text{km}^2/\text{year}$ in 1986–2000 and 2001–2015 respectively while water body had just little increased with the change rate of $0.9688\text{km}^2/\text{year}$ and $0.6443\text{km}^2/\text{year}$ 1986–2000 and 2001–2015 respectively due to deforestation and later became stagnant because of conservation of soil and reforestation.

Settlement areas had the highest increase in the area, from the initial estimate of 70.0560km^2 in 1986 to 257.15km^2 in 2015 with the change rate of $4.688\text{km}^2/\text{year}$ between 1986–2000 and $7.7849/\text{km}^2/\text{year}$ between 2001– 2015, this is the most dynamic land-cover the cause is obvious that urbanization and rapid population growth which extend it self every year. Unbalanced and uncontrolled urbanization lead to environmental degradation in the quality of urban life (Saied et al, 2004).

Bare land slight decline 87.8958km^2 79.7622km^2 and 59.192km^2 of the total area of interest under classification of the year 1986, 2000 and 2015 respectively this is mainly due to initiatives of afforestation, rehabilitation program and soil conservation.

NDVI is an equation that takes into account the amount of infrared reflected by plants (Simmon, 1980). Live green plants absorb solar radiation, which they use as a source of energy in the process of photosynthesis. The reason NDVI is related to vegetation is that green leaves have a reflectance of 20% or less in the 0.5 to 0.7 micro range (green to red) and about 60% in the 0.7 to 1.3 micro range (near-infrared). These spectral reflectance are themselves ratios of the reflected over the coming radiation in each spectral band individually once, they take on values between 0.0 and 1.0. Thus, NDVI itself varies between -1.0 and +1.0. Negative values of NDVI (values approaching -1) correspond to deep water. Values close to zero (-0.1 to 0.1) generally correspond to barren areas of rock, sand, or snow. The nature and extent of this change showed variations across time and space. The changes attributed to socio-economic and environmental parameters reflect a host of other factors. Overall, the results of the urban green space/sub city show that, Yeka and Gulele sub city contains about 0.005% of green space area, while Kolfe-keranio cover 0.03 % green area coverage and Akaki-Kality , Nifassilk-Lafto and Bole contain less than 0.002% green space per area while other inner area of the city Arada Kirkose and Lideta hold too low green areas and Addis-ketema sub city contains almost zero or not vegetation cover. Green space in Kirkose, Addis-ketema, Lideta, Arad and kolfe having least green space (4.8×10^{-6} square meter) are the poorest. Other as Gulele and Yeka having less than (1.5×10^{-5} square meter) still poor part. Comparing these result to suggested standards of green space for the city is 7 to 12 square meters (Zoeshtiagh, 1998) this results indicate that none of Addis Ababa sub-cities contains considerable green spaces in consideration to environmental quality.

Over all, the results point to a decline in forests, and an increase in human settlements, cropland, bare land, impending population explosion, several cases of immigration as well as greenhouse gas emission which raised a major threat to the environment and natural systems of the region.

Finally raster calculation overlay analysis gives a direction of what we are likely to expect with a more holistic work. Based on Weighted overlay raster analysis of result, there is a need to have a universal integration result of five summing up parameters Risk map to overall green to isolate the hotspot areas of environmental deteriorate. Overall housing density is a more important negative predictor of the extent of green space and tree cover (Davies et.al, 2008).

Based on this the environmental quality result , with fewer green spaces, over polluted, high heat accumulation, high Greenhouse gas emission and crowded areas where identified as critical regions and the area with high vegetation density and distribution, low greenhouse gas emission, low heat island and sparsely population as environmentally suitable (Fig 5.14). Arada, and Addis_Ketema are in the category in between very high and high critical areas Kirkose and Lideta sub city were within the critical and moderate, Kolfe, Gulele, Yeka, Nifas_Silke Bole and

Akaki_Kality are very low critical. Hence the RS and GIS based methodology described in this manuscript is useful for assessing state of environmental quality. Weighted overlay methodologies can also be customized for this purpose, for the subject reclassification and map algebra techniques expand the ability of spatial analyzing.

The accuracy of the study can be enhanced by using high resolution satellite imagery. Additionally, change detection analysis can also be done more accurately with high resolution satellite imagery. Hence High resolution imagery usage is planned for future studies. Not only the urban environmental quality, but also the other subjects important for ecological and environmental impacts analysis such as air, water, and noise pollution limitations can also be determined using RS and GIS integration. Environmental risk map and environmental quality map are also source of data for city and regional planners.

