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REMOTE SENSING AND GEO-INFORMATICS

URBAN SPRAWL MAPPING AND LANDUSE CHANGE DETECTION USING SPATIAL METRICS METHOD: A CASE STUDY OF ADDIS ABABA CITY AND ITS SURROUNDING AREAS, ETHIOPIA

A Thesis Submitted To

The School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Remote Sensing and Geo-Informatics.

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This is to certify the Thesis Prepared By Sewunet Shiferaw Entitled as "*Urban Sprawl Mapping and Land-use Change Detection Using Spatial Metrics Method: A Case Study of Addis Ababa City and Its Surrounding Areas*, *Ethiopia*" Is Submitted in Partial Fulfillment of the Requirements for The Degree of Master of Science in Remote Sensing And Geo-Informatics Compiles with the Regulations of the University and Meets the Accepted Standards with its Originality and Quality.

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ABBREVIATIONS

AI	Aggregation Index
CA	Class Area
CSA	Central Statistical Agency
ED	Edge Density
EEA	European Environmental Agency
EPA	US Environmental Protection Agency
ETM^+	Enhanced Thematic Mapper Plus.
GIS	Geographic Information System
GPS	Global Positioning System
LPI	Largest Patch Index
LSI	Landscape Shape Index
MSS	Landsat Multispectral Scanner
NCE	New Climate Economy
NP	Number of Patches
OLI	Landsat-8 Operational Land Imager
ORAAMP	Office for Revision of Addis Ababa Master Plan
PAFRAC	Perimeter –Area Fractal Dimension
PD	Patch Density
PLAND	Percentage of Landscape
PZ	Percentage of Zone
RS	Remote Sensing
SHEI	Shannon's Evenness Index
SIDI	Simpson’s Diversity Index
TE	Total Edge
TM	Thematic Mapper
UNEP	United Nations Environmental Program
UN-Habitat	United Nation Human Settlement Program
USGS	United States Geological Survey
ZA	Zone Area

ABSTRACT

Rapid and unprecedented urban expansion is becoming the characteristics of cities in developing countries. Hence, it is customary to assess and monitor urban growth changes using remote sensing and other spatial tools to quantify urban sprawl that provide paramount information for city planners. This study was conducted on Addis Ababa metropolitan area with aim of measuring urban sprawl in four years perspective 1984, 1995, 2006 and 2016. Landsat images of each perspective year were used and pan sharpened (fused) with SPOT-5 (5m) using hyperspectral color merging algorism to get better images with 5m spatial resolution. The resulted satellite images were classified and land-use/cover maps were produced using maximum likelihood of supervised classification method. The classification process was checked by producer's, user's, overall accuracy and kappa statistic accuracy assessments from confusion metrics. The results show acceptable agreement between the classified maps and reference data with a producer's accuracy value greater than 74.14%, and user's accuracy greater than 84.09%. Post classification change detection analysis and selected spatial metric indices calculation were made to detect, assess and monitor urban growth and quantify urban sprawl in the study area. Change detection analysis results indicated that Addis Ababa is growing rapidly with an average rate of 5% per year for the past 32 years from 1984–2016. In terms of area, the expansion of the city was found to be 12,218, 15,981.58, 22,513.29 and 38,801.35 in 1984, 1995, 2006 and 2016 out of the total area in hectare, respectively. In other words, the built-up area constituted 15% for 1984, 19.6% for 1995, 27.5% for 2006 and 47.5% for the year 2016 in the study area. From spatial metrics analysis, aggregated number of built-up area patches were 621, 476, 574 and 840 for the years 1984, 1995, 2006 and 2016. The decrease in number of patches in 1995 indicates that merging of previous patches into the main built-up area forming continuous urban agglomeration. The zonal analysis of urban sprawl shows that Addis Ababa is expanding by leaps and bounds to the east, south, south west and north east directions, particularly in the past ten years consuming a large amount of agricultural and green areas. Therefore, the city planners need to plan ahead and implement plans properly to cope up with the rapid and unprecedented growth of the city in the years to come.

Key Words: Spatial metrics, Zonal metrics, change detection, urban sprawl, Addis Ababa

CHAPTER ONE

1. Introduction

1.1 Background

Urban area can be defined as places with the concentration of people engaged in non-agricultural activities with relatively high density than rural areas. According to European Union Regional Policy (2011), urban area refers to both Cities and towns with an administrative unit or a certain population density and the population of towns is mostly smaller between 10,000 and 50,000 inhabitants whereas cities have larger population greater than 50,000 inhabitants. Urbanization is the increasing proportion of population living in urban areas whereas urban growth is the increase in the physical size of urban areas (Johns Hopkins University, 2006). UN (2014) indicated that the percentage of urban population in 1950 was 30 per cent which increased to 54 percent in 2014 and estimated to be 66 percent by 2050. More recently, world's urban population is estimated to be about 54.5 percent (Demographia, 2016).

While the highest urban population is found in developed world, Rapid urbanization and expansion have been the characteristics of cities and towns in developing world in the past few decades, taking a considerable non-built up area of their surroundings. Contrary to this, a vast majority of the population in the third world remain residing in rural areas. By now Asia and Africa are the least urbanized, sharing 48 and 40 per cent of their population urbanized, respectively (UN, 2014). However, by 2050, it is expected that about 90% of world's urban population increase will be concentrated Asia (52%) and Africa (21%) (Moir, 2014). As the pace of urbanization becomes rapid, it gives little time for national governments and municipalities to plan and fulfill infrastructures and services needed by increasing number of people. Angel et.al. (2011) indicate that under the current rate of growth world urban population will double in 43 years but urban expansion will double in 19 years.

On the other hand, urban growth and urban built-up area expansion in large cities and small towns is increasing leading to urban sprawl. Recent studies made by various researchers indicate that the expansion of cities and towns has a positive correlation with different factors. Reis et.al, (2015) described urban growth in relation to three concepts *population change* which is the increasing number of population through time because of the natural increase (birth – death) and migration into urban centers, *economic performance* which refers to economic growth of the cities and associated changes in GDP, income, employment etc., and *spatial growth* refers to the expansion of urban built up area i.e., urbanization and urban expansion. Therefore, for the purpose of this study, urban growth is considered to the last term spatial growth and related concepts of urbanization and urban expansion.

Addis Ababa has for long been the capital city and a hive of economic activities in the country. The city is in a construction boom (Antos et al., 2016) and observing the scale of development and construction activities occurring on Addis Ababa, Young (2014) described the entire city as it seems one construction site. Especially in recent years, the city has witnessed a number of changes with new development and redevelopment programs- the construction of mega structures such as malls and business centers, international hotels, high ways and creation of new settlement areas. Mainly newly emerging condominium sites with a group of building blocks launched by the Government, the construction of individual villas by real estate companies, the expansion of double and wide roads in suburban areas contributed a lot for the city's horizontal expansion. Hence, the city is expanding time to time and a considerable amount of agricultural area is being consumed by non-agricultural activities. As such, it is necessary to measure and quantify the amount of change brought about by the city sprawl and/or expansion. According to RUAF Foundation (2010), Addis Ababa is the thirty first fastest growing City in the world with an annual growth rate of 3.4 from 2006-2020.

Urban areas are complex geographic dimensions with a mixed combination of various surface cover types that exhibit a unique spectral signature (Melesse, 2007). Remote sensing has been the best cost effective mechanism of data acquisition for a wide range of applications ever since the launch of landsat-1 in 1972 (Lo and Yeung, 2005). Urban growth and the physical expansion of cities can be detected, mapped and analyzed using remotely sensed data obtained from mostly Landsat multispectral scanner (MSS) thematic mapper (TM) enhanced thematic mapper plus (ETM+) , and SPOT (Ward et al., 2000). Therefore, GIS and remote sensing play a great role in shaping and managing urbanization by measuring urban sprawl and spatial expansion of urban areas using various techniques of change detection and spatio-temporal satellite images. In addition, spatial and zonal metrics used to study the form and pattern of urban development in the study area.

1.2 Objectives

A. General objective

The study takes Addis Ababa city and its surrounding areas as a case study to measure urban sprawl and urban growth change detection in four years perspective 1984, 1995, 2006 and 2016. The years are selected at ten year interval to address the changes efficiently and each year is selected based on data availability. Therefore, the general objective of the paper is to identify the urban land-use/cover and measure urban sprawl of the city in the past 3 decades between 1994 and 2016 using satellite image analysis and calculating spatial metrics indices.

B. Specific objectives

The following specific objectives are targeted by the proponent of the study:

- ✓ to map different land-use activities of Addis Ababa city and its surrounding urban areas for individual years (1984, 1995, 2006 and 2016).
- ✓ to know the land-use/cover changes and rate of urban growth of the city between 1984 and 2016 using remotely sensed images.
- ✓ to quantify the location and direction of changes or expansion in the past 3 decades by calculating selected zonal metrics.
- ✓ to measure and examine spatial pattern of the city and its surrounding areas by calculating selected spatial metrics indices.
- ✓ to measure the composition and configuration of urban landscape in the study area.
- ✓ to assess and quantify accuracy level of the classification techniques using error matrices.

1.3 Statement of the problem

Urbanization and urban growth are complex systems involving social, economic, technological and political forces interacting together. Urban areas are the basis for development but rapid urbanization is posing a major threat to the lives of residents and the environment fabric they live on (Moir, 2014). We all like to grow and live in a better way of life but what matters is the pattern of development and the way we plan and design for our cities. Urban development should not be haphazard that puts the lives of society and their environment in jeopardy. Nowadays, there are a number of issues concerning urban growth that should be addressed by nations and city governments: climate change, increasing energy costs due to sprawl, loss of agricultural lands, urban sprawl and associated impacts, increased residency in urban slums and informal settlements, challenges in providing urban services due to urban growth and so many others (EPA, 2001; Besussi et al., 2010; UN-Habitat, 2011; UN-Habitat, 2016). According to US Environmental Protection Agency (2001), unplanned urban growth brings long lasting and irreversible impacts such as degradation, loss and fragmentation of habitat, loss of water resource, heat island effect, air quality degradation, greenhouse gas emission and climate change. The rapid urbanization will increase its pace in developing countries in the coming 30 years while their level of economy remain the lowest, hence cities and towns of developing countries will face toughest challenges in the years to come.

Addis Ababa is ranked 31st fastest growing city in the world and took the 6th place in Africa after Dar es Salaam, Kampal, Nairobi, Antananarivo and Maputo (RUAF Foundation, 2010). About 80% of the city’s expansion had been occurred in the past 20 years (George Washington University, 2014). Furthermore, Addis Ababa will double its population in the coming 20 years (World Bank, 2015). Urbanization in Addis Ababa is not only rapid but it is also sprawling along byways and highways, illegal settlements, increasing real estate buildings, industrial establishments, housing programs, and a number of other expansion activities following recent economic developments and privatization policies. These development activities in aggregate lead to spatial expansion of the city towards surrounding areas and absorption of non-built up environments, i.e., agricultural lands, open spaces and green areas. Therefore, the study will give the picture of the expansion and the pattern of urban development in the study area.

1.4 Significance of the study

Twenty-first century is a period of change and the emergence of new form of urbanization such as smart city, green city, compact city, eco city etc. (EEA, 2006) that fulfill the needs of the modern society with the minimum costs and lower impacts on health and urban environments (URDPFI, 2014; Moir, 2014,). In order for cities fully achieve their potential to increase prosperity, better living standards, ensure health and well-being for citizens, and bring about improved standards of environmental efficiency, urbanization and urban growth must be planned, shaped and managed (Moir, 2014).

Therefore, GIS and remote sensing play a great role in shaping and managing urbanization by measuring urban sprawl and spatial expansion of urban areas using various techniques of change detection and spatio- temporal satellite images together with, spatial metrics methods to study urban sprawl. Addis Ababa is one the fastest growing city in the world, hence the study will be pivotal in indicating the current expansion of the city into the surrounding areas, in the past 3 decades from 1984 to 2016. The study can also give the amount of built up area converted from non-built up area (agricultural lands, green and open spaces), rate of change and identify the major contributor for the city growth in the past 30 years. More importantly, the study will provide a good understanding about the sprawl of the city for urban planners and city administrators, by measuring various spatial metric indices based on its shape, area, edge, form, number and fragmentation of built up area patches. City planners and policy makers can benefit from the study and make adjustments for development to make plans harmonious with the surrounding areas.

1.5 Research questions

Due to various activities that cause urban sprawl in the city, it is believed that there would be a considerable urban land cover changes in the study areas in recent times. Therefore, the research was intended to answer the following questions:

- Whether there have been major changes in the urban environment of the study areas or not.
- What was the amount of change in the urban environment of Addis Ababa city and its surrounding areas in the past 3 decades?
- Which feature, agricultural, open space or green area, was contributed the highest for spatial expansion of the city?
- What was the pattern of development and rate of spatial expansion of the city?
- What can the spatial indices tell us, will there be any indication of urban sprawl?

1.6 Scope of the study

The spatial extent of the study is the urban footprint of Addis Ababa city and its surrounding areas of Oromia towns. It aims to conduct the study on Addis Ababa metropolitan area- the continuous urban development through times. Although urbanization and urban growth is at its lowest stage in Ethiopia, there have been a number of changes in respect to urban expansion in the study area in the past few decades. Therefore, main scope of the study is to monitor urban growth using various change detection techniques and temporal satellite images from 1984–2016, and measure urban sprawl using spatial and zonal metrics methods.

1.7 Limitation of study

As it is common in many studies, there are some constraints for the study in relation to the availability of appropriate data. The main problem in conducting researches in urban areas in developing countries like Ethiopia is lack of appropriate satellite data. Most third world countries are not at the level of development to generate their own satellite data. Therefore, the countries as whole or researchers from these countries, mainly depend on external sources such as government agencies which provide data with acceptable quality at free of charge or affordable price and commercial organizations that provide high quality satellite data but high and unaffordable price.

Studies in urban areas that involve Satellite images are deemed to be high spatial resolution. I tried to get high resolution satellite images both from internal agencies such as Ethiopian Mapping Agency (EMA) and Information Network Security Agency (INSA) as well as external organizations for my study but that had ended unsuccessful for both unavailability (in the case of internal sources) and affordability (external sources) of data that cover the spatial and temporal extent of the study area. For these reasons, I was forced to look into another mechanisms by which I can minimize the limitation of the data on spatial resolution with consulting my supervisor. Therefore, I used Landsat TM and ETM plus images (for the years 1984, 1995, and 2006) and Landsat 8 OLI image (2016) by pan sharpening all with SPOT-5 (5 m resolution) to get a better high resolution image (5m) so that the interpretability of the images will increase and to ease feature extraction in the classification process.

1.8 Organization of the paper

The document is organized in five chapters. The first chapter is about introduction of the paper dealing with background of the study, objectives, statement of the problem, research questions, scope of the study, limitation of the study and organization of the paper. Chapter two deals about review literature that discusses general background of urbanization at world, Africa and Ethiopia level as well as urban sprawl, impacts and consequences of urban sprawl, application of remote sensing and spatial metrics for urban study and urban sprawl measurement. The third chapter is about the methods and materials. There are two subtitles under this portion, materials and methodology. The subtitle Materials deals about description of study area, data sources and software programs employed to the study while the subtitle methodology deals with all the procedures followed in image rectification, preprocessing, classification, spatial metrics analysis. Chapter four is all about results and discussions that deals with change detection, all the results of the spatial metrics analysis and zonal metric findings. The last chapter discusses about conclusion and recommendation based on the research findings of the study.

CHAPTER TWO

2. Literature Review

2.1 Urbanization

This subtitle deals with the definition of urbanization in detail as well as the past, current and future of urbanization at world, Africa and Ethiopia. Urban background, planning history and previous studies made on Addis Ababa are also reviewed under the subtitle.

2.1.1 Definition of urbanization and urban growth

Urbanization: the definition of urbanization and urban areas vary from place to place and country to country (Mason, 1989; Frey and Zimmer, 1998; Sudhira, 2008; Rui, 2013; Wray et al., 2013; UN, 2014). The word 'urban' has its root in a Latin word 'Urbanus' meaning city dwellers (Sudhira, 2008), and urbanization can be defined as the increasing proportion or percentage of peoples living in urban areas. It is precisely defined as "the increasing share of a nation's population living in urban areas (and thus a declining share living in rural areas)" (Satterthwaite et al., 2010 p. 2011). Urbanization is a process leading to the formation of towns, cities and agglomeration of people and their socio-economic activities in areas classified as urban based on different criteria.

According to Buettner (2014) there are four broad criteria that countries use to differentiate urban areas from rural areas: administrative criteria, the proclamation of localities as urban; population-related criteria refer to population size and density, for size localities with threshold population of ≥ 10,000 are designated as urban and for density localities with at least 400 persons per km^2 are considered as urban; economic criteria are specified as significant presence of non-agricultural activities; and criteria based on urban functions may be defined as the existence of paved streets, water supply and sewer systems or electric lighting and so forth.

United Nation Population Division also makes use of a minimum total population of 2000 people to classify urban areas from rural areas (Ofem, 2012) and a number of countries apply the criteria, e.g. Ethiopia. However, still other countries set their own minimum total number of population to differentiate urban area from the rural counter parts, e.g. Nigeria uses 20,000 (Ofem, 2012) while India and Japan use 5,000 threshold population (Frey and Zimmer, 1998). As a result, a place with a specified total population identified as urban area by one country may be considered as rural area by another country and as such the level of urbanization in country may decrease or increase depending on threshold population. This is what makes the comparison of urbanization among countries difficult and should be understood based on the countries definition of urbanization.

Mostly the urban areas are defined by national statistical offices for census purposes based on different criteria: total population, proportion of population engaged in non-agricultural activities and the presence of other infrastructures. Therefore, the term urban area may refer to any settlement from smallest towns to largest megacities (Mason, 1989). According to European Union Regional Policy (2011), urban area refers to both Cities and towns with an administrative unit or a certain population density and the population of towns is mostly smaller between 10,000 and 50,000 inhabitants whereas cities have larger population greater than 50,000 inhabitants. A country is said to be urbanized when more than 50% of its population is living in urban areas.

Urban Growth: refers to the rate or pace of urbanization and associated physical expansion of cities and towns (Johns Hopkins University, 2006). The precise definition is given as "the process through which a city changes its spatial structure as a result of an increase in population and normally but not necessarily accompanied by the expansion of its urbanized area." (Reis et.al, 2015 p. 1941).

Various theories and models explain the growth and evolution of urban expansions. Cheng, et al. (2003) state urban growth as a complex system of physical expansion and functional change i.e. physical expansion refers to the change in space– transition from non-built-up to urban whereas functional change refers to the change in major land-uses activities. It explains that space and activity should be the basic elements of any system defined for urban growth/expansion and the evolution of urban growth (G) is the result of three major systems (P, U & N).