7.1 Conclusion

In the light of this finding, the practical use of a geospatial approach involving natural and census data, GIS and remote sensing in tracking urban environment quality change stands appropriate for sustainable environment planning. Considering the little efforts in the past to assess the urban environmental quality, GIS technology can be used to fulfill this purpose of storage, manipulation and mapping of urban data. It also stands as an effective tool for sustainable environmental quality analysis and planning. Integrated data analysis using remotely sensed satellite imagery and GIS modeling facilitated the analysis of the spatial distribution of environmental change involving land-use/land-cover classification change from time to time NDVI, greenhouse gas emission, thermal mapping and demographic issues facing the Addis Ababa environment. Urban Environmental Quality maps are also data layers for city planners. In general based on the overall accuracy, the result is a fair representation of the actual situation. The results of this study could impact policy assessment instruments and assist local governments and environmental agencies in monitoring UEQ. The UEQ models established in this research can be applied to assist urban planners not only to evaluate the city's current UEQ condition, but also to devise efficient development policies to construct a more desirable future UEQ environment at the national level. Land-use planners and policy makers can thus make policy adjustments to encourage effective urban landscape and economic development for building a green and prosperous city, a better UEQ environment rather than a crowded city, poor UEQ environment. This helps making essential progress towards achieving greater urban sustainability that emphasizes the long-term integration of environmental protection and social health. It suggested a more sustainable city is featured by green space. Which correspond well with the key factor in determining a city's UEQ condition. Evidently, cities with favorable UEQ environment hold the possibility of delivering a more sustainable future.

7.2 Recommendations

The following recommendation suggested base on the findings

1. Environmental protection Authority and responsible body implement reforestation program for deforested area.
2. Urban planner design and implement renewal and LDP program for crowded and depletion of greenness.
3. Finally recommended that, attention be given to the inclusion of other environmental parameters such as water, soil and air quality. A multi scale approach (high and medium resolution image) would also probably yield a better result

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Appendix 1: Addis Ababa greenhouse gas emission inventory 2012 (draft) report (source: Addis Ababa environmental protection authority 2014)

Addis Ababa's GHG emission by scope, sector and subsector

Sector	Subsector	Total emission(tCO ₂ e)				%
		Scope 1	Scope 2	Scope 3	Total	
Stationary	Residential	1,376,262			1,376,262	27.29%
	Commercial	24,652			24,652	0.49%
	Industries	209,452			209,452	4.15%
	Energy industries	100,214			100,214	1.99%
	Sub-Total	1,710,586	0		1,710,586	33.91%
transportation	On-road transportation	937,570		474,862	1,412,432	28.00%
	Aviation			860,705	860,705	17.06%
	Sub-Total	937,570	0	1,335,568	2,273,138	45.07%
waste	Solid waste	470,875			470,875	9.34%
	Waste water	332,206			332,206	6.59%
	Sub-Total	803,081	0		803,081	15.92%
IPPU	Industrial Use	10,514			10,514	0.21%
	Sub-Total	10,514	0		10,514	0.21%
AFOLU	Livestock	246,541			246,541	4.89%
	Sub-Total	246,541	0		246,541	4.89%
Total		3,708,292	0	1,335,568	5,043,860	100%

**Appendix 2: counted and projected Population data of the study area
(source: CSA 2015)**

Counted and projected population of Addis Ababa Sub CSA 2015			
Sub City	2015		
	Male	Female	Total
ADDIS KETEMA	148,504	156,772	305,277
AKAKI KALITI	105,481	111,212	216,693
ARADA	117,908	134,979	252,886
BOLE	172,673	196,780	369,453
GULELE	153,853	166,089	319,942
KIRKOS	123,062	141,465	264,527
KOLFE KERANIYO	246,886	265,850	512,736
LIDETA	114,468	126,694	241,162
NEFAS SILK-LAFTO	177,143	201,020	378,163
YEKA	192,134	222,375	414,509
TOTAL POPULATION	1,552,113	1,723,235	3,275,348

Appendix 3: land use land cover ground truth sample data and their location from different filed data in the study area

Forest 2015		Settlement		Crop land		Bare land		WATER body	
Y	Y	Y	Y	Y	Y	Y	Y	X	Y
476141.01	1003901.4	471548.83	999687.7	473073	986747.8	484157.7	484157.7	475786.55	977536.29
1003901.4	1002458.1	471012.05	1000529	472598.4	986250.3	484545.5	998017.5	475960.86	978262.92
481482.79	1002367.9	470759.71	1001221	472399.8	985661.4	484341.6	998443.7	475704.27	978649.99
482380.77	482380.77	478622.09	994947	472161.8	984890.3	484776.5	998266.7	475350.02	978910.69
482073.11	997693	478857.89	995362.6	486262.9	988695.5	485535.2	998933.3	475339.27	979340.89
481926.51	997997.72	475874.81	981820.3	484175.9	989520.9	485537.3	999179.4	474888.03	979660.15
478577.96	998438.18	473971.03	981531.2	481883.2	988491.6	477577.3	999492.9	475184.5	979958.15
479210.12	997961.64	487956.39	992266.4	478744.8	988838.9	488257.3	998450.8	475795.63	980084.26
478459.4	997717.01	478792.03	993809.9	476510.2	986437	489639.7	996680.4	475496.92	980493.08
472556.91	985972.73	479016.62	995056.9	476958	985764.3	489252.9	994713.6	477117.83	984173.1
472519.97	986092.87	476668.2	996336.4	476748.6	982433	488918.2	994310.6	476065.44	987789.73
472567.21	986180.24	471070.35	996784.6	475797.8	980031.7	485875.6	991921.2	472994.41	986651.27
487888.64	990686.4	470984.64	996234.8	472336.3	990236.3	483891.9	993302.5	472386.5	985360.35
487888.31	990842.65	470370.01	997631.2	471713.4	990191.2	482246.3	993946.5	471973.54	983973.38
487765.53	990772.16	469722.21	997250.9	470629.4	989702.3	480990.5	993514.6	471831.19	983346.29
487732.1	990960.41	468299.71	998335.8	469345.2	990612.8	471242.9	999901.2	472342.41	982993.4
487508.52	990819.39	468212.76	998640.3	468055.4	991369.7	471269.7	999796.8	472312.12	982364.01
487506.21	990853.55	465201.44	994937.6	469032.5	993237.8	471181.8	999548.2	473677.32	988788.25
487373.97	991031.34	464447.29	994924.2	475487.3	993833.1	473656.9	997556	475423.42	987992.05
466008	997887.87	463949.07	995676.9	474600.9	993203.6	473865.8	997274	475119.65	989495.94
467285.24	998396.36	463145.8	995724.5	471299.6	999421.1	471398	990638.9	475505.86	989951.17
465315.2	997683.39	465371.83	997063.7	471219.3	999141.6	471019.3	990195.1	475178.02	990743.05
465837.1	996898.07	466276.78	997350.7	471368.1	995935.3	467329.7	990836	470862.24	990930.86
465700.53	991839.19	465666.91	998875.2	471093.1	994847.5	467781.3	991646.5	471385.54	992790.28
465742.67	988262.87	473959.09	994014.1	468874.6	995210.8	469563.9	990429.2	468116.46	993471.28
472136.23	981897.91	473915.95	992922	468563.5	994821.7	469808.8	990302.3	468766.69	995109.06
478290.92	989100.69	473144.17	993168.5	468298.4	994414.6	469348.8	990135	468279.87	996040.75
478606.99	988821.95	472635.78	992465.5	468244.3	993764.1	469806.1	990259.2	468824.98	998956.48
478224.02	988885.42	471936.2	991965.2	470011.6	997421.5	469855.1	989967.2	469143.29	1000179
478806.36	988805.69	471630.55	989057.1	470016.9	997685	469294.9	989798.3	470529.37	1002273.1
477359.1	988642.41	472220.74	989161.4	469072.7	997368.3	470511.5	989742.3	473211.61	1000284.5
476759.21	988395.72	484388.11	995220.4	469055.9	997883.1	468496.7	989665.3	473260.71	999283.01
476238.85	988250.24	485897.24	996951.1	469039.6	998442.4	470238.7	984523	474702.35	1003699.7
475489.22	987867.91	473147.86	989759.6	468910	998798.8	470446.8	984294.4	474716.14	1003720.6
475654.21	990122.04	472040.09	989738.1	468994	999348.6	478888.8	979197	474842.09	1004234.1
475480.01	990553.57	469518.36	989718.2	468932.1	468932.1	467893.4	991507.8	475113.77	989416.49
474858.55	990768.65	467649	990477.9	469146.7	1000307	468273.9	993859.2	475571.3	990040.08
474617.8	991077.12	469228.13	992754.7	469291.5	1000528	468388.4	994359.3	475609.92	990579.97
474905.29	991655.83	468806.64	992948.3	467965.4	1002360	468012.4	993150.9	475142	991086.97