N -is developable Non-urban system U- is developed urban system at time t_1

P -is planned urban system at time t_2 G ‑ is urban growth from (t_1–t_2)

According to this theory, urban growth G, is a system resulting from the complex interaction between the three systems (P, U & N) from time t1, to t2. U represents a highly a complex social and economic system and offers current activities rather than space for urban growth to come whereas N represents a typical physical and ecological system, i.e. various ecological units – water body forest agricultural land etc. and primarily provides possible opportunities & potential for urban growth in a space until time t2 and P represents a spatial and conceptual system that results from a spatial planning scheme and prepares organized space and activities for urban growth is the future. This is under properly planned urban growth system, but the situation is very different in developing countries.

2.1.2 World urbanization

United Nations World Urbanization Prospect (2014) indicated that the percentage of urban population in 1950 was 30 per cent which increased to 54 percent in 2014 and estimated to be 66 percent by 2050. More recently, world's urban population is estimated to be about 54.5 percent (Demographia, 2016). As such with the current pace of urbanization the third millennium is expected to be urban (Weber, 2005). Studies indicate that big differences of urbanization between developing and developed world expected to happen by 2050 and world urban growth will shift towards developing nations. There will be rapid and unprecedented increase in developing countries but it will remain stagnant even a decrease in developed world. About 90% of world urbanization will be from developing countries by 2050 (Baudot, 2005; Moir et al., 2014) and only three countries India, China and Nigeria will account 37% of world urban growth between 2014 and 2050. It is also indicated that the annual urban population increase of only six large cities in developing countries (New Delhi, Mumbai, Dhaka, Lagos, Kinshasa and Karachi) will be greater than Europe's entire population (Moir et al., 2014). Angel et.al. (2011) indicate that under the current rate of growth world urban population will double in 43 years but urban expansion will double in 19 years.

While the highest urban population is found in developed world, rapid urbanization and expansion have been the characteristics of cities and towns in developing world in the past 20 years from 1995-2015, taking a considerable area of their surroundings (UN-Habitat, 2016). Contrary to this, a vast majority of the population in the third world remain residing in rural areas. By now Asia and Africa are the least urbanized, sharing 48 and 40 per cent of their population urbanized, respectively. As the pace of urbanization becomes rapid, it gives little time for government and municipalities to plan and fulfill infrastructures and services needed by increasing number of people.

2.1.3 Urbanization in Africa

Urbanization and urban expansion are increasing at an alarming rate in developing courtiers particularly in Africa due to increasing flux of population concentrating in urban centers. The share of urban growth for developing countries from 2000–2025 is estimated to be 90%

which was 57% from 1975–2000 (Johns Hopkins University, 2006). According to Mundia & Murayama (2013) Africa will have 11 mega cities with a population of more than 10 million and about 3, 000 towns with population of more than 20, 000 by 2020. Africa is urbanizing rapidly and expected to triple in the coming 50 years (Freire et al.., 2014; Moir et al., 2014). Eastern Africa will experience higher than African average urban growth (RUAF Foundation, 2010). Africa is changing the trend of urbanization happened before in other part of the world for two reasons first it is urbanizing fast, second urbanization in Africa is not producing the economic growth and capital investment it is expected to generate. Freire et al., (2014) indicated that Africa's urbanization faces four major challenges:

1. Rapid population growth with low level of economic activity based on inadequate capital
2. Low density, sprawl and informality in peri-urban fringe.
3. Poor coverage of infrastructure services such as water, energy and sanitation that makes difficult to improve welfare in both in urban and rural.
4. Weakness in administration, institutions and overall planning capacity.

Therefore, despite economic rise in some African countries in recent times, urbanization in Africa has been described as 'pathological' or 'dysfunctional' i.e., urbanization without growth (UN-Habitat, 2011). The United Nation Human Settlement Program (2011) indicate Africa's urbanization has been viewed as 'abnormality' or 'exceptionalism' by economists which means that unlike the rest of the world, urbanization in Africa has not been accompanied by sustained economic growth or reduced poverty. As a result, African countries are expected to face the challenge and critical problems associated with rapid urbanization in the years to come.

2.1.4 Urbanization in Ethiopia

Despite being the cradle of human being, a mosaic of mankind- a home for more than 80 ethnic groups, and its ancient civilization with a long history of state formation, all didn't help the country for urbanization and remained to be predominantly agrarian society. Before the establishment of Addis Ababa as a permanent capital city, different towns and cities rise and fall at various times in connection with the rise and fall of the royal kings and associated power shift in the country. Urbanization in Ethiopia goes back to the ancient and medieval history of the country with the construction of hundreds of stelas in Aksum (around first century A.D) and the rock hewn churches of Roha or Lalibela (11^{th} century) (Aalund, 1985). Urbanization also continued with the establishment of Gonder (17^{th} century) and the walled city of Harar (Aalund, 1985; Marcus, 1994). Particularly, Aalund, (1985) indicated that the population of Gonder reached 70,000 at its pick whereas the population of Harar was about 35,000 in 1875 and 42, 000 in 1885. However, the percentage of urbanization is still less than a quarter of the total population, far behind even in African standards. Ethiopia is one of the least urbanized country in the world with only 16.1% of its population lived in urban areas in 2007 and estimated as 20.4% for 2017 and 25.4% for 2027 (CSA, 2013).

Currently, urbanization in Ethiopia is changing following economic growth and establishment of universities and industries not only in Addis Ababa and regional cities but also in a number of other smaller towns in the country. Until recent times, there was no comprehensive guiding urban plan in the country. Now, the government of Ethiopia prepared a strategic urban plan that covers the whole regions of the country based on their capacity and suitability for future development. It looks like plan of agglomeration in indicating the future urban expansion of current major urban centers including Addis Ababa with eight urban clusters (NCE, 2015): Mekele-Combolcha Industrial corridor, Lake Tana Development Area, Dire Dawa- Jigjiga International trading Cluster, Gambela Regional Export Hub, Addis Ababa National capital area, Jimma Agricultural Commercial Hub, Hawassa Southern Economic Cluster and Degeh-Bur kebri Dehar Corridor as the preferred scenario.

2.1.4.1 Urban sprawl and gentrification of Addis Ababa city

Addis Ababa was established in 1886 by Empress Taitu, wife of Menelik II, and become the capital city of Ethiopia since 1889 (Mikyas Tesfaye, 2011; Mulu Eshete, 2015). According to Marcus (1994), the city began like conglomeration of villages and the population of the city reached about 65,000 in 1900. Soon, the emperor began to bring modern life particularly to his palace such as paved roads and streets, railway connecting the city to the outside world, piped water, electricity, telephonic and telegraphic services, the opening of schools and hospitals. However, the change of urbanization began by Emperor Menelik didn’t continue to reach a higher level due to lack of internal peace that prevailed in the country for many years and occupation of Italians. It took the country about 100 years to build the second railway line not only in the city but also in the country, after the first was built by the emperor.

From the beginning of the cities establishment until recent times, it seems a culture to see both the poor and the rich or the slums and rising towers live side by side in a close proximity in Addis Ababa. Although this is seen for the majority of the city dwellers still now, residential separation is appearing these days due to 1) most of the slums in the inner city are being replaced by rising towers, and 2) the coming of real estate companies that build individual houses and villas for the middle and high income groups. As a result, the haves are separating themselves from slums and the poor crowd in the city center grouping in some specific areas particularly in the fringe areas of the city leading to urban sprawl.

Fig 2.1 Newly established urban development of Yeka Abado area.

Fig 2.2 Typical urban sprawl in Legetafo Legdadi area.

According to RUAF Foundation (2010), Addis Ababa is one of the fastest growing City in the world with an annual growth rate of 3.4 from 2006–2020. Addis Ababa has for long been the capital city and a hive of economic activities in the country. The city contributes about 50% of the national GDP and its economy grows 14% annually (World Bank, 2015). The majority of industries and other economic sectors are located in Addis for many years. Addis Ababa is in a construction boom (Antos et al., 2016) especially in recent years, the city has witnessed a number of changes with new development and redevelopment programs- the construction of mega structures such as malls and business centers, international hotels, high ways and creation of new settlement areas. Mainly newly emerging condominium sites with a group of building blocks launched by the Government (Fig 2.1), the construction of individual villas by real estate companies, the expansion of double and wide roads in suburban areas contributed a lot for the city's horizontal expansion. Observing the scale of development and construction activities under going in Addis Ababa, Young (2014) described the entire city as one construction site. Hence, the city is expanding time to time and a considerable amount of agricultural area is being consumed by non-agricultural activities (Fig 2.1 to 2.3**)**. As such, it is necessary to measure and quantify the amount of change brought about by the city sprawl and/or expansion.

Fig 2.3 New urban development in Bole Arabsa area.

Another idea which is worth mentioning that Addis Ababa is experiencing these days is displacement of the old residents from the central part of the city for new development programs, what is known as gentrification in western world metropolitan areas. Gentrification was first used by Ruth Glass, in 1960's in London (Mathema, 2013) and became a bone of contention for urban planners and researchers since then because of its negative and positive impacts. Gentrification is the idea to describe the socio-economic upgrading of low-income central city neighborhoods replacing the low income residents by high and middle income residents in the process (Ding et al., 2016; Zuk et al., 2015). It is also described as the middle and upper class remake of the inner city (Levy et al., 2006). According to Levy et al., (2006) there are various types of displacements caused by gentrification e.g., '*direct displacement'* occurs due to renewal programs or processes that directly replace low income residents by high income groups, '*secondary or involuntary displacement*' occurs when low income households relocate by new developments for they cannot afford to remain because of higher rents and appreciated taxes. In this respect, it is customary to see wide open spaces at the downtown of Addis Ababa which were once dense residential areas but now waiting for redevelopments by private investors. As such, we are observing gentrification in Addis Ababa for most of old particularly poorly developed slum neighborhoods are being moved to suburban areas to condominium sites and replaced by high rising private towers by developers or government development programs (UNEP, 2014).

2.1.4.2 Urban planning of Addis Ababa

Addis Ababa lacked proper urban planning and implementation for the majority of its history and only 25% of the housing units in Addis Ababa were built under the municipal permission. According to Tolon (2008), the development of Addis Ababa can be summarized in four stages: the early period from 1886 to 1935-its establishment; the period of Haile Selassie and Italian occupation from 1935 to 1974; the socialist period under the Derg regime from 1975-1991 and post 1991 under the present government of Ethiopia. Thus the city was subject to different administrative and planning reforms under each ruling systems.

Urban planning in Addis Ababa was started in 1936 during the Italian occupation but the modern master plan by which Addis Ababa followed for most of its implementation was achieved by Sir Patrick Abercrombie, a known British planner, in 1956 (Yusuf, 2009). A number of reforms and city master plans were prepared after this but most of the master plans suffered by lack of proper implementation. According to a document written by George Washington University (2014), the government of Ethiopia adopted 9 city master plans but all suffered from inefficient implementation and urban sprawling has continued to occur haphazardly along major transportation corridors for a long period of times. Currently, the city is under development and redevelopment programs. As a result, spatial expansion of Addis Ababa is visible encroaching the hinterland along roads, highways and byways on the expense of agricultural areas, environmental degradation, water resource pollution and loss of biodiversity. On the other hand, the city center is overcrowded (30,000 people per square km) with poor living condition residing 30% of the total population in 8% of the city area (World Bank, 2015). The government is trying to alleviate city center congestion by relocating residents to the fringe areas in condominium sites but this also increasing the city sprawl.

2.1.4.3 Previous studies made on Addis Ababa

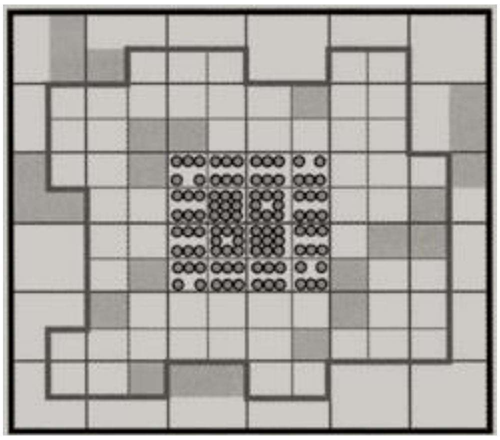
Addis Ababa is growing rapidly putting pressure on the surrounding environment. Most of the studies on urban growth of Addis Ababa are made by international organizations such as World Bank and UN-Habitat. Their focus is mainly on spatial expansion of the city and its impact on environment in relation to population growth. Therefore, they do not show detail studies about urban sprawl, pattern of development, composition and configuration of the city’s growth. There is one study on the field made by Mesfin Tadesse (2009) 17 years ago for the years 1985 and 2000. It indicates detail findings showing the sprawl of the city but he too give emphasis to physical expansion. In addition, recent studies by international organizations indicate that Addis Ababa has expanded by more than 80% in the past 20 years and the growth will continue in the coming decades with its population expected to double by 2030 (George Washington University, 2014; UNEP, 2014; world Bank, 2015).

Therefore, this study is intended to show those changes happened in the past 30 years and to fill the gap with detailed emphasis on the pattern of development. It also serve as a complement of the past studies. Furthermore, there is complain from the surrounding people about the expansion of Addis Ababa city for consuming agricultural land and environmental degradation. Hence, the study is intended to show how the recent expansion, pattern and composition of the city look like and how much of agricultural, open space and green area is incorporated to the built up area of Addis Ababa and its surrounding towns.

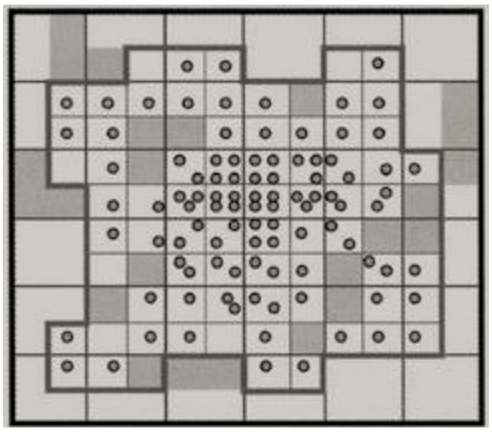
2.2 Urban sprawl

Different literatures indicated that urban sprawl is a complex phenomenon caused by a wide range of factors. Hence there is no single definition for the term urban sprawl and studies prefer giving description of the phenomenon rather than providing a single and precise definition. There are quite a lot of definitions for urban sprawl and addressing all the definitions given by various experts is beyond the scope of the this document. The term ‘Urban Sprawl’ harkened first in the late 1930s as a problem of suburban growth in the United States but gained the attention of city planners and urban researchers after second world war in the 1960s and 1970s (Handy, 2003; Bowyer, 2015). Generally urban sprawl is the reminiscent or manifestation of unplanned, uncontrolled, and haphazard expansion of urban developments or low-density physical expansion of cities into the surrounding non-urban areas (Besussi et al., 2010; Angel et al., 2011; Reis et al., 2015). In this respect, urban sprawl is explained by its spatial characteristics as "extensive urbanization, low density, single use, fragmentation/scatter or poor accessibility" (Reis et al., 2015 p. 8). The European Union regional Policy, in their publication 'Cities of Tomorrow', described it as "urban sprawl is a specific form of land take, resulting from the spread of low-density settlements, and is one of the main challenges that cities face. Urban sprawl concerns cities attractiveness, their resource efficiency, their transport infrastructure and the location of public and private services. What is more, it is very difficult to control, as the land being consumed by sprawl often lies outside the cities' administrative areas" (EU, 2011 p. 26). Hence, sprawl is failure to shape and manage the growth of our cities but one should bear in mind that while urban sprawl is always associated with urban growth, it does not mean that all urban growth causes urban sprawl.

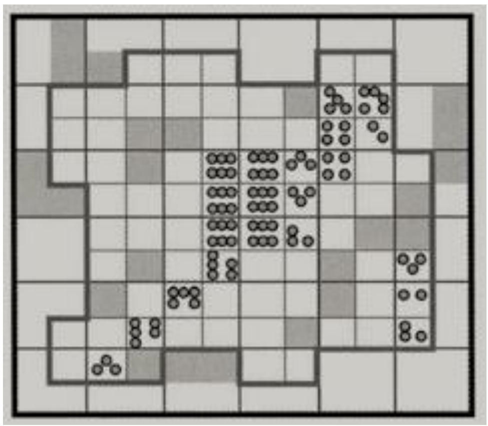
Urban sprawl is also described in various ways taking the processes, forms and patterns of urban developments into consideration. The most illustrative explanation was given by Galster et al. (2001) based on development patterns which is cited by various experts since then (Besussi et al., 2010; Yu, 2013; Reis et.al, 2015). The authors characterized urban sprawl based on forms, density and land-use patterns. According to Galster et al. (2001) forms refer to the physical growth or expansion of urban areas and represented by five types of patterns (Fig 2.4**)** compact development, scattered development, linear strip development, polynucleated development, and leapfrog development. Compact development is physical growth around existing developments without interruption, mostly the preferred form of urban development (Batty, 2004; Tsai, 2005; Besussi et al., 2010). Scattered development is a dispersed form of urban growth whereas leapfrog is a form of urban sprawl that appears as discontinues development leaving open spaces in between (Caicedo, 2015). On the other hand, linear strip development is expansion of cities following the development of main roads, on the lines of accessibility (Batty, 2004; Yu, 2013), this is the most common form of urban sprawl in Ethiopia. The last form of development pattern is polynucleated which is a type of growth around many smaller centers with a considerable distance in between them. On the other hand, Haregewoin (2005) indicated some characteristics of urban sprawl as land-use phenomenon on American context. Accordingly urban sprawl is a form of 'excessive land consumption' with: repetitive one story development, low densities at peripheries, fragmented open space or wide gaps between development and scattered appearance.



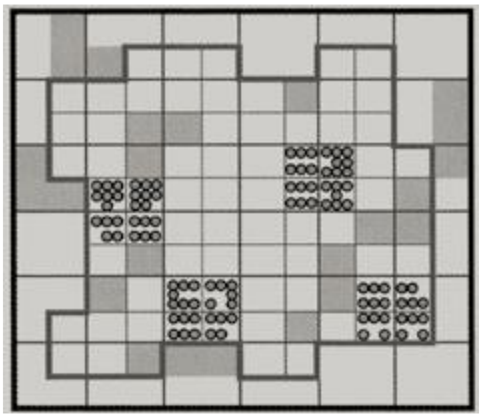
Compact Development



Scattered Development



Linear Strip Development



Polynucleated Development

Leapfrogging Development

Fig 2.4 Development patterns describing urban sprawl (Galster et al., 2001)

2.2.1 Driving factors of urban sprawl

At first urban sprawl has been a major a challenge in developed world but now it has already become a concern for cities in developing countries too. Urban sprawl is caused by different drivers and has in turn a wide range of consequences to the surrounding environment.