474408.55	992800.68	470493.28	998865.4	467595	1002256	469920.3	992745.1	480311.98	987959.14
474785.84	993241.49	470713.66	999025.3	468155.4	1003023	469992.3	993013.2	482773.21	989001.55
475236.71	995344.56	470573.55	999199.7	467526.2	1002746	469849.9	992405.3	485777.59	989130.97
475370.7	995264.08	470152.58	999535.8	469337	1003026	471217.1	992357.9		
475686.93	994974.87	469515.44	1000324	469349.8	1002707	466446.7	992012.7		
475567.85	995848.05	476611.03	997166.1	471136.1	1003059	466148.9	990743.3		
475616.64	996223.7	478379.55	983546.1	470810.7	1002628	466722.6	991576.9		
475688.6	996484.18	477737.88	992939.5	469420.6	1001981	466328.5	997948.7		
475714.65	996580.1	478735.39	993984.8	469356.2	1001377	466387.5	996276.1		
475938.73	475938.73	476589.07	995814.9	469496.4	1001685	466394.4	996319.7		
478369.66	989100.31	475209.99	996600.7	468898.9	1001325	484729.3	998581.4		
478279.62	988959.16	474460.17	998753.1	467899.5	1000004	485409.8	998109.5		
488155.45	990701.26	474162.84	999693.3	467928.4	998960.6	485007	1000303		
487885.54	990677.92	474224.3	999574.6	467983.2	998566.7				
487770.53	990779.17	471553	999375.5	468211.6	997879.5				
488152.82	990927.53	465086.65	994364.6	467092.1	997231.5				
488161.17	990934.32	463674.83	994292.1	467265.7	996989.1				
471695.26	990199.1	463707.91	995007	468481.3	996662.4				
471983.95	990396.23	463954.54	993546.3	465887.4	997761.2				
469880.33	992470.97	465324.03	993745.6	481923.9	993815.5				
469472.28	993407.59	465373.99	994648.6	482597.4	995495.7				
469253.53	994224.09	464438.43	994952	483131.7	998265.3				
469484.42	994360.2	464763.8	995691.7						
		465622.65	994369						
		466415.6	994762.5						

Appendix 4 Multi regression ordinary list square coloration result

Summary of OLS Results - Model Variables						
Variable	Coefficient [a]	t-Statistic	Probability [b]	Robust_t	Robust_Pr [b]	VIF [c]
Intercept	0.31966	4.195808	0.005943*	7.353267	0.000393*	-----
Population	-3.038025	-8.255098	0.000132*	-10.294585	0.000002*	1.923088
Temperature	-0.006742	-2.649933	0.037747*	-4.367938	0.004997*	1.463664
Greenhouse gas emission	0.000027	2.722399	0.034257*	4.62643	0.003897*	2.416063

OLS Diagnostics			
Input Features:	Addis_Sub_City_Border_E	Dependent Variable:	M_NDVI
Number of	10	Akaike's Information Criterion	-45.217932
Multiple R-Squared [d]:	0.947801	Adjusted R-Squared [d]:	0.921701
Joint F-Statistic [e]:	36.314814	Prob(>F), (3,6) degrees of freedom:	0.000305*
Joint Wald Statistic [e]:	262.42237	Prob(>chi-squared), (3) degrees of freedom:	0.000000*
Koenker (BP)	1.599903	Prob(>chi-squared), (3) degrees	0.659412
Jarque-Bera Statistic [g]:	0.615625	Prob(>chi-squared), (2) degrees of freedom:	0.735053

Notes on Interpretation

*An asterisk next to a number indicates a statistically significant p-value ($p < 0.01$).