Experts and institutions wrote about causes and drivers of urban sprawl (Handy, 2003; Batty, 2004; Bhatta, 2010; EPA, 2013) but the best description is given by the European Environmental Agency (2006). The research classified major factors into seven categories that lead into urban sprawl: economic, both macro and micro factors, demographic factors related with population growth, more space and better housing preference, problems associated with inner city, transport related factors and factors related to regulatory frameworks. All the factors are indicated below for more understanding:

- *macro-economic factors*- such as economic growth and globalization;
- *micro-economic factors*- rising living standards, price of land, availability of cheap agricultural land, competition between municipalities;
- *demographic factors*-population growth and increase in household formation;
- *housing preference*-need of more space per person and better housing conditions;
- *inner city problems*- which include: poor air quality, noise, small apartments, unsafe environments, social problems, lack of green open space and poor quality of services;
- *transportation*-private car ownership, availability of roads, low cost of fuel and poor public transport;
- *regulatory frame works*- weak land use planning, poor enforcement of existing plans, lack of horizontal and vertical coordination and collaboration.

All are the underlying factors of urban sprawl and the presence of some or a combination of all will lead to haphazard development of urban centers that manifests in development patterns to form urban sprawl. In addition to the above mentioned factors, trends of lifestyles and interests of urban societies in recent decades also believed to cause urban sprawl (Handy, 2003). These lifestyles and attitudes include: the desire for new housing and commercial space at affordable prices; the desire for a larger house and the resulting growth in the average size of new houses; the adoption of policies aimed at increasing levels of home ownership; perceptions of higher crime levels and lower service quality in urban areas compared to suburban areas; the desire to live in smaller jurisdictions in the hope of ensuring better services and more responsive government; the desire to live in a homogeneous community, historically expressed in racial and ethnic terms but increasingly expressed in terms of income and class are the most causes of urban sprawl. All these force people to prefer the suburban areas for life and lead to urban sprawl.

2.2.2 Consequences of urban sprawl

Urban sprawl has so many impacts both to the surrounding rural environment and the inner city as well (Li, 2012). The US Environmental Protection Agency (2013) and Gurin (2003) indicated a host of environmental impacts and costs of urban sprawl. According to Gurin (2003) who wrote 'Understanding Sprawl' a citizen guide in Canada, the cost of urban sprawl is immense. The document lists 9 major impacts of sprawl: low density, increasing household cost, consuming agricultural land, affecting public health, energy consumption, degrading water quality, wildlife and aesthetics costs. In the same way, Weijers (2012), indicated the effect of urban sprawl in 3 major perspectives: " 1) the despoiling of countryside eroding and ruining its characteristics and economy, 2) Sprawl is less efficient than a compact city, as there is more infrastructure, utilities and other related services needed i.e. urban sprawl is more time consuming for commuters, it causes congestion, increases money spent on transport, loss of agricultural land, and loss of ecologies, to summarize greater costs because of the spread out, 3) Social structure (equity), those who earn more money have more possibilities for housing, sprawl can thus generate segregation of the population.'' (Weijers, 2012 p. 23–24).

Let's see some of the points in detail based on the explanation of Gurin (2003):

Low density means high cost-which is related to the idea that the cost of providing services increases with distance but decreases with density, and hence it is obviously more expensive to provide roads, telecommunication, electricity, sewerage and pipelines, sanitation, police and other services for a long distance and large low density area;

Consuming Agricultural Land: urban areas are indeed growing and expanding on the cost of agricultural and other non-built up areas, moreover, once the change happens, it is irreversible.

Public Health and Climate Change: as people prefer to live in the suburban areas and their job or business remain in the inner city, it deemed necessary to use thousands of automobile for transportation and these vehicles since they burn billions of liters of fossil fuels each year, they emit millions of tons of pollution, including carbon monoxide, nitrogen oxides, sulphur oxides, particulate matter and unburned hydrocarbons. Each type of pollution has substantial impacts on human health and the environment. This in turn leads to Climate Change*:* the burning of fossil fuels for transportation and energy also produces harmful greenhouse gas (GHG) emissions and the concentration of these gases is increasing dramatically. The gases collect in the atmosphere and act like a heat-trapping blanket to prevent the earth's excess heat from escaping. As the blanket thickens, the earth's average temperature increases which result in climate change.

Water: as encroachment to suburb increases, sprawl puts danger on water resource pollution. Water pollution occur in urban areas in two different ways, point source and non-point sources. Point source pollution of water occurs from factory or sewage outflow directly into rivers, streams and lakes whereas non-point source occurs when flood and rain storms take oils and toxic chemicals from road ways and parking lots to water sources. More important effects of urban sprawl was shown by Handy (2003) both negative and positive impacts.

2.3 Urbanization and development

Urbanization is the basis for development and the driver of economic growth. Urbanization is both inevitable and desirable (Spence et al., 2009) in order for countries and cities achieve their aspiration in economic development. According to Spence et al. (2009) nearly all countries were urbanized or at least 50% urbanized before achieving middle income economic level and all high income countries are 70–80 percent urbanized. The past records of urbanized countries indicate that no country has achieved sustained economic growth without urbanization- countries with high per capita income tend to be more urbanized while countries with low per capita income remain least urbanized (UN-Habitat, 2011; Freire et al., 2014). Satterthwaite et al. (2010) state that "No nation has prospered without urbanization and there is no prosperous nation that is not predominantly urban." (Satterthwaite et al., 2010, p. 2810). According to UN-Habitat (2011) cities are vehicles of social changes where new values, ideas and believes can forge a different growth paradigm for inhabitants and urbanization brought fundamental economic growth in developed world.

In all cases, it indicates that urbanization is the basis for economic transformation. However, this seems a paradox for most of low income countries for the obvious reason that urbanization and economic growth is very low but the rate of urbanization is at its highest pace. This is especially true for Ethiopia to achieve its plan to be a lower middle income country by 2025 (World Bank, 2015) as the country's urbanization level is currently 20.4% for 2017 and 25.4% for 2027 (CSA, 2013). The fact that rapid urbanization accompanied by low economic growth in developing countries means it puts pressure on local, city and national governments to fulfill even the bare necessities of life for city residents.

Therefore, urbanization is not a problem in and of itself or cannot be a curse for developing countries and a bless for developed world. Rather, urbanization is a process resulted from rural-urban migration, economic growth, social and cultural transformation that will continue in the future. The problem is rapid, unplanned and uncontrolled urbanization that leads to urban sprawl and its associated causes and consequences. Urban sprawl, in most developing countries, generates two types of developments (1) peripherization and (2) suburban sprawl (UN-Habitat, 2011). Peripherization is a form of urban sprawl characterized by informal and illegal pattern of suburban area developments combined with lack of infrastructures whereas suburban sprawl is characterized by residential zones for high and middle income groups connected by individuals rather than public transport.

Therefore, it can be concluded that cities are the basis for economic growth but their spatial growth should be managed, controlled and shaped so that their impact on the environment will be limited and resources will be sustainably utilized.

2.4 Measuring urban sprawl and applications of spatial metrics, GIS and RS

2.4.1 Application of GIS and remote sensing in urban sprawl

Remote sensing has been the best cost effective mechanism of data acquisition for a wide range of applications ever since the launch of landsat-1 in 1972 (Lo and Yeung, 2005). In remote sensing each sensor is designed for a specific purpose (Melesse et al., 2007). Urban growth and the physical expansion of cities can be detected, mapped and analyzed using remotely sensed data obtained from mostly landsat multispectral scanner (MSS) thematic mapper (TM) enhanced thematic mapper plus (ETM+), and SPOT (Ward et al., 2000). Urban areas are complex geographic dimensions with a mixed combination of buildings, roads, gardens, soils, water etc. Such surface cover types, exhibit a unique radiative and thermal moisture properties hence unique spectral signature (Melesse et al., 2007) and the advancement in satellite has helped its application in urban land-use/cover change detection using high spatial resolution sensors such as IKONOS and QuickBird-2.

One of the most difficult problem we face in studying urban areas in developing countries is lack of reliable data. Most of the data obtained in developing countries are outdated, unreliable or in some cases totally unavailable (Baudot, 2005). On the other hand, urban areas are the most dynamic features on the earth’s surface and urban landscapes are the most complex combinations of various built-up and non-built up surface cover types (Melesse et al., 2007). Therefore, both GIS and Remote Sensing (RS) have a wide range of applications in solving these problems in urban areas- planning, change detection, monitoring, and mapping. Remote sensing is a sound alternative to provide the most valuable and cost effective data from different sources mainly aerial photography and satellite images to assess, monitor and map urban sprawl (Baudot, 2005; Jat, et al., 2008). According to Kumra (2011) the data obtained from remote sensing can be utilized for various applications in urban areas: to study urban sprawl and trend of growth i.e. mapping, updating and monitoring using repetitive coverage; urban morphology; space use surveys in city centers; slum detection; transportation system and important aspects both in static and dynamic mode and site suitability area analysis. Weng (2010) also compiled so many urban area applications by integrating GIS and remote sensing such as feature extraction, urban landscape characterization and landscape metrics computation, impact of urban growth on air pollution and land surface temperature, quality of life and health assessments. According to Antos et al., (2016), the advancement in Geographic Information System (GIS) and Remote Sensing (RS) provide urban planners and policy makers with new tools to analyze the changing morphology of cities- to better understand the composition of cities, and how land occupied by residential, commercial, green space, agricultural and/or open space changes over periods of times.

The integration of GIS and RS together with Global Positioning System (GPS) is paramount in measuring urban sprawl and monitoring changes in urban areas. According to Gao (2002) the integration of the three technologies, GIS, GPS and RS coupled with modeling tools benefited managers and planners in multi-use and complex resource management activities. As such RS provides satellite images to generate land-use maps while GPS used for ground truthing and point sampling in the interpretation and rectification of satellite data. Obviously, GIS is a powerful tool to managing, analyze, database creation and overlay analysis of the processed data. Therefore, GIS, RS and GPS are pivotal for various urban area applications particularly in measuring and quantifying urban sprawl.

2.4.2 Measuring urban sprawl

There are various ways to quantify urban sprawl. Urban sprawl is monitored and measured by taking different factors into consideration. Most of researchers use urban density decline in terms of households, housing units, population and employment, accessibility to streets, distance from central business districts (CBD), fragmentation of built up areas and land-use mix to measure urban sprawl (Ewing et al., 2002; Angel et.al., 2011; Ewing and Hamidi, 2014). The most sited method in measuring urban sprawl was provided by Galster et al.

(2001) that indicate about 8 dimensions of the development patterns of land-use which are taken as the best indicators to measure urban sprawl. The authors presented land-use dimensions with graphical descriptions based on the concentrations or cluster of housing units or workers per square mile. Mostly the lower concentration or cluster of developed units under these eight dimensions is considered as a measure and an indication for urban sprawl. All the dimensions are being used by various scholars (Handy, 2003; Tsai, 2005; Yongqing, 2010; Angel et al., 2011; Li, 2012). Galster et al., (2001) developed them and described all the dimensions as follows:

1, ***Density:*** is and indicator to show the number of residential or non-residential units per square mile of developable land.

2, ***Continuity:*** indicates the degree to which development has taken place in unbroken fashion in urban areas.

3, ***Concentration:*** shows how development is located disproportionately in few square miles of the total urban area rather than even distribution.

4, ***Clustering:*** is the degree to which development has tightly bunched to minimize the amount of land occupied by residential and non-residential units.

5, ***Centrality:*** an indicator used to show how developments are close or far to the central business district (CBD) of the urban area.

6, ***Nuclearity*****:** the extent to which urban area is characterized by polynuclear development patterns.

7, ***Proximity:*** is the degree to which different land-uses are close to each other in the urban landscape.

8, ***Mixed Use:*** shows the degree how two different land-use types exist within the same area. It measures whether an urban area is characterized by mixed use or single use.

Others also used Shannon Entropy index to measure urban sprawl at zonal level as a measure of dividedness and spatial dispersion (Cabral et al., 2013). In this method, the study area is divided into many concentric circles (zones) and the built up area in each circle is calculated to find out whether the built up area is evenly distributed across all zones or concentrated in a single zone or small zones. The result of Shannon entropy index becomes 1 if the urban built up area is evenly distributed and becomes 0 if the built up area is concentrated in few zones.

2.4.3 Change detection

Change detection is the process by which we identify the status of objects or a phenomenon from remotely sensed images obtained at different times (Singh, 1989). There are quite a number of change detection methods applied for various purposes. Lu et al. (2004) lists about 7 methods of change detection techniques: (1) algebra, (2) transformation (3) classification, (4) advanced models, (5) geographic information system, (6) visual analysis, (7)other approaches. Each category has its own advantages and disadvantages. The categories are in order of their complexity and there are a number of subclasses under each main category.

The classification category includes supervised and unsupervised change detection, post-classification comparison, spectral–temporal combined analysis, expectation–maximization algorithm (EM) change detection, hybrid change detection, and Artificial Neural Networks (ANN) (Lu et al.,2004). The supervised classification and post classification comparison method is applied for this study.

2.4.4 Spatial metrics method

Recently there are other methods applied to measure urban sprawl and spatial metrics is one of the most important mechanisms used by different experts in the field. Spatial metrics is the main methodology applied to measure urban sprawl for this study. Spatial metrics was first developed in ecological landscape to assess habitat loss and ecological fragmentation (Gustafson, 1998; McGarigal, 2015), but in recent times there are a number of works done applying the same methodology in urban area to assess the pattern of developments and to quantify urban sprawl (Rutledge, 2003; Weijers, 2012; Gezahegn Aweke, 2013; Meeli, 2013; Ramachandra, 2014; Reis et al, 2015; Megahed, 2015). Spatial metrics are numerical indices that give a good indication of urban sprawl (Gilbrook, 2014) and used to describe structure and pattern of landscape (Cheng, 2003). Spatial metrics use patches as a basic unit or element to measure landscape structure and pattern (Knaap et al., 2005). Patches are defined as discreet areas of homogeneous environmental conditions in a landscape (McGarigal, 2015; Reis et al, 2015). The shape, size and division or isolation of patches are important characteristics to measure a landscape under investigation (Knaap et al., 2005).

There are hundreds of spatial metrics indices but only tens of these indices are selected for urban sprawl measurement purpose by many researchers. The selection of spatial metrics is determined by three main factors (Kupfer, 2012), a) data requirements and ease of calculation

b) structural and functional properties of a landscape c) ease of interpretation of the indices. The most commonly applied spatial metrics in most literatures of urban sprawl studies include: Class Area (CA), Number of Patches (NP), Patch Density (PD), Total Edge (TE), Edge Density (ED), Largest Patch Index (LPI), Landscape shape Index (LSI), Aggregation Index (AI), Perimeter –Area Fractal Dimension (PAFRAC), Clumpiness Index (Clumpy), Percentage of Like Adjacencies (PLADJ) and some other metrics. Most of these spatial metrics are applied for this study and all are elaborated in detail in the next chapter.

CHAPTER THREE

3. Methods and Materials

3.1 Materials

3.1.1 Description of the study area

The location of the study is in Addis Ababa and its surrounding areas (Fig 3.1**).** The main aim is measuring urban sprawl following the footprint of built up area both in Addis Ababa and its surrounding towns. The surrounding urban areas are included in the study area because there is strong relationship between Addis Ababa and surrounding Oromia towns. The cost of living has not been easy in Addis Ababa in the past few decades. Therefore, people are working in the city and living in the suburban areas and surrounding Oromia towns or vies-versa to cope up with cost of life. Urban sprawl is mostly the movement of people (both rich and poor) outwards from the city center to the suburban areas to get a better life. The urban poor move to the suburban areas to get the better worse for they cannot cope with the life standards of the city center whereas the rich move out to lead a better individual life i.e. to get a relief from noise, slums, traffic congestion etc. For that matter, the impact of urban sprawl is strongly related with the movement of workers from home to office, transportation systems, driving duration and traffic congestion. In addition, the surrounding towns are included in the study area because urban sprawl and its impact expand beyond the city boundary. It has related impacts on the surrounding areas such as loss of agricultural land, water pollution and degrading ecology of the areas. On the other hand, the construction of real estates, establishment of industries and other development activities has been conducted in both the city and surrounding towns in the past decades following privatization policy of the country. Therefore, the study area is delineated (Fig 3.1) following Addis Ababa city boundary and the built up area footprint of the surrounding Oromia towns- Sululta, Burayu, Sebeta, Akaki and Legedadi-Legetafo areas, from recent satellite images to assess urban expansion, composition and configuration in both areas.

As shown in Fig 3.1 geographically, Addis Ababa is located in the central part of the country with a total area of 528 km^2. The longitudinal and latitudinal extent of the city is from 38º 39' 00" – 38º 54' 15" E and 8º 50' 18" – 9º 6' 5" N. According to Mesfin Tadesse (2009), the city’s elevation ranges from the lowest point, around Bole International Airport, at 2,326 m (7,630 ft.) above sea level in the southern periphery, to over 3,000 m (9,800 ft.) in the Entoto Mountains to the northern.