[a] Coefficient: Represents the strength and type of relationship between each explanatory variable and the dependent variable.

[b] Probability and Robust Probability (Robust_Pr): Asterisk (*) indicates a coefficient is statistically significant ($p < 0.01$); if the Koenker

(BP) Statistic [f] is statistically significant, use the Robust Probability column (Robust_Pr) to determine coefficients significance.

[c] Variance Inflation Factor (VIF): Large Variance Inflation Factor (VIF) values

(>7.5) indicate redundancy among explanatory variables.

[d] R-

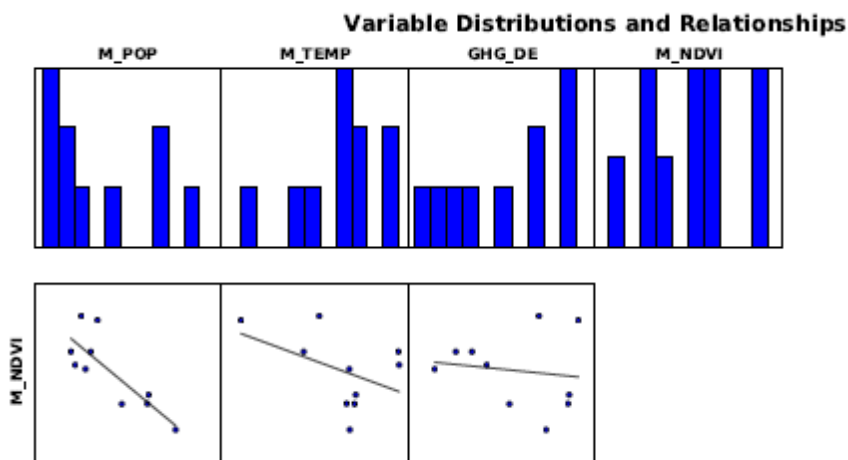
Squared and Akaike's Information Criterion (AICc): Measures of model fit/performance.

[e] Joint F and Wald Statistics: Asterisk (*) indicates overall model significance ($p < 0.01$); if the Koenker (BP) Statistic [f] is statistically significant, use the Wald Statistic to determine overall model significance.

[f] Koenker (BP) Statistic: When this test is statistically significant ($p < 0.01$), the relationships modeled are not consistent (either due to non-stationarity or heteroskedasticity). You should rely on the Robust Probabilities (Robust_Pr) to determine coefficient significance and on the Wald Statistic to determine overall model significance.

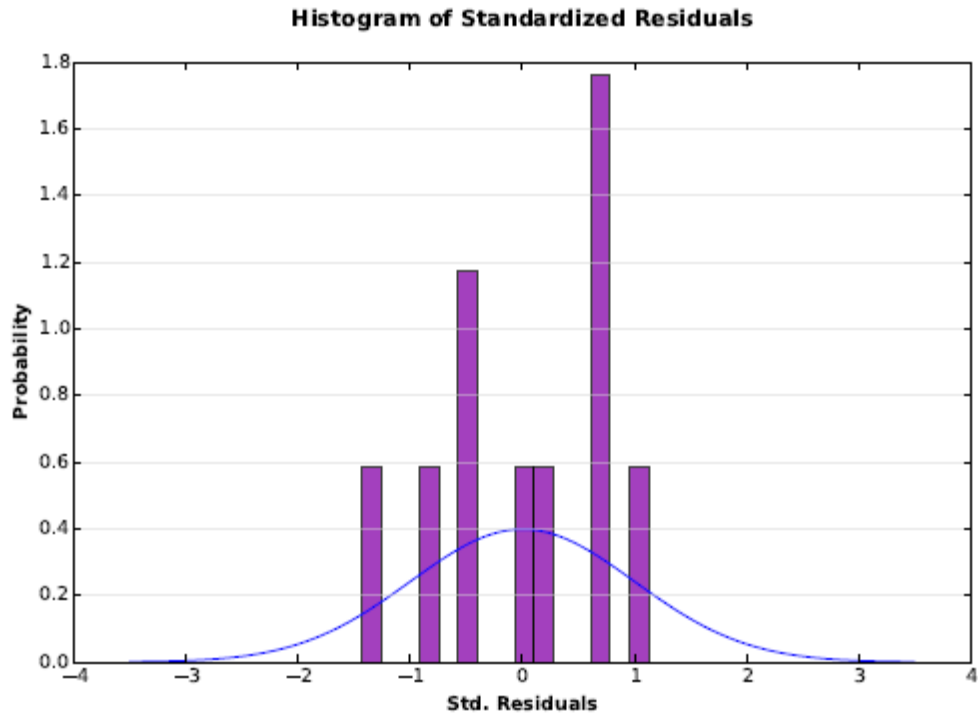
[g] Jarque-

Bera Statistic: When this test is statistically significant ($p < 0.01$) model predictions are biased (the residuals are not normally distributed).