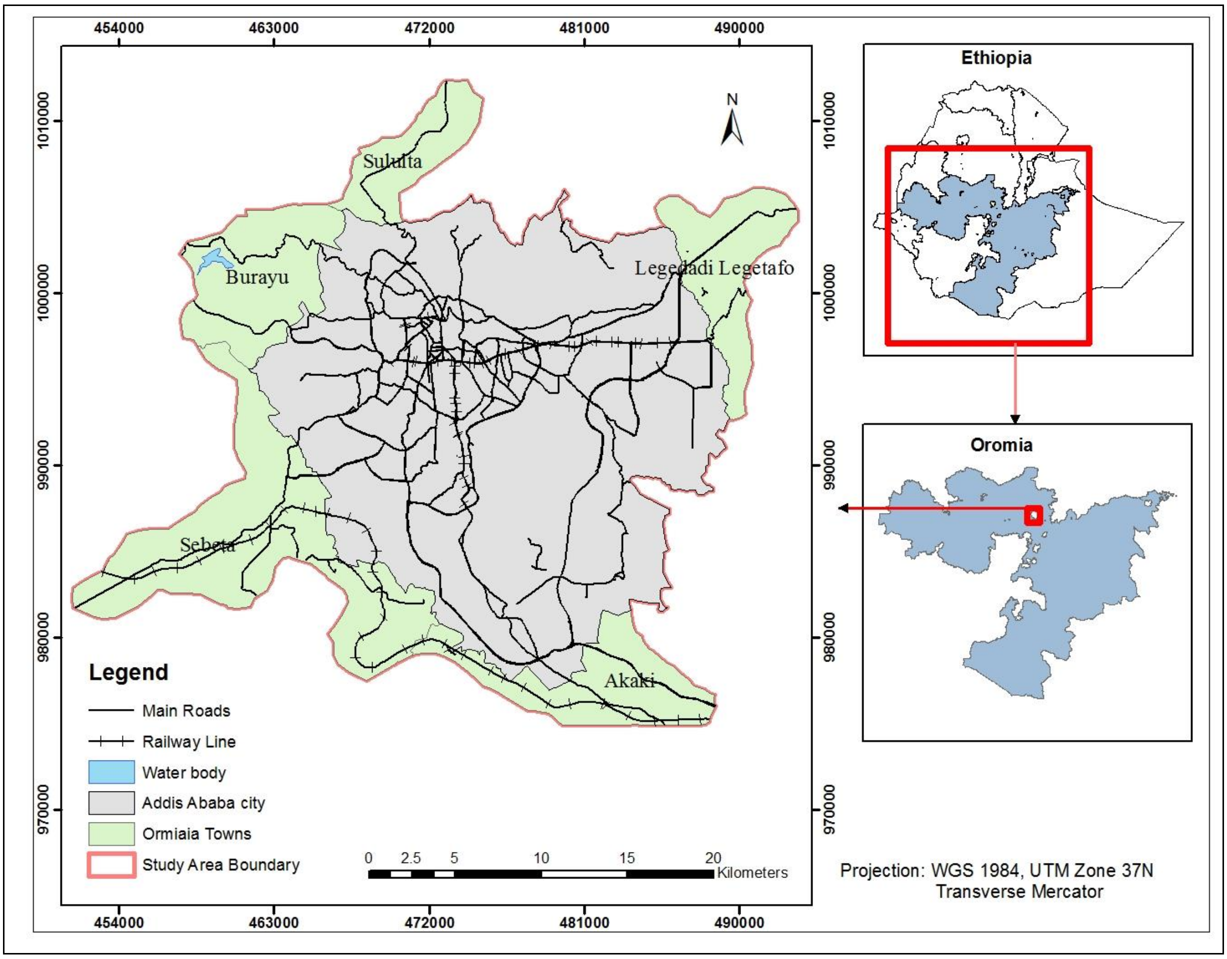


Fig 3. 1 Location map of the study area

Population

Addis Ababa is one of the metropolitan cities in Sub-Saharan Africa hosting 25% of the countries urban population (World Bank, 2015). Though there are various conflicting numbers about the total population of the city, the official population projection by Central Statistical Agency (2013) as shown in Table 3.1 for the current population in 2017 is assumed to be about 3.4 million and estimated to be 5.1 million by 2037.

Table 3.1 Medium population projection for Addis Ababa

Gender	Projection Years and Projected Population in Thousands										
	2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2025**	**2030**	**2037**
Total	3,119	3,194	3,272	3,353	3,435	3,519	3,604	3,689	4,114	4,530	5,132
Male	1,480	1,515	1,551	1,588	1,625	1,664	1,703	1,747	1,939	2,128	2,400
Female	1,639	1,679	1,765	1,765	1,810	1,855	1,900	1,946	2,175	2,402	2,732

Source: CSA (2013, p. 58).

Population number has a strong relation with urban expansion. As the number of people living in towns increases, it obvious that it needs additional place, resources and services to accommodate the increasing number.

Climate

Longest record of rainfall in Addis Ababa was started in 1898 but the record of temperature began in 1951 (Conway et al., 2004). Addis Ababa has sub-subtropical highland climate 'Woina Dega' with mean annual temperature 16.02 ˚C and annual average rainfall of about 1150mm from 1951–1998 (UNEP, 2003). In addition to its central location in the country, the city has moderate and suitable climatic condition that makes it preferable for living by many citizens.

A. Rainfall

According to Conway et al. (2004) rainfall data had been recorded in Addis Ababa since 1898 with some interruptions in some years and the mean annual rainfall in the past 100 years was 1220 mm from 1898-1950 and 1171 mm from 1951–2002 which can be summarized as a mean annual of 1196 mm from 1898–2002. Under normal conditions, the city receives rainfall nearly in all months of the year as shown in Table 3.2 and Fig 3.2 (2014 and 2016) but the amount varies with maximum amount of rainfall occurring in seven rainy months from March to September and lowest in dry seasons from October to February (UNEP, 2003). The amount of rainfall in 2015 (Table 3.2) indicates some irregularities due to the drought condition that occurred in the country. July and August are the highest rainy months while the lowest rainfall occurs in November, December and January.

Table 3.2 Average monthly and annual rainfall (mm) of Addis Ababa from 2014 –2016

Year	Monthly and Annual Rainfall in mm												Total
	Jan	Feb	Ma	Apr	Ma	Jun	Jul	Aug	Sep	Oct	No	De	
2014	0.5	35	44	30	79	63	241	266	173	32	5	0.1	970
2015	0	5	0	NA	120	158	364	322	86	14	30	NA	1095
2016	42	25	104	164	127	128	221	226	137	8	3	0	1188

Source: Ethiopian National Meteorology Agency.

B. Temperature

It is a known fact that temperature decreases with an increase in altitude. Addis Ababa has a moderate or temperate climatic condition due to its high altitude. The formal recording of temperature began in 1951 with the establishment of Addis Ababa Observatory near Tikur

Anbesa Hospital (Conway et al., 2004). A detailed analysis of temperature data from 1951–1998 made by UNEP (2003) in collaboration with Addis Ababa University (AAU) and Addis Ababa Water and Sewerage Authority (AAWSA) indicated that the average annual temperature of Addis Ababa was 16.02˚C with the average maximum and minimum temperature being 22.7 ˚C and 9.9 ˚C, respectively for about 47 years record from 1951–1998. The recent record in the past 3 years (Table 3.3) indicate that the highest average monthly maximum temperature was 27.2˚C in March (2015) while average monthly minimum temperature was 7.5 ˚C in December (2016).

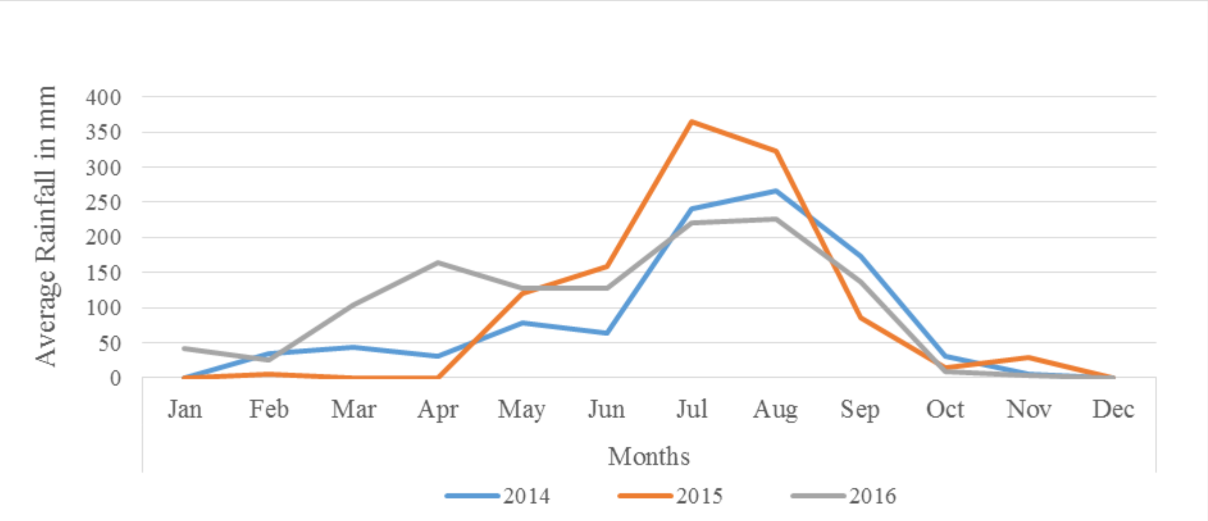


Fig 3.2 Graph showing average monthly rainfall of Addis Ababa

Table 3.3 Monthly minimum and maximum temperature of Addis Ababa from 2014–2016

Year	Temp	Average Monthly Temperature in °C											
		Jan	**Feb**	**Ma**	**Apr**	**Ma**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2014	MIN	9.8	11.9	12.5	13.7	13.2	13	12.1	11.6	11.9	10.7	9.8	8.5
	MAX	24.6	25.2	25.9	26.2	25.5	24.7	22.3	21.4	22.7	23.7	23.7	23.3
2015	MIN	8	10.2	10.8	12.5	13.6	13.1	12.4	12.2	12.1	12	8.1	10.2
	MAX	24.5	26.5	26.1	27.2	25	23.5	22.3	21.2	22.2	25.1	25.2	23.8
2016	MIN	11.4	11.4	13.9	14.1	13.1	13.1	12.5	12	12.1	10.7	9.58	7.5
	MAX	23.9	26.4	28.1	24.7	24.7	26.1	21.3	21.6	22.8	24.3	24.5	24.4

Source: Ethiopian National Meteorology Agency

3.1.2 Data Source

Nowadays, a wide range of data is available at various scale local, regional and national levels from various commercial and government agencies. The United States Geological Survey (USGS) is a gold mine of information and the known source of satellite image free of charge that cover wide areas. The main problem in developing countries like Ethiopia is lack of high resolution satellite images such as IKONOS and QuickBird because of their expensive price. For this reason, Landsat images, Landsat Thematic Mapper (TM), Landsat Enhanced Thematic Mapper Plus (ETM+) and Landsat-8 Operational Land Imager (OLI), for the years 1984, 1995, 2006 and 2016, respectively are obtained from USGS Earth Explorer (Table 3.4) and panned with SPOT-5 image from the year 2006 (5m resolution) to increase the interpretability of the Landsat images. For all years, high quality cloud free images were selected from row 54 and path 168, full scenes. The season of the year was preferred to get cloud free images for ease of classification and facilitate comparison in post-classification activities.

Table 3.4 Satellite images and other data sources

Data	Platform	Ground Resolution	Season/Year	Source	Data Type
Image	Landsat TM	30m/5m Panned	December 1984	USGS	Primary
Image	Landsat TM	30m/5m Panned	January 1995	USGS	Primary
Image	Landsat 7	30m/5m Panned	January 2006	USGS	Primary
image	Landsat 8	30m/5m Panned	January 2016	USGS	Primary
Image	SPOT –5	5m resolution	2006	CSA	Secondary
Shapefiles	Road, railway, study area boundary			CSA	CSA

3.1.3 Tools and software programs used

As the study is about urban change detection and urban sprawl measurement, mainly ERDAS Imagine 14, FRAGSTATS 4.2, ZonalMetrics and ArcGIS 10.2 software programs were used for data processing and urban sprawl measurement in this study. ERDAS Imagine is important software for image preprocessing, enhancement, transformation, classification and accuracy assessment activities. FRAGSTATS is another important software program to measure urban sprawl in spatial metrics using classified images. FRAGSTATS calculates several spatial metric statistics in landscape environment to measure urban sprawl while ZonalMetrics Toolbox is a new open source tool to calculate spatial metrics at zonal level for measure urban sprawl in the study area. Other materials, such as Garmin GPS 78 and digital camera were used for ground data collection for accuracy assessment of classified images.

3.2 Methodology

The methodology applied in this study is calculation of spatial metric indices from categorical maps generated from satellite images to quantify urban sprawl. Therefore, the activities conducted in this portion include acquisition of satellite images for four years 1984, 1995, 2006 and 2016, preprocessing, image classification and categorical map generation, accuracy assessment, reclassification, parameterization, change detection, spatial metrics selection and zonal metric analysis as shown in Fig 3.3 the general work flow of the thesis.

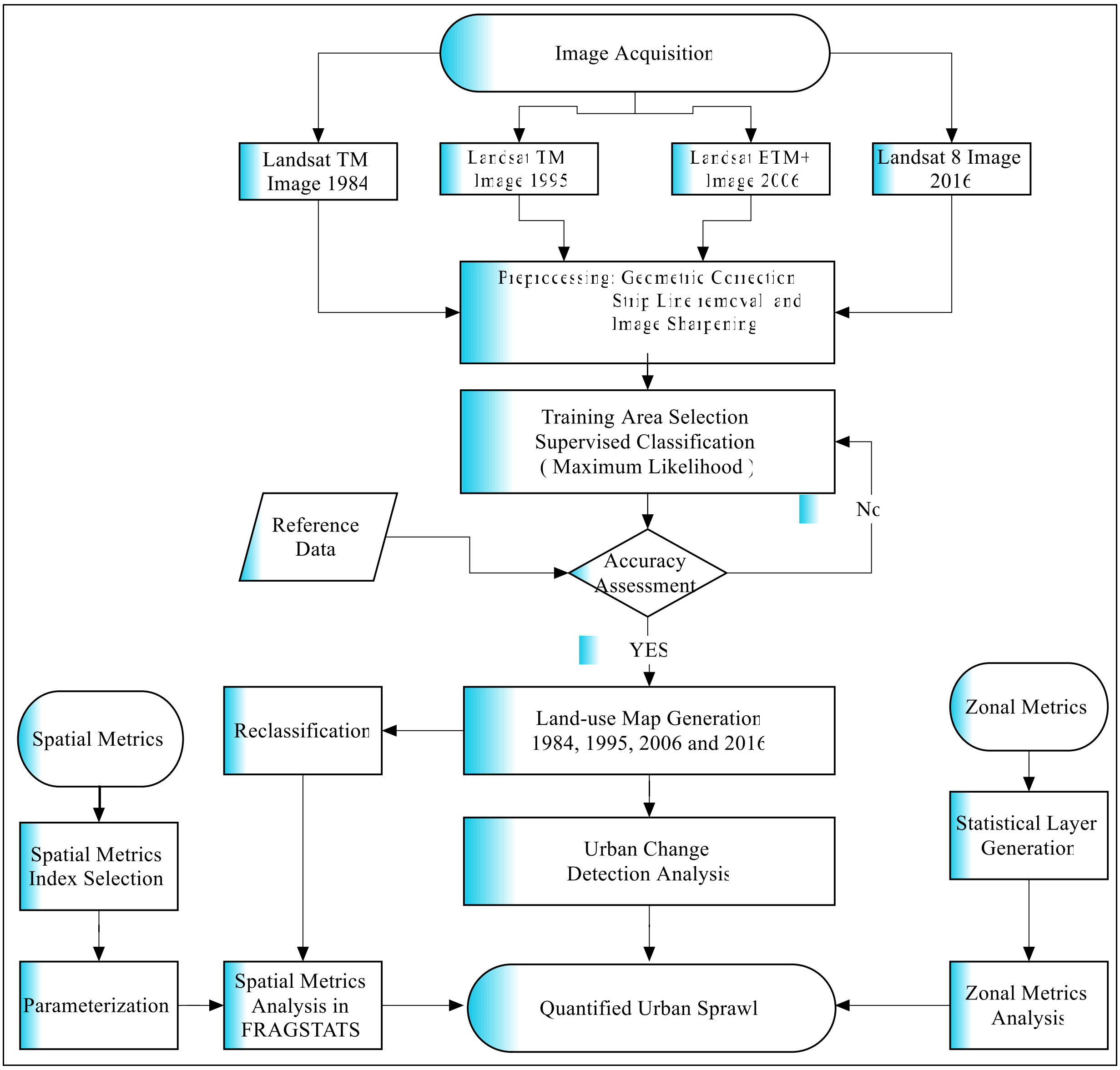


Fig 3.3 General work flow of the thesis

3.2.1 Preprocessing

Image preprocessing activity is compulsory for the reason that satellite images are subject to geometric and radiometric distortions. Preprocessing activities such as image sub-setting or clipping by the study area, re-projection, and image panning or resolution merge are performed for all images in order for all images be ready for use.

Preprocessed level 1 Satellite images were obtained from NASA Earth Explorer web site for this study. The images were downloaded from USGS Landsat archive web site and layer stacked after extracting the compiled file. Image selection and preference of seasons was based on, one for its free availability of the data and the other it was free from cloud coverage. After data acquisition, image to image geometric rectification was made using QuickBird image acquired in 2006. The SPOT-5 image (2006) was re-projected and calibrated using Projection UTM Zone 37N, Datum WGS 1984 and European Petroleum Survey Group (EPSG) code 32637 to make it fit with Landsat images and the study area. Geometric rectifications, re-projection and clipping by the study area were performed for all images but strip line removal by using focal analysis was performed only for Landsat ETM+ image (2006) in ERDAS Imagine, focal analysis. Strip line removal analysis was performed repeatedly until the lines were removed and a clear image was obtained. Study area image extraction or clipping the images using boundary shapefiles to get an image fit to the study area was made to all images in ArcGIS data management, Raster Processing 'Clip Tool'.

In order to increase the interpretability and spatial resolution of the raw images, resolution merge was performed by using the 15 m panchromatic band (Band 8) for ETM plus and Landsat 8 images. First layers from 1–7 for ETM+ image and 2–7 for the Landsat 8 image were stacked for each year and then merged using the panchromatic band 8 as a high resolution layer in ERDAS Imagine. Then the resulting 15 m resolution images and Landsat TM (30m) image were again fused with SPOT-5 (5m) of the year 2006 using the Hyperspectral Color Sharpening algorithm- Hyperspectral Color Space Resolution Merge (HCS resolution merge) that combine high-resolution data with lower resolution multispectral data. Hyperspectral Color Sharpening was first designed for WorldView-2 sensor 8-band data, but the algorism works with any multispectral data containing 3 bands or more. Hence, after all the processes, a better 5 m resolution images were generated for each year that are found to be better interpretable. Therefore, all preprocessing activities helped a lot to get a better quality image which improves the interpretation and classification processes in the later stages.

3.2.2 Image classification

After all the pre-processing activities, one of the actual work of the study is image classification which is the basis for change detection activity. Classification is one of the seven change detection mechanisms and supervised classification was employed for this study. Supervised classification requires the selection of training areas to get accurate classification output. It is profoundly based on the quality and quantity of training samples to produce good quality classification results.