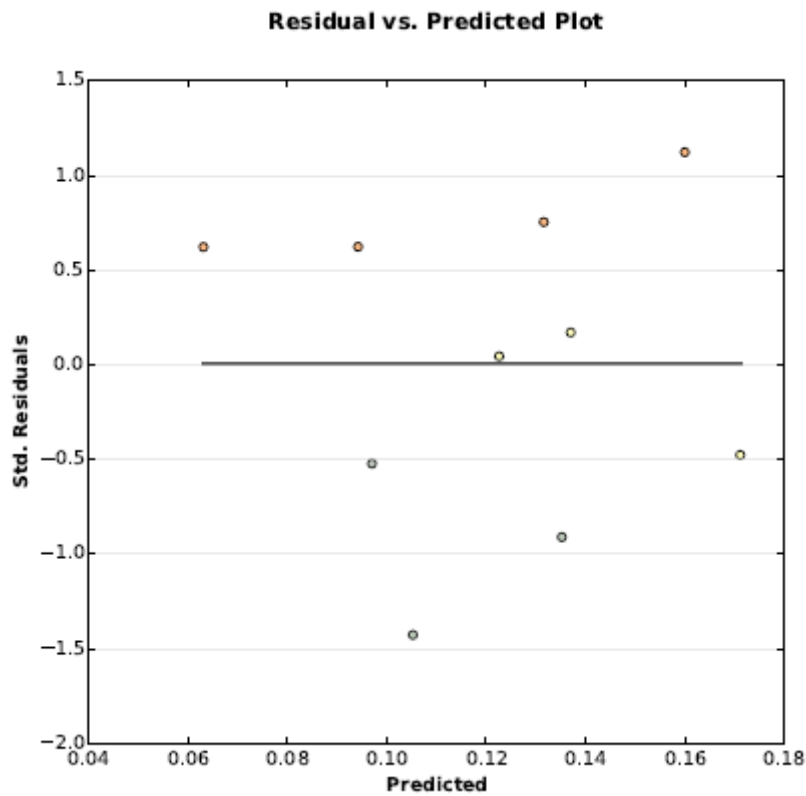


The above graphs are Histograms and Scatterplots for each explanatory variable and the dependent variable. The histograms show how each variable is distributed. OLS does not require variables to be normally distributed. However, if you are having trouble finding a properly-specified model, you can try transforming strongly skewed variables to see if you get a better result.

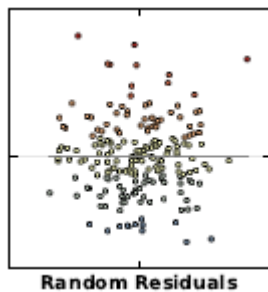
Each scatterplot depicts the relationship between an explanatory variable and the dependent variable. Strong relationships appear as diagonals and the direction of the slant indicates if the relationship is positive or negative. Try transforming your variables if you detect any non-linear relationships. For more information see the Regression Analysis Basics documentation.



Ideally the histogram of your residuals would match the normal curve, indicated above in blue. If the histogram looks very different from the normal curve, you may have a biased model. If this bias is significant it will also be represented by a statistically significant Jarque-Bera p-value (*).



This is a graph of residuals (model over and under predictions) in relation to predicted dependent variable values. For a properly specified model, this scatterplot will have little structure, and look random (see graph on the right). If there is a structure to this plot, the type of structure may be a valuable clue to help you figure out what's going on.



Ordinary Least Squares Parameters

Parameter Name	Input Value
Input Features	Addis_Sub_City_Border_Edited
Unique ID Field	Id
Output Feature Class	None
Dependent Variable	M_NDVI
Explanatory Variables	M_POP M_TEMP GHG_DE
Selection Set	False