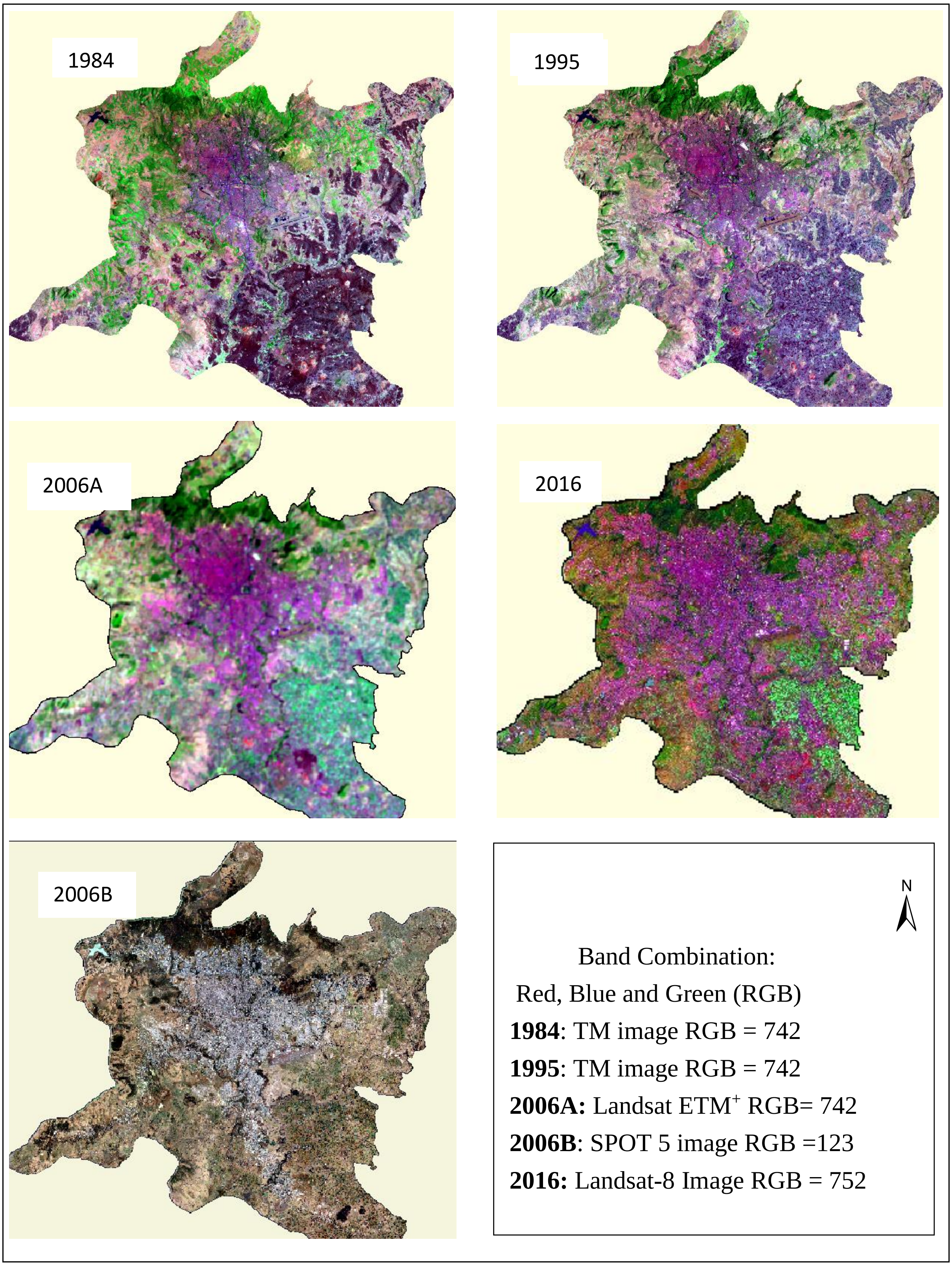


Fig 3.4 Landsat images after preprocessed and pan sharpened with SPOT 5 image.

In supervised classification, identifying feature cover types, selecting high-quality and sufficiently numerous training sample sets is the time consuming and one of the major challenges that the investigators face during digital image analysis to producing highly accurate classification results. As the main objective of the study is change detection and measuring urban sprawl of the city, only five main land-use/cover categories were selected for the purpose: built-up area, agricultural area, green area, barren land/open space and water body (Table 3.5.). Classification nomenclatures were selected according to Anderson et al. (1976) and the categories were made same for all 1984, 1995, 2006 and 2016 images so that the comparison of the classification output will be possible.

More than 20 training areas were carefully selected from each surface cover types of each category and the number of training areas increases when the reflectance of the surface cover types varies in the category. This is particularly true for built-up areas category which required more than 30 training samples for each year as it includes various land-use types such as roads, residential, non-residential, different colors of building roofs and what you have. The classification process began by selecting training areas with careful observation of the images and feature cover types within the images. Training area selection process was also helped by true and false color combination (Fig 3.4). Additional high resolution images such as QuickBird and SPOT that cover the study area were used to identify the features. Therefore, during training area selection, care has been taken to include all pixels of objects observed in the images.

Table 3. 5 Land-use land-cover categories applied for classification in the project

No	Land Use Category	Description
1	Built-up Area	Includes all developed areas roads, buildings, housing units, Commercial and resident areas, under construction areas etc.
2	Agricultural Area	Includes all areas employed for agricultural activities farmland parcels both with and without crop.
3	Green Area	Refers to areas covered by vegetation of any type, including riverine trees or vegetation and other pockets of green areas.
4	Barren Land	For this study, it mainly refers to open spaces without any function, bare soils, rocky areas, quarries and gravel pits, grazing land, open areas in side vegetation and resident areas, it might be covered by grasses.
5	Water Body	Geferssa water source.

3.2.3 Accuracy assessment

Accuracy assessment is a compulsory activity after any satellite image classification analysis to know whether or not the classification process met its objectives. Accuracy assessment is the degree of correspondence between observation and reality (Levin, 1999). It refers to assessing the accuracy level of the final categorical map generated by image classification. This can be done by generating a random set of points and comparing the land-cover map of the image with that of obtained in the field i.e. image map with reference data (Eastman, 2003). According to Levin (1999), reference data for accuracy assessment can be obtained from existing maps, large scale aerial photos/images and field checks. The most commonly applied methods of accuracy assessment include, producer's accuracy, user's accuracy, overall accuracy and Kappa coefficient (Lu et al., 2004). All of these techniques are applied to check the performance of classification activities for all years. The formula provided here are adopted from Lo and Yeung (2005).

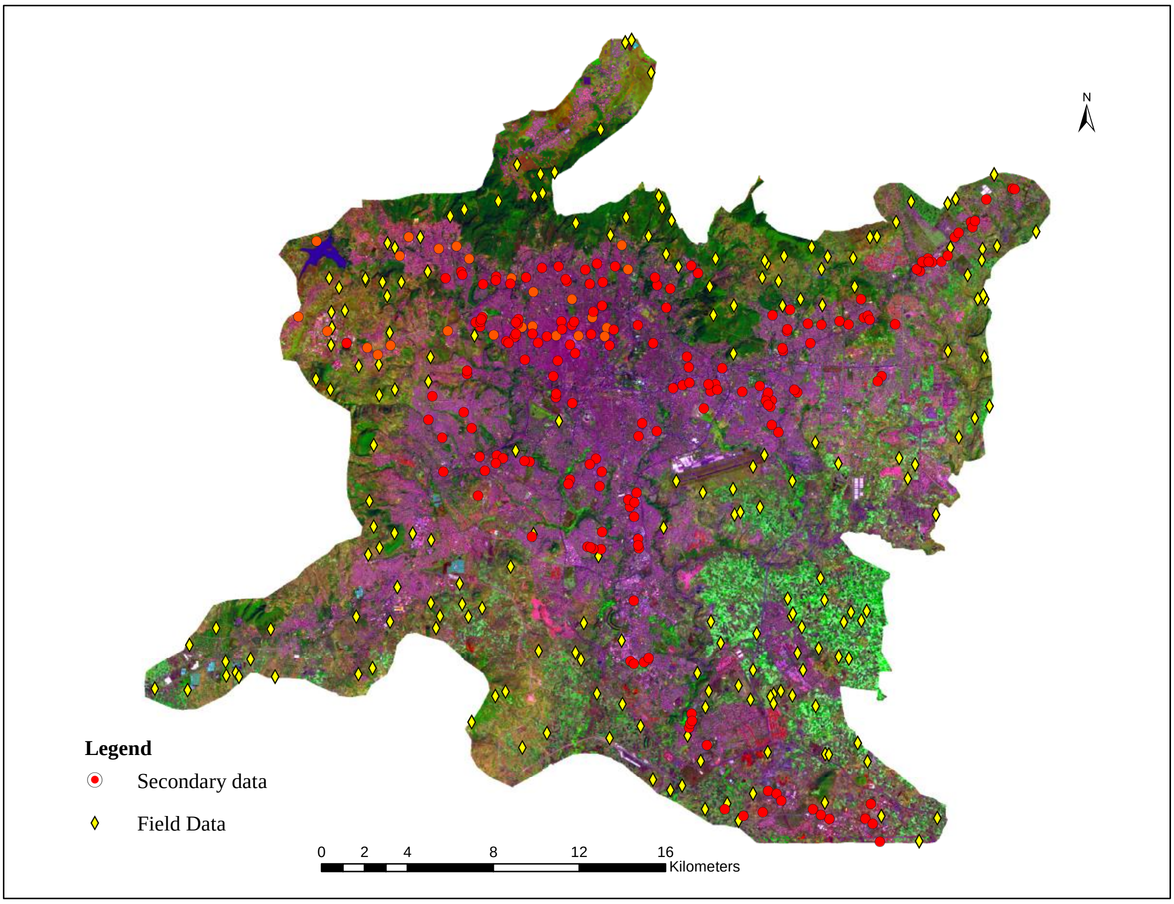


Fig 3.5 Ground Controlling Points used for accuracy assessment of 2016.

Producer's Accuracy: measures the percentage of correctly classified pixels from a sample data or indirectly indicates errors of omission for a particular class. It is calculated by dividing the number of correctly classified locations to the total number of samples in the reference data or column.

$$\text{Producer's Accuracy} = \left(\frac{C_i}{C_t}\right)100 \quad \text{(Eq-1)}$$

Where C_i = correctly classified sample locations of the reference data or column and C_t = total number of sample locations of the column.

User's Accuracy: measures the probability of each category classified on the map represented actually on the ground. It indirectly indicates the error of commission to a particular category. It is calculated as:

$$\text{User's Accuracy} = \left(\frac{R_i}{R_t}\right)100 \quad \text{(Eq-2)}$$

Where Ri = correctly classified samples in the row and Rt = total number of samples in the row.

Overall Accuracy: also known as Percent Correctly Classified (PCC) simply measures the overall accuracy of the data and calculated as the sum of the diagonal divided by the total number of samples (n). Hence, the formula is given as:

$$\text{Overall Accuracy(PCC)} = \left(\frac{Sd}{n}\right)100 \quad \text{(Eq-3)}$$

Where Sd = sum of values along diagonal and n = total number of sample. According to Lo and Yeung (2005) overall accuracy does not differentiate between errors of commission and errors of omission and over estimates the accuracy of the data due to various limitations.

Overall Kappa Statistics: is another measure of accuracy assessment that makes a better estimate than overall accuracy because it is capable of controlling the PCC index and incorporates off-diagonal values to calculate the coefficients. Kappa coefficient results are always less than 1 and results approaching to 1 indicate excellent agreement between the classified map and reference data.

Accuracy assessment of the classified images of all years- 1984, 1995, 2006 and 2016 has been conducted in ERDAS Imagine 14. The classification for years 1984 and 1995 is evaluated by selecting 277 and 256 points randomly from their correspondent images, respectively. Accuracy assessment for the year 2006 classification is made by taking 276 randomly selected points from SPOT–5 image.

The evaluation of 2016 classification is made by a total of 389 points both from field data and secondary data obtained from Central Statistical Agency (CSA). The secondary data was applied only for built-up category and a total of 189 reference points were selected randomly from existing business and facility locations. Field data verification was conducted for other classes mainly agriculture, barren land/open space and green areas. A total of 200 points were selected from classified map randomly from these categories and field verification was conducted by using Garmin GPS 78 which is one of better Garmin products with 2m accuracy level. The verification was conducted by entering all coordinates into the GPS unit and waypoint navigation page to find the location of points. Most of the green area points were verified from Google earth due to the difficult of navigation to those location using GPS tool. Fig 3.5 shows all the secondary and primary points used for field verification and accuracy assessment of 2016 classified map.

3.2.4 Change detection

Change detection is the identification of variations in land cover types by observing a specified area at different times using multi-temporal data sets from satellite images. Spatio-temporal satellite images of a specified geographic area were processed and classified to produce thematic maps for 1984, 1995, 2006 and 2016 then the classified maps were compared and overlaid to visualize the changes on the area in the span of time. It is also possible to compute the amount of increase (positive) and/or decrease (negative) of each category and see the change in percent in each year using the following formula:

$$\text{Change in \%} = \left(\frac{\text{Total area in } T_2 - \text{Total area in } T_1}{\text{Total area } T1}\right)100 \qquad \text{(Eq-4)}$$

Where T_1 is earlier point of time and T_2 is the later or recent point of time in the series.

Dynamic Change: the dynamic degree of spatial structure is an important indicator that can reflect the dynamic changes or rate of spatial expansions and calculated using the formula (Li, 2012):

$$DC = \left(\frac{BA_2 - BA_1}{BA_1} \text{ x } \frac{1}{T_2 - T_1}\right)100 \qquad \text{(Eq-5)}$$

Where DC is the dynamic change rate of urban sprawl for a period, T_1 and T_2 are specific years, BA_1 is total built-up area at time T_1, and BA_2 is total built-up area at T_2.

The total area covered by each class in each study year was also calculated and the amount and rate of change for each land cover classes analyzed. However, this cannot tell us further information about the process, pattern and structure or configuration and composition of urban sprawl. Therefore, the use of additional methods like spatial metrics is necessary to measure urban sprawl patterns and structures.

3.2.5 Reclassification

This is a processes appropriate for spatial metric system to measure urban sprawl in FRAGSTATS. It is necessary to reclassify the class values of categorical maps into positive integer and the background value into negative integer in ArcGIS spatial analyst tool. This is particularly important to calculate spatial metric indices of built up area in FRAGSTATS. Because, unless we change the class value of background into negative integer, FRAGSTATS computes the background cells with the focal classes and the result is absolutely different. In other words, FRAGSTATS recognizes cells with positive class values as inside and cells with negative class values as outside. For this reason, the background in all maps was assigned with -999 to exclude it from calculation and other class categories assigned integers from 1-5. The new categorized maps were used as an input in FRAGSTATS to calculate spatial metric indices.

3.2.6 Spatial metrics

3.2.6.1 Concepts and definitions of spatial metrics

There are some definitions and concepts which are frequently used in the document and need to be elaborated so that the reader will be able to understand their meanings accordingly. These terms and concepts are defined as follows:

Spatial Metrics: also known as **landscape metrics** refer to 'numerical indices' developed to quantify categorical map patterns based on area, edge, shape and core area (McGarigal, 2015). They are algorithms that quantify specific spatial characteristics of patches, patch types or classes, entire landscape mosaics, or the spatial context of individual cells within a patch mosaic.

Zonal Metrics: are spatial metrics to calculate selected numerical indices at zonal level. They are newly developed spatial metrics in **'ZonalMetrics python toolbox**' which is a new open source tool developed by Adamczyk and Tiede (2017) with a specialized functionality for calculating landscape metrics on the zone level. The source code is free and open to the community and can be customized with ArcGIS 10.2 or latest versions. In zonal metrics the study area is divided into user specified zones and statistics are computed per zones.

Patches: are defined as surface areas that differ from their surroundings in nature or appearance (Laurent, 2006) and one of the basic elements that make up a landscape and building blocks of spatial metric calculation. Patches must be defined in relation to the phenomenon to be investigated. For this study patches refer to individual built-up area polygons surrounded by non-built up environments such as agricultural, open spaces or green areas, irrespective of their size.

Patch Level Metrics: are spatial metrics designed to calculate the spatial character and context of individual patches. Patch level metrics are the basis for class and landscape metrics. They are statistics that describe about individual patches. Patch level metrics summarize area, perimeter, shape, core area etc. of patches in the landscape.

Class Level Metrics: refer to metrics or statistics calculated for overall patches of a particular class and are indices of fragmentation for the class in focus (McGarigal, 2015). Patch metrics are integrated by averaging or weighted averaging to give class metrics. They measure the amount and spatial configuration of built up patches indicating the extent and fragmentation of each built up patches in the urban landscape. For this study class level metrics refer to spatial indices calculated for built-up class and most of the selected metrics belong to this category for the simple reason that the main focus of the study is the fragmentation and sprawl of built-up area.

Landscape Level Metrics: refer to spatial metrics calculated to describe the entire landscape or all classes in the landscape. They represent the spatial pattern of the landscape. Landscape level metrics quantify the spatial relationship of patches in the landscape i.e., spatial composition and configuration (Laurent, 2006). According to Gustafson (1998) Landscape metrics in general fall into two categories those that quantify landscape composition and those that quantify landscape configuration.

Landscape Composition: refers to the abundance or proportion of patch types or classes including patch richness (number of classes), patch evenness (abundance of classes) and patch diversity but not spatial characteristics of patches (Wagner and Fortin, 2005).

Landscape Configuration: is the spatial characteristics of patches, i.e. arrangement, position or orientation of patches within a class or landscape (McGarigal, 2015). Examples of configuration metrics include patch and edge size, shape complexity, core area, aggregation index etc.

3.2.6.2 Spatial metrics selection to measure urban sprawl

Spatial metrics method is the main methodology to be employed to study urban sprawl in Addis Ababa city and the surrounding towns using FRAGSTATS version 4.2 software.

FRAGSTATS is a foremost fragmentation program currently available and a spatial pattern analysis software program for quantifying the structure of landscape i.e., composition and configuration of landscape (McGarigal, 2015, Maclean and Congalton, 2013). Spatial metrics are quantitative measures of spatial structures and patterns that can be used to describe urban sprawl (Weijers, 2012). According to McGarigal (2015), FRAGSTATS computes several spatial statistics representing area, shape and perimeter (edge) at the patch, class, and landscape levels, i.e., levels of heterogeneity. FRAGSTATS accepts only raster data and gives statistical data as an output.

FRAGSTATS compute a number of spatial metrics that measure urban sprawl with some criteria and parametrization by the user. Most of these metrics are redundant and calculate almost similar values. Therefore, it is responsibility of the user to select appropriate metrics for his/her purpose. Hence, here the selection of indices listed below were based on their purpose and the fragmentation they calculate. In FRAGSTAS, the user needs to select spatial metrics, specify common tables, select analysis parameters, parameterize patch, class and landscape metrics, before using the software. All were set according to instructional manual and purpose of study.

The main metrics that serve as indices of urban sprawl in urban studies were selected to be used for this study. These spatial metrics are elaborated next by mainly consulting FRAGSTATS manual (McGarigal, 2015), (Maclean and Congalton, 2013) and other studies made on landscape ecology and urban sprawl measurement (Rutledge, 2003; Gillanders, 2009; Weijers, 2012; Gezahegn Aweke, 2013; Roose, 2013; Ramachandra, 2014).

1. **Class Area (CA):** is a measure of landscape composition in urban environment (Roose, 2013) and shows the absolute growth of built up area (Weijers, 2012). It is selected to calculate the total area covered by patch types (classes) and/or estimates how much a particular patch type comprises in the landscape. It is calculated as the sum of the areas (in meter square) of all patches of a corresponding patch type divided by 10,000, i.e., it gives total area of the intended class (McGarigal, 2015). When the entire image is comprised of a single patch type, CA = Total Area of the landscape. McGarical (2015) calculated CA using the formula:

$$CA = \sum_{j=1}^{n} a_{ij} \left(\frac{1}{10{,}000}\right) \quad \text{(Eq-6)}$$

Where aij = area in (m^2) of patch ij.

2. **Number of Patches** (NP): refers to the number of built-up patches in meter/hectare in the landscape and selected to measures level of fragmentation of built-up area of the study area.

An increase in number of patches in time series study, indicate an in increase in fragmentation, sprawling urban area (Rutledge, 2003). However, it conveys no information about area, distribution or density of patches.

NP= N where N is total number of Patches.

4. **Edge Density(ED):** is also an indicator of urban sprawl. It is calculated as the sum of lengths of all edge segments (m) in the landscape divided by the total area of the landscape (m^2) and multiplied by 10,000 to change it into hectare (McGarigal, 2015). It measures the total edges of the urban area per hectare taking the shape and complexity of patches into consideration (Gezahegn Aweke, 2013). It increases with the emergence of new urban areas but decreases when urban areas agglomerate (Weijers, 2012; Ramachandra et al., 2014). FRAGSTATS calculates ED as:

$$ED = \sum_{k=1}^{m} \frac{e_{ik}}{A}(10{,}000) \qquad \text{(Eq-7)}$$

Where e_{ik}= total length (m) of edge in landscape involving patch type (class) i; includes landscape boundary and background segments involving class i. A = total landscape area (m^2).

5. Percentage of Landscape (PLAND): is the proportional abundance of each patch type in the landscape**.** It is a measure of landscape composition at class level and indicates the percentage of the corresponding class under study or each class in the landscape. PLAND is calculated as the sum of the areas (m2) of all patches of the focal class, divided by total landscape area (m2), multiplied by 100 (to convert to a percentage). The formula PLAND is:

$$PLAND(P_i) = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100) \qquad \text{(Eq-8)}$$

Where Pi = proportion of the landscape occupied by patch type (class) i, a_{ij} = area (m^2) of patchij. A = total landscape area (m^2). The result ranges between 0 and 100.

6. **Largest Patch Index (LPI):** is an indication of dominance. LPI quantifies the percentage of total landscape area comprised by the largest patch (Araya, 2009; Ramachandra, 2014). It is calculated as the area (m^2) of largest patch divided by the total landscape area multiplied by 100 (McGarigal, 2015). It ranges from 0 to 100 and approaches to 0 when the largest patch is small and to 100 when the entire landscape is comprised from a single patch. The formula to calculate LPI in FRAGSTATS is given by McGarigal (2015) as:

$$LPI = \frac{Max\ (a_{ij})}{A}(100) \qquad \text{(Eq-9)}$$

Where aij = area (m^2) of larges patch ij. A= total landscape area (m^2).

7. **Landscape shape Index (LSI):** is a standardized measure of total edge or edge density that adjusts for the size of the landscape. LSI equals ¼ (adjustment for raster cells) times the sum of the entire landscape boundary and all edge segments (m) within the landscape including the patch type in focus divided by the square root of the landscape area (m^2) including any internal boundary. LSI =1 when the landscape is comprised of a single square patch of the corresponding patch type (built up class) and increases when the shape of the landscape becomes irregular or as the edge length of the corresponding patch type increases in the landscape (Gezahegn Aweke, 2013). McGarigal (2015) given the formula LSI as follows:

$$LSI = \frac{.25 \sum_{j=1}^{n} e^{*}_{ik}}{\sqrt{A}}(10{,}000) \qquad \text{(Eq-10)}$$

Where e^{*}_{ik} = total length (m) of edge in landscape between patch types (classes) i and k; includes the entire landscape boundary and some or all background edge segments involving class i. A = total landscape area (m^2).

8. **Aggregation Index (AI):** is a measure of aggregation and disaggregation of patch types (class) within the landscape. It takes into account the like adjacencies of the same patch type, and not the adjacencies with another patch type. AI is calculated by the formula:

$$AI = \left[\frac{g_{ii}}{max\ g_{ii}}\right](100) \qquad \text{(Eq-11)}$$

Where g_{ii} = number of like adjacencies (joins) between pixels of patch type (class) i based on the single count method. $maxg_{ii}$ = maximum number of like adjacencies (joins) between pixels of patch type (class)i based on the single-count method. AI=0 when the class is maximally disaggregated i.e., no like adjacencies and increases when the patch type increasingly aggregates. It becomes 100 when the patch type is maximally aggregated into a single compact patch. Therefore, it is a good measure of compactness and sprawl of the built up patch types.

9. **Perimeter –Area Fractal Dimension at class level (PAFRAC)**: provides patch shape complexity index across varying patch size in the landscape. The value ranges between 1 and 2. Values greater than 1 indicate a departure from simple Euclidean geometry and increase in complexity of shape. PAFRAC approaches to 1 for shapes with simple perimeter such as

square and approaches to 2 for shapes which are highly convoluted i.e., it indicates fragmentation of patches (Gezagegn Aweke, 2013). It is calculated by FRAGSTATS as 2 divided by the slope of regression line obtained by regressing the logarithm of patch area (m^2) against the logarithm of patch perimeter (m) or as shown (Eq-12) (McGarigal, 2015; Torrens, 2008).

$$PAFRAC = \frac{2}{\frac{\left[ni \sum_{j=1}^{n} \ln P_i \times a_{ij}\right] - \left[\left(\sum_{j=1}^{n} \ln P_{ij}\right)\left(\sum_{j=1}^{n} \ln a_{ij}\right)\right]}{\left(ni \sum_{j-1}^{n} \ln P_{ij}^2\right) - \left(\sum_{j=1}^{n} \ln P_{ij}\right)^2}} \quad \text{(Eq-12)}$$

Where a_{ij} = area (m^2) of patch ij. p_{ij} = perimeter (m) of patch ij. n_i = number of patches in the landscape of patch type (class)i.

10. **Simpson's Diversity Index (SIDI):** is a spatial metric that measures the diversity of landscape. Its value represents the probability that any 2 pixel selected at random belong to a different classes (McGarigal, 2015). It is calculated in FRAGSTATS as 1 minus the sum of the proportional abundance (Pi) of each patch type squared. The formula to calculate SIDI is:

$$SIDI = 1 - \sum_{j=1}^{m} P_i^2 \quad \text{(Eq-13)}$$

Where Pi = proportion of the landscape occupied by patch type (class) i. The proportional abundance (Pi) is based on total landscape area. SIDI ranges between 0 and 1, i.e., SIDI = 0 when there is only 1 patch (i.e., no diversity) but SIDI approaches 1 as the number classes in the landscape increases and the distribution of area among patch types or classes becomes more equitable.

11. **Shannon's Evenness Index (SHEI):** is again spatial metric at landscape level and measures the even distribution of area among patch types or classes. It is calculated as minus the sum of the proportional abundance multiplied by the logarithm of the proportion of each class divided by the logarithm of number of classes (m) in the landscape. The formula given as:

$$SHEI = \frac{-\sum_{i=1}^{m}(P_i \times \ln P_i)}{\ln m} \quad \text{(Eq-14)}$$

Where Pi = proportion of the landscape occupied by class i, m = number of patch types (classes) present in the landscape.

The index ranges between 0 and 1 i.e., SHDI = 0 when the landscape contains only 1 patch (i.e., no diversity) and approaches 0 as the distribution of area among the different patch types becomes increasingly uneven (i.e., dominated by 1 type) and SHDI = 1 when distribution of area among patch types is perfectly even (McGarigal, 2015).

3.2.6.3 Parameterization

This refers to analysis parameters and input layer preparation to run FRAGSTATS in order to calculate spatial metric indices. This includes categorical map formatting and setting analysis parameters (sampling strategies and specifying neighbor rule to delineate patches). FRAGSTATS accepts several types of input image data formats, ESRI grid, ArcGIS raster grid, GeoTIFF grid (.tif), ERDAS Imagine grid (.img), SAGA GIS binary format grid (.sdat) and several others. For this study, classified maps with ERDAS Imagine grid (.img) formats used as an input. All input maps were integer grids i.e., each cell assigned an integer value corresponding to its class membership or patch type with the measurement units in meters. Regarding neighborhood rule, there are two options, the four cell and eight cell neighborhood rules to determine patch membership. The eight cell rule was selected because, two cells of the same class that are diagonally touching are considered as part of same patches. There are seven sampling option to calculate sub-landscapes but here as the study area is a single landscape, the no sampling option -the conventional approach was selected. In the analysis of edge length and edge density, there are three options to specify the percentage of the background- ‘None’, ‘All’ and ‘Partial’ and none was selected to exclude the background from calculation so that the measurement of these indices will not be exaggerated. All other settings were kept by the default and the desired metrics were selected using the check boxes from each tabbed page straightforward.

3.2.6.4 Calculation of spatial indices in FRAGSTATS

All the aforementioned indices on section 3.2.6.3 were calculated in FRAGSTATS at class and landscape level and applied to measure the composition and configuration of urban sprawl in the study area. The indices are calculated for all 1984, 1995, 2006 and 2016 generated land-use maps with the same parameterization and specification so that the comparison between time series results will be possible. Outputs of all indices from FRAGSTATS were compared against each other for each year to find out the changes in fragmentation, compactness and/or sprawl of the urban landscape in the study area and results presented in maps, tables and graphs at class and landscape level.

3.2.7 Statistical layer generation and Zonal Metrics analysis

This is conducted mainly to address and measure the direction and location of urban sprawl in the study area using ZonalMetrics Toolbox. ZonalMetrics toolbox is a new open source tool developed by Adamczyk and Tiede (2017) and written in python script to be added as toolbox in ArcGIS 10.2 or latest versions. It is such an important python tool with a specialized functionality for calculating spatial metrics at zonal level. The tool computes selected spatial metrics such Class Area (CA), Number of patches per class (NPC), Zone Area (ZA), Percentage of zone (PZ), Total Class Edge (TE), Edge Density (ED) and Diversity (SHDI) indices in the same way they are calculated in FRAGSTATS but here indices are calculated per class and per specified zones. The toolbox has the following 3 available utilities (Adamczyk, and Tiede, 2017): it accepts user-defined vector based categorical (polygon) layers for direct analysis; it provides landscape metrics designed to calculations within any user-defined zones for example regular gridded zones, administration zones, environmental zones, and last it provides functionalities to generate specific zone (pies, hexagons) to serve as statistical zones.

Therefore, two main layers are required as input for each tool to calculate zonal metrics in the toolbox**:** (1) **the input layer with categorical values** e.g. thematic maps generated from image classification and metrics are calculated only for selected classes (2) **the zonal layer** for which the metrics will be calculated. The user can generate hexagonal or pie statistical layers by using study area map layer as an input or can simply use the administrative zones. For this study, the pie statistical zones generated for the study area by using ZonalMetrics Toolbox are found to be appropriate to show the change at different time than the hexagonal zones as they radiate from the center of the study area as shown in Fig 3.6 (A). The pie zones divide the study area into 12 zones with equal size and width but different length due to the shape of the study area. These pie zones are applied to analyze the change in built up area at different times. A total of four pie statistical layers generated to calculate zonal metrics for each year 1984, 1995, 2006 and 2016. Some area and edge metrics are selected for zonal metrics analysis to show the sprawl of urban area in the study area and the amount of change is compared against each pie zones.

Zonal metrics are calculated independently using each zonal tool and the results are added automatically to the statistical layer as an attribute table. Selected zonal metrics are:

Class Area (CA): refers to area of the patches of the corresponding class within the zone.

Percentage of zone (PZ): Percentage of the area of the corresponding class in each zone.

Zone Area (ZA): refers to the area of the statistical zone to which landscape metrics are calculated.

Total Class Edge (TCE): Calculates Class Edge length (TCE) for edges of all patches of the selected classes aggregated within the statistical zone.

Edge Density (ED): the length of the edges within the statistical zone per unit area (ha).

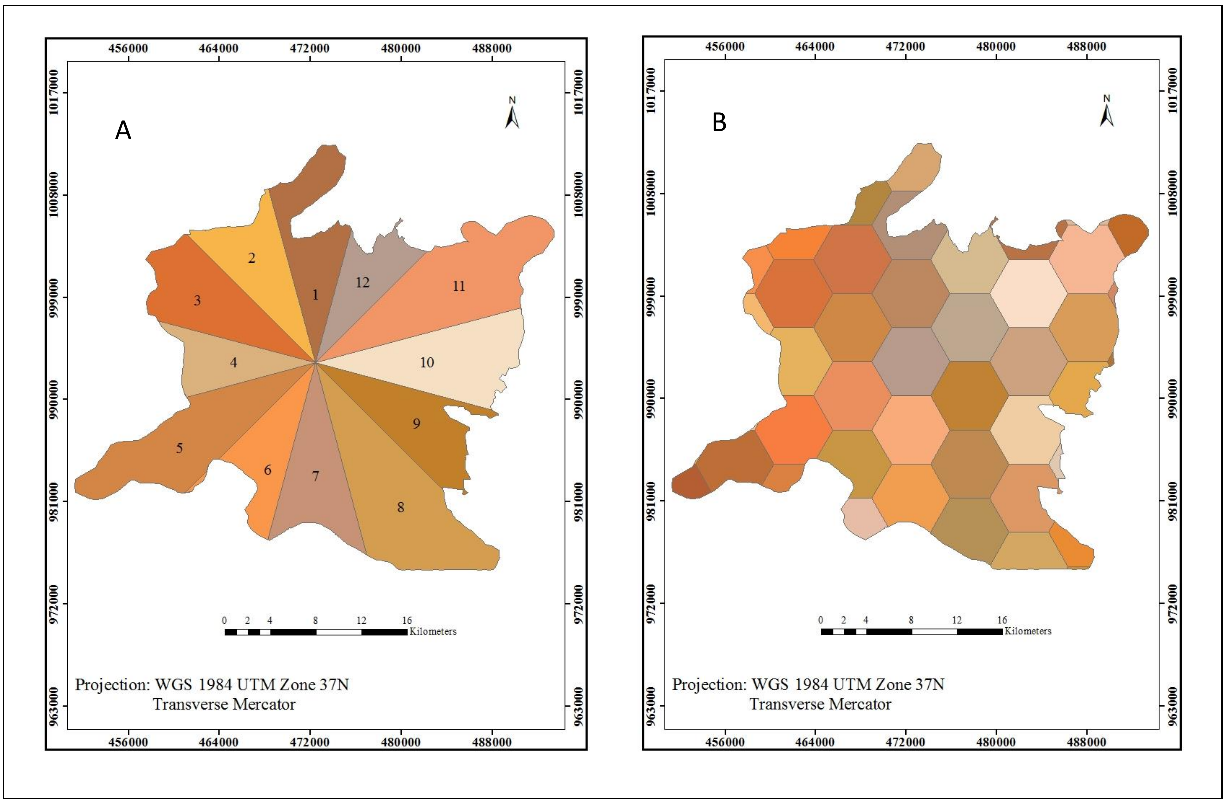


Fig 3.6 Pie (A) and Hexagonal (B) Statistical zones generated using ZonalMetrics Toolbox for the study area.

CHAPTER FOUR

4. Results and Discussion

4.1 Change detection

Land-use/cover maps were produced for the year 1984, 1995, 2006, and 2016 (Fig 4.1). These maps show built-up area with purple color shows built-up area, the light yellow is agricultural area, the light red color is barren land/open space, the green color shows green areas and finally the water body is represented in blue color. The change in areal coverage for each category from 1984 to 2016 is clearly visible on the maps. At the beginning in 1984, Addis Ababa city occupied only small area at the center of the study area and surrounding Oromia towns were almost non-existent. The result also shows that there was no much change in years between 1984 and 1995 but the city began to expand a little bit towards the south, east and west following road outlets. The growth of the city continued between the years 1995 and 2006 following the same direction but this time the surrounding Oromia towns particularly those to the west of Addis Ababa, Burayu and Sebeta also appeared to grow following the Ambo and Jimma road lines, respectively. The onset of growth seems to be around the year 2006 as the city and its surrounding towns grow dramatically after wards. As the map of 2016 (Fig 4.1) shows, the city has grown dramatically in all directions between the years 2006 and 2016. Built-up area increased a lot in the past 10 years- by a total area of 38,801.35 (ha) consuming a considerable amount of other land-use/cover types. On the other hand, other land-use types particularly agricultural areas decreased profoundly in 2016 than it was in the previous years, indicating its highest contribution to built-up areas.

The change in built-up area is also mapped (Fig 4.2**)** by visualizing all the classification results separately in single map to show the expansion of built-up area in each year. The change in each year is shown on the map with the light red color representing the built-up area for 1984, the yellow color for 1995, the green color represents the growth of built-up area in 2006 and the red color represents the profound expansion of built-up area in 2016. The map shows that the expansion of the city from 1984–2006 for about 20 years indicated in yellow and green colors is smaller than the expansion of the city from 2006 –2016 in the past 10 years. The expansion of built-up area in 2016 is very special in that it covered the study area wall to wall and increased by a large amount of land which indicates rapid and unprecedented urban growth of the city consuming the surrounding non-built-up areas. This type of urban growth is a typical urban sprawl increasing in all direction.

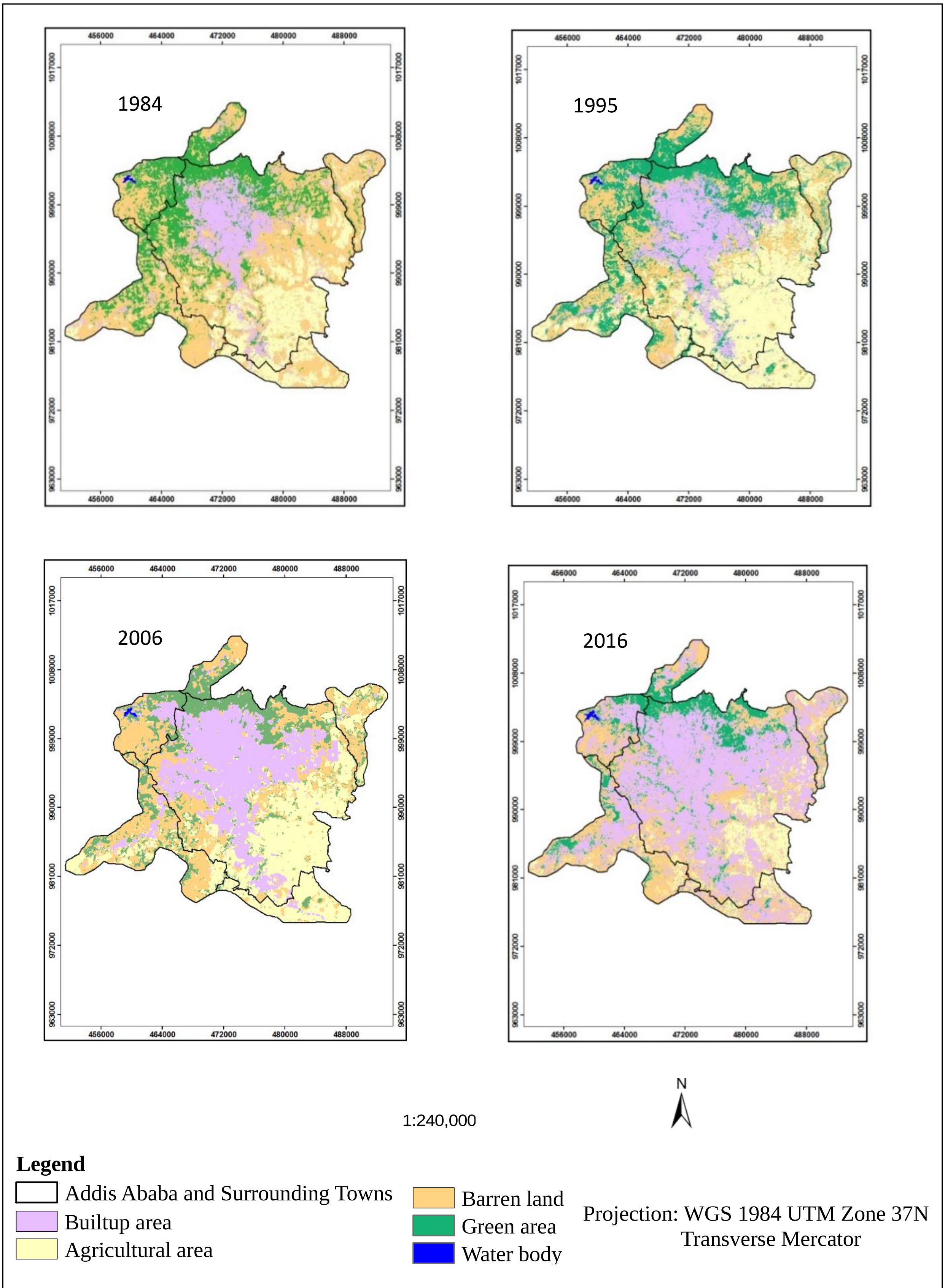


Fig 4.1 Land-use types of Addis Ababa city and surrounding towns from 1984–2016.

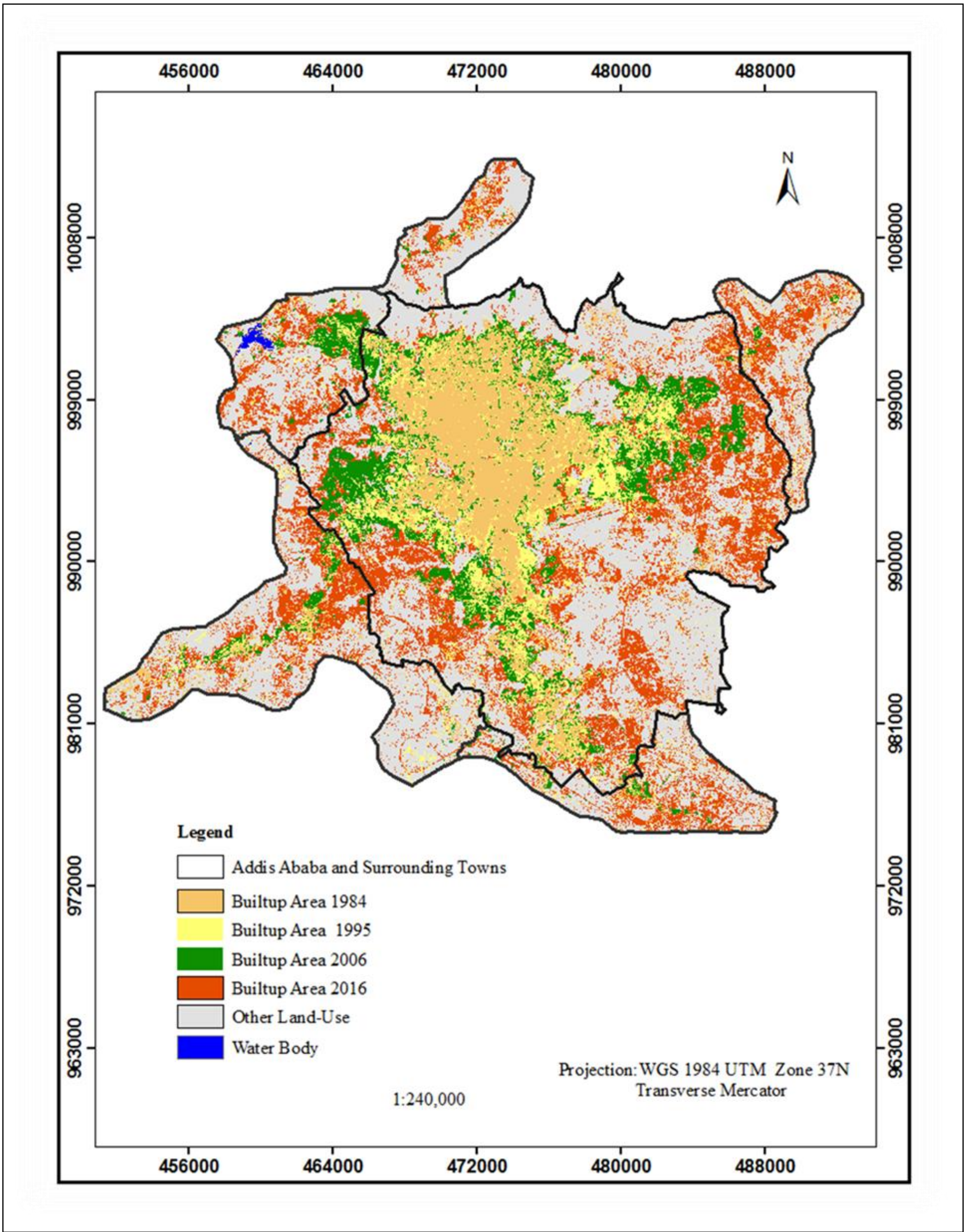


Fig 4.2 Overlaid built-up area of Addis Ababa city and surrounding towns from 1984–2016.

In addition to representing the change in maps, the total area (ha) covered by each category and its percentage in the landscape was also calculated in FRAGSTATS to quantify the amount of change (Table 4.1). FRAGSTATS calculates the total area of each category as Class Area (CA) in hectares and the percentage as Percentage of Landscape (PLAND) for each year. These are the two major spatial metrics that measure spatial composition of a categorical map at landscape level.

Table 4.1, Total amount of land in hectares for each category from 1984–2016.

Land-use	1984		1995		2006		2016	
	Area	%	Area	%	Area	%	Area	%
Built-up A.	12,218	14.94	15,981.58	19.55	22,513.29	27.53	38,801.35	47.46
Agri. Area	15,830	19.36	26,294.42	32.16	25,012.84	30.59	9,814.35	12
Barren Land	35,869.80	43.87	20,738.92	25.36	20,695.20	25.32	23,605.40	28.87
Green Area	17,769	21.73	18,664.71	22.83	13,459.74	16.46	9,422.91	11.52
Water Body	77.1	0.1	84.33	0.1	82.91	0.1	119.19	0.15
Total	**81,763.90**	**100**	**81,763.96**	**100**	**81,763.98**	**100**	**81,763.20**	**100**

It indicates that the total area of built-up class in the table increased steadily from 12, 218 hectares in 1984 to 38, 801.35 hectares in 2016 while the green area decreased in all years. The trend of other categories varies increasing and decreasing at various times. The barren Land was exceptionally higher at first in 1984 but decreased then after dramatically. This could be due to the presence of areas like hill sides and gully areas which area unsuitable for agricultural areas. However, this decreased in the later years showing the utilization of these areas for agricultural activity and its conversion into built-up areas. This is presented graphically so that the trend of all categories can be seen more clearly as shown in Fig 4.3 and 4.4 in line and bar graphs, respectively.

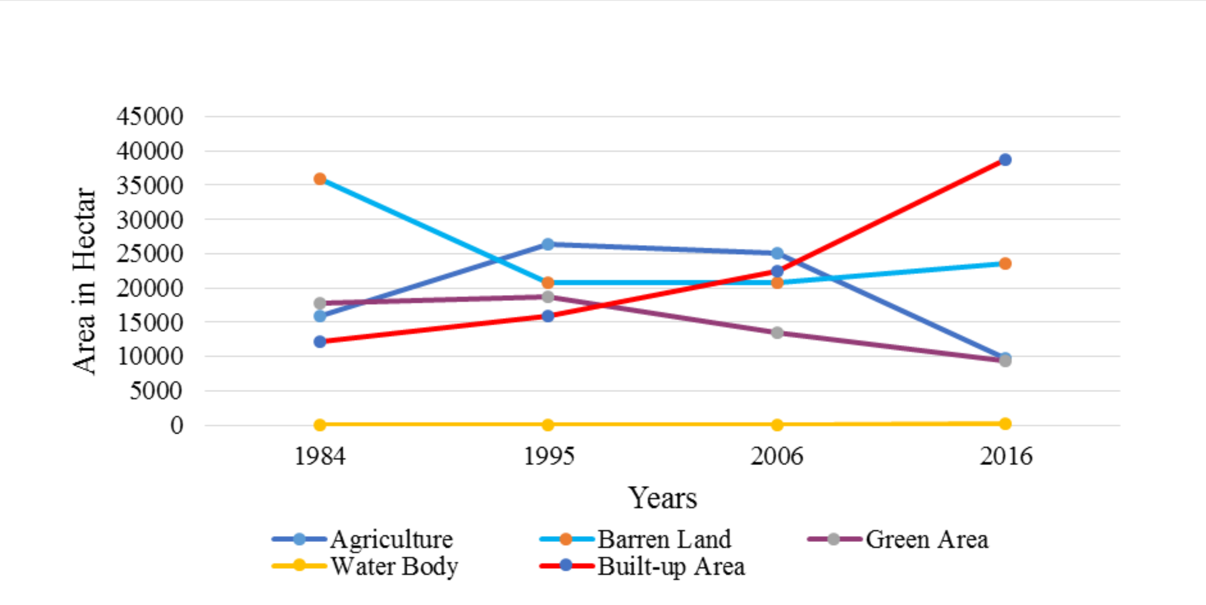


Fig 4.3 Graph of total area for all land-use types from 1984–2016.

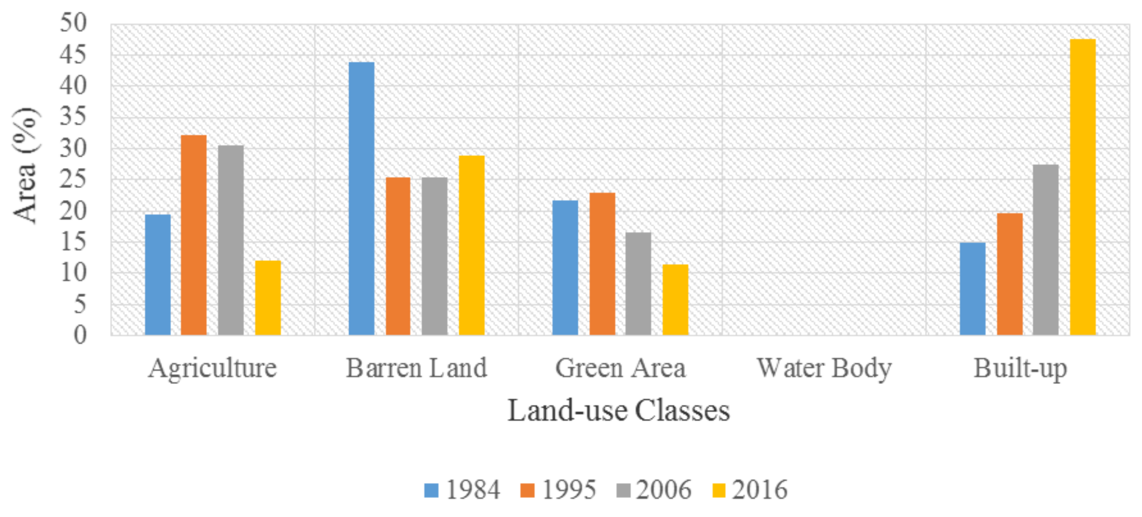


Fig 4.4 Percentage of each land-use types in the landscape from 1984–2016.

The change in percent, the amount of increase (positive) and/or decrease (negative) in each year was also computed. Table 4.2 shows the result of change in percent for each categories as calculated using equation Eq-4**.**

Table 4.2 Change in percent in time series analysis from 1984–2016.

Land-use	Change 1984–1995		Change 1995–2006		Change 2006–2016	
	Area (ha)	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**
Built-up Area	3,763.58	30.8	6,531.71	40.87	16,288.06	72.4
Agri. Area	10,464.42	66.1	-1,281.58	-0.57	-15,198.49	-61
Barren Land	-15,130.88	-42.2	-43.72	-0.21	2,910.2	14.1
Green Area	895.71	5.04	-5,204.97	-27.9	-4,036.83	-30
Water Body	7.23	9.38	-1.42	-1.68	36.28	43.8

The result indicates that built-up area increased 30.8% from 1984–1995, 40.87% from 1995–2006 and 72.35% from 2006–2016. Particularly, the major change took place in the past ten years indicating paramount expansion of the city and its surrounding areas. On the other hand, other categories mainly agricultural and green areas showed a major decrease except the first ten years at which both show some increase. This indicate that these two categories are the main contributors to the built-up area.

Even though there is no detailed spatial metric study made on Addis Ababa so far by other researchers to be compared by this study, individuals and organization try to comprehend the spatial expansion of the city at different times. However, most of the studies give figurative data but don't show the detailed methodology how the quantification is made. The total built-up area of Addis Ababa was estimated to be 10,838.0 (ha) from 1976–1985, 13,763.3 (ha) from 1986–1995and 14,672.7 (ha) from 1996–2000 (ORAAMP, 2001 as cited in Minwuyelet Melesse, 2005). On the other hand, Mesfin Tadesse (2009) applied similar methodology to quantify the built-up area of Addis Ababa from Landsat TM images with spatial resolution 30 (m) and found a total area of 7,801 (ha) and 11,646 (ha) for the years 1986 and 2000, respectively. When compared with the results of this study, the total built-up area of Addis Ababa was 12,218 in 1984, 15,981.6 in 1995, 22,513.3 in 2006 and 38,801.4 in 2016. The results of this study are relatively closer to the estimation of ORAAMP but the estimation of Mesfin Tadesse vary greatly particularly the estimation for the year 1986 is very low when compared with the results of ORAAMP and this study. There might be different reasons for the variation but one of the causes would be, Mesfin Tadesse used Landsat image with spatial resolution 30 (m) and this might affect the extraction of built-up area.

Dynamic change: this is the rate of change or rate of spatial expansion for built-up area in between two time periods. Time series analysis of land-use/cover change shows the dynamic degree of spatial structure in different periods. It is calculated using Eq-5.

Therefore, the dynamic change of built-up area between the years 1984 and 1995 is:

$$\mathrm{DC}\ (1984-1995)=\left(\frac{15981.58-12218}{12,218}\ \mathrm{x}\ \frac{1}{1995-1984}\right)100$$

DC = (0.027999)100 = **<u>2.80%</u>**

The dynamic change of built up area between 1995 and 2006 is again calculated as:

$$\mathrm{DC}\ (1995-2006)=\left(\frac{22{,}513.29-15981.58}{15981.58}\ \mathrm{x}\ \frac{1}{2006-1995}\right)100$$

DC= (0.03715)100 = **<u>3.72%</u>**

In the same way, the dynamic change of built up area between 2006 and 2016 is calculated as:

$$\mathrm{DC}\ (2006-2016)=\left(\frac{38{,}801.35-22{,}513.29}{22{,}513.29}\ \mathrm{x}\ \frac{1}{2016-2006}\right)100$$

DC = (0.0723486)100 = **<u>7.24%</u>**

This means that built-up area of Addis Ababa city together with the surrounding Oromia towns increases its spatial extent by 2.80% from 1984–1995, 3.72% from 1995–2006 and

7.24% from 2006–2016 per year. The dynamic change between 1984 and 1995 is lower than other periods. The rate of change for the two periods from 1995 to 2006 and 2006 to 2016 is among the highest and indicates that the trend of suburbanization is more and more increasing, particularly in the past ten years. It means that the land around the city is incorporated into urban areas and became much more valuable site for new housing and industrial centers.

The growth of Addis Ababa predicted by different organizations in the past few years. George Washington University (2014) is one of the institutions that indicated the population of Addis Ababa increased by 17% while its spatial extent grew by 51% from 2007–2014. However, as found out from this study, the period from 2006–2016 is the time in which the highest spatial expansion - about 72.4% of Addis Ababa is observed. RAUF Foundation (2010) predicted the annual growth rate of Addis Ababa for the years from 2006–2020 to be 3.4. But, the estimated growth rate is far less when compared with the observed growth rate of Addis Ababa city and its surrounding areas which is 7.24% per year from 2006–2016. The discrepancy might be due to the fact that the prediction is made based on the past trends and may not take the rapid expansion of the city from 2006–2016 into account. The present study is made by image sharpening to extract the built-up area. Therefore, it is relatively closer to the reality to show the trend of urban growth of the city.

4.2 Accuracy assessment

In order to calculate accuracy levels, an error matrix is constructed to show the discrepancy between classified categorical maps and their corresponding actual or reference maps for the selected locations (Lo and Yeung, 2005). The error matrix or confusion metrics is an array of values assigned to a particular category in the reference data and the classified map to be evaluated. The rows represent the categories of classified map while columns represent for the categories of reference data in the error matrix as shown in Tables 4.3–4.6. The values along the diagonal represent the number of correctly classified points or the number of points that agree with reference data. All non-zero values off the diagonal indicate disagreement of the classified map and reference data or misclassification of pixels, i.e. errors of commission and omission. Commission errors are wrong inclusions and indicate number of points whose pixels wrongly included to row categories but omission errors are wrongly excluded pixels from column categories. As such the elements in the error matrix are represented as Cij (the value in the ith row and jth column) and refers to the number of points assigned to category i of classified map while it actually belongs to category j.

Accuracy assessment reports from ERDAS Imagine for producer's accuracy, user's accuracy, overall accuracy and kappa statistics are discussed in detail next.

Producer's Accuracy: measures the percentage of correctly classified pixels and calculated by using Eq-1. The minimum producer's accuracy report for the study is found to be 88.10%, 85.90%, 87.50% and 74.14% for 1984, 1995, 2006 and 2016 classification results, respectively. The accuracy assessment for water category is exceptionally 100% in all accuracy assessment results for samples drawn from this category are very small and the area covered by water is easily differentiated during classification. The producer's accuracy for other categories ranges between 74.14% and 95.89% for all years which indicates that the classification performances were reliable and the results are acceptable. The producers accuracy for agricultural area category in the year 2016 is a little bit lower (74.14%). As found during field work, this is mainly because some of agricultural area samples were classified as barren land due to the similarity of pixels. This is also found to be the reason for the increase in in barren land in 2016 (Fig 4.4).

User's Accuracy: accuracy assessment evaluation results for user's accuracy range from 84.09% to 100% for 1984, 85.71% to 92.59% for 1995, 84.85% to 96.88% for 2006 and 83.33% to 96.77% for 2016 in all categories except water body which is 100% in all cases as stated before. Therefore, the results in both producer's and user's accuracy show that the performance of classification was performed very well and the error margins are within acceptable accuracy.

Overall Accuracy: the overall accuracy of the report for this study are 92.42%, 90.63%, 90.22% and 91.26% for 1984, 1995, 2006 and 2016 classified maps, respectively.

Table 4.3 Accuracy assessment results of 1984.

Classified Data	Reference Data Agri. Area	Barren Land	Green Area	Water Body	Built-up Area	**Row Total**	**Producer's Accuracy (%)**	**User's Accuracy (%)**
Agri. Area	50	0	0	0	0	**50**	90.91	100
Barren Land	3	111	4	0	0	**123**	95.69	90.24
Green Area	0	2	56	0	5	**58**	90.32	96.55
Water Body	0	0	0	2	0	**2**	100	100
Built-up Area	2	3	2	0	37	**44**	88.10	84.09
Column Total	**55**	**116**	**62**	**2**	**42**	**277**		

Table 4.4 Accuracy assessment results of 1995.

Classified Data	**Reference Data**					**Row Total**	Producer's Accuracy (%)	User's Accuracy (%)
	Agri. Area	Barren Land	Built-up Area	Water Body	Green Area			
Agri. Area	70	4	0	0	0	**74**	95.89	94.59
Barren Land	1	67	1	0	5	**74**	85.90	90.54
Built-up Area	2	4	36	0	0	**42**	92.31	85.71
Water Body	0	0	0	1	0	**1**	100.	100.00
Green Area	0	3	2	0	60	**65**	92.06	92.06
Column Total	**73**	**78**	**39**	**1**	**65**	**256**		

Table 4.5 Accuracy assessment results of 2006.

Classified Data	**Reference Data**					**Row Total**	**Producers Accuracy** (%)	**Users Accuracy** (%)
	Green Area	Agri. Area	Barren Land	Water Body	Built-up Area			
Green Area	19	0	2	0	0	**21**	90.48	90.48
Agri. Area	0	56	10	0	0	**66**	87.50	84.85
Barren Land	2	8	111	0	3	**124**	88.80	89.52
Water Body	0	0	0	1	0	**1**	100	100
Built-up Area	0	0	2	0	62	**64**	95.38	96.88
Column Total	**21**	**64**	**125**	**1**	**65**	**276**		

Overall Kappa Statistics: Kappa coefficient results are always less than 1 and results approaching to 1 indicate excellent agreement between the classified map and reference data. Overall kappa statistics results for the data was found to be 0.89 for 1984, 0.87 for 1995, 0.85 for 2006 and 0.86 for 2016 classification maps.

Table 4.6 Accuracy assessment results of 2016.

Classified Data	**Reference Data**					**Row Total**	**Producers Accuracy** (%)	**Users Accuracy** (%)
	Built-up Area	Agri. Area	Barren Land	Green Area	Water Body			
Built-up Area	180	1	4	1	0	**186**	97.30	96.77
Agri. Area	1	43	1	1	0	**48**	74.14	93.48
Barren Land	4	13	98	2	0	**115**	90.74	83.76
Green Area	0	1	5	30	0	**36**	88.24	83.33
Water Body	0	0	0	0	4	**4**	100	100
Column Total	**185**	**58**	**108**	**34**	**4**	**389**		

4.3 Urban sprawl measurement using spatial metrics method

This portion is the main body of the research work that intends to measure urban sprawl of the study area by calculating selected spatial metric indices from classified maps. Spatial metrics method is a new way of measuring urban sprawl from categorical maps. As discussed in previous portions of the thesis, four categorical maps were generated for different years and spatial metrics were calculated for each categorical maps in FRAGSTATS 4.2. FRAGSTATS is a powerful standalone program designed for spatial pattern analysis to quantify the composition and configuration of a landscapes under investigation (McGarigal, 2015). The software computes several spatial indices from categorical maps and gives out results in ASCII file formats that can be exported into excel for manageable conversion and utilization of the data. FRAGSTATS calculates distance metrics in meters and area metrics in hectares but the user can convert the outputs into the desired unites. Selected built-up area indices obtained after FRAGSTATS analysis (Table 4.7**)** and the results are analyzed in detail in the next portion. Spatial metrics in general whether patch, class or landscape fall into two main categories: those that measure composition and those that measure configuration of the categorical map (Meeli, 2013; McGarigal, 2015) or spatial and non-spatial (Rutledge, 2003) metrics. Therefore, the results of spatial indices obtained from FRAGSTATS are interpreted based on these categories.

Table 4.7 Class metric indices for built-up area from 1984–2016.

Years	**Class Metrics**							
	CA	**PLAND**	**NP**	**LPI**	**ED**	**LSI**	**PAFRAC**	**AI**
1984	12218	14.94	621	8.77	129.24	256.11	1.435	88.44
1995	15981.6	19.55	476	13.67	148.49	241.61	1.406	90.48
2006	22513.3	27.53	574	23.61	167.03	287.63	1.378	87.97
2016	38801.4	47.46	840	35.76	283.53	296.81	1.361	92.49

Spatial composition metrics are metrics that indicate the abundance of patch types in the landscape without referring to spatial characteristics of patches (McGarigal and Marks, 1995). They quantify the dominance and proportion of each patch type but not related with location and placement of patches in landscape. The most common and direct indices at class level that measure spatial composition include number of patch types, proportion of classes in the landscape and diversity indices (Gustafson, 1998; Meeli, 2013; McGarigal, 2015). From the selected metrics to measure urban sprawl in the study area, Class Area (CA) percentage of landscape (PLAND) and Number of Patches (NP) are under this category. The diversity measures selected for landscape indices i.e. Shannon's Diversity Index (SIDI) and Simpson's Evenness Index (SHIE) are also spatial composition metrics but are discussed at the end of this portion under landscape metrics.

Class Area (CA) and Percentage of landscape (PLAND) are direct measures of urban sprawl by showing the total built-up area and its percentage in the landscape. CA is discussed on section 4.1 of this chapter together with other categories but here is the focus is specific explanation for built area. CA shows how much built-up area comprised out of the total landscape in absolute terms for each year. The increase in total area is important indication of urban growth and expansion of the city. As shown in Fig 4.5 the total built-up area increased its dominancy from 12, 218 hectares in 1984 to 38, 801.4 hectares in 2016 in the landscape. On the other hand, the percentage or proportion of built-up area in the landscape from 1984–2016 has increased from about 15% in 1984 to 47.46% in 2016 which is about half of the total area.

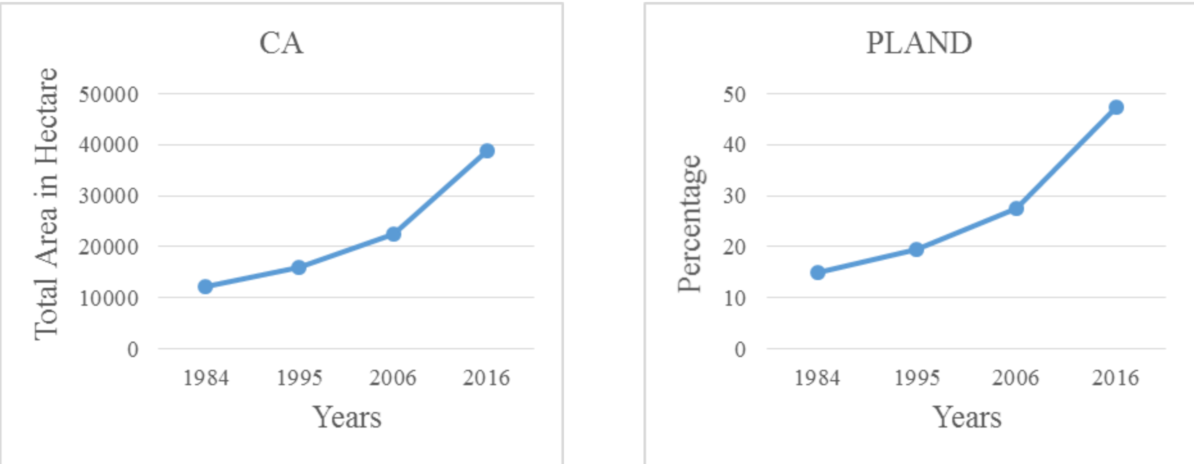


Fig 4.5 Total class area in hectare and its percentage (PLAND).

Number of Patches (NP) is another spatial composition metric that best describes urban sprawl and fragmentation of built-up area. NP simply refers to the number of individual urban patches and shows how the landscape particularly the built-up area subdivided into patches or smaller pieces. The results for Number of Patches after filtering by area were found to be 621 for 1984, 476 for 1995, 574 for 2006 and 840 for the year 2016. At first NP was 621 in 1984 but decreased to 476 in 1995 which shows that the merging of patches into the main built-up area in the later periods. It also shows that even though there was urban growth and spatial expansion between 1984 and 1995, the development in this period took place within the city or continuously adjacent to the main built-up area. However, from 1995 onwards, NP shows increasing trend with the highest increase 840 in 2016. This shows that urban sprawl and fragmentation was increasing in this period indicating detachment of new developments from the previously built-up areas in each consecutive years and urban sprawl was the highest in 2016.

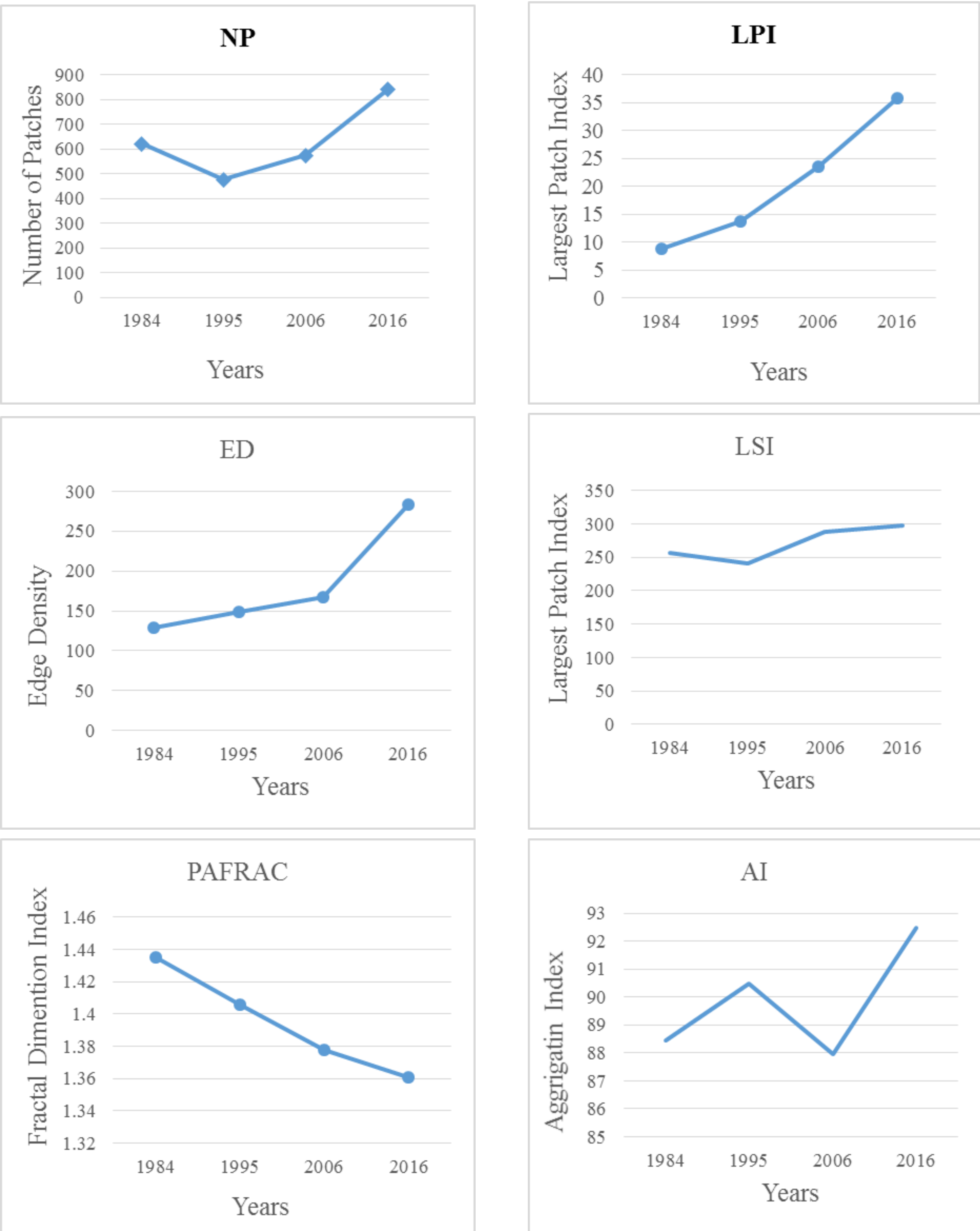


Fig 4.6 Spatial configuration metrics of built-up area from 1984 –2016.

Other metrics selected to measure urban sprawl are those that measure spatial configuration which includes Largest Patch Index (LPI), Edge Density (ED), Landscape Shape Index (LSI), Perimeter–Area Fractal Dimension at class level (PAFRAC) and Aggregation Index (AI). These metrics are selected at class level for this study and quantify spatial characteristic of the categorical maps to measure urban sprawl. The outputs from FRAGSTATS for all of these metrics are shown on Table 4.7.

Largest Patch Index (LPI) indicates percentage of the area covered by the largest patch of the focal class, built-up area in this case, in the landscape. LPI increased its dominancy from 8.77% in 1984 to about 35.76% in 2016 (Fig 4.6). It shows that the core area –city center, is growing by infill development and merging of patches to already developed built-up area forming more and more continuous urban agglomeration in the landscape. Growing trend of LPI pushes the city fringe and leads to suburbanization which agrees with the increasing number of patches specifically in the past ten years. When the 35.76% of LPI in 2016 compared with the percentage of built-up area (PLAND) 47.46 % (Fig 4.5**)** in the same year, LPI is almost close to the total built-up area which means the core area of Addis Ababa city and the surrounding towns formed a continuous greater urban agglomeration while there is highest fragmentation and spatial expansion of the city in the same year.

Edge Density(ED) is another spatial configuration metrics which describes the density of all edge segments (m) involving the built-up class per hectare. ED is proportional to the fragmentation of a landscape i.e. ED increases as a landscape subdivided into smaller patches. For this study ED increases steadily from 129.24 per hectare in 1984 to 283.53 per hectare in 2016 almost 120% increase which shows fragmentation of urban area. Increasing level of ED is one of the best spatial metrics that characterizes urban sprawl in a landscape under investigation. As shown in Fig 4.6 ED shows highest increase 2016, which coincides with the highest number of patches in the same year. As a result, the indices show the presence of highest urban sprawl in the study area.

Another metric that characterizes urban sprawl is Landscape Shape Index (LSI). LSI is a measure of perimeter-area ratio and interpreted as the overall shape complexity of a particular class in the landscape (McGarigal, 2015). LSI is a standardized measure of ED for it adjusts the size of the landscape. It approaches to 1 when the landscape of the intended class is nearly square or circle (compactness) and increases without limit when the edge length or shape of the class becomes more complex. For this study LSI varies from 241.61 in 1995 when number of patches are lower to 296.81 when the number of patches of the built-up area are the highest. The increase in LSI shows greater similarity with the number of patches (NP) and Edge Density (ED) in each year but the amount is much greater than one which indicates shape complexity and irregularity of built-up area in the landscape. This deviation from one and increasing amount of LSI is one of the spatial configuration metrics that shows the deviation from compactness and measures urban sprawl in the landscape.

Urban sprawl can also be quantified by a host of shape metrics but for this study Perimeter-Area Fractal Dimension (PAFRAC) is selected as an index for urban sprawl in the study area. PAFRAC is based on perimeter-area relationship and indicates how patch perimeter increases per unit of patch area. FRAGSTATS takes all the patches of the intended class and their perimeter area relationship to calculate the index. PAFRAC is an index of shape complexity and its value ranges between 1 and 2. The value of one refers to simple Euclidean geometries such as square and circle but Values that approach to two are for geometries with highest shape complexity. For this study, PAFRAC shows very small changes but declining trend in the past 3 decades with values 1.44 for 1984, 1.41 for 1995, 1.368 for 2006 and 1.36 for 2016. Though the values are declining, the results obtained from FRAGSTATS indicate highest shape complexity of built-up area in the landscape and this is an indication of highest sprawling.

The last spatial configuration index selected to quantify urban sprawl at class level is Aggregation Index (AI). Aggregation index shows the tendency of the category or built-up class to be spatially aggregated or clumped into a large group. The result of AI shows uniformly high aggregation ranging from 88.44% to 92.49% for the years 1984 to 2016 with small difference which means that even though other results show higher rate of urban sprawl and fragmentation, built-up area patches are found in larger group. Aggregation index is for the year 2006 shows exceptionally lower than previous year. This might be due to the effect of strip line removal on the image that may aggregate non-built-up area patches and disaggregate urban patches.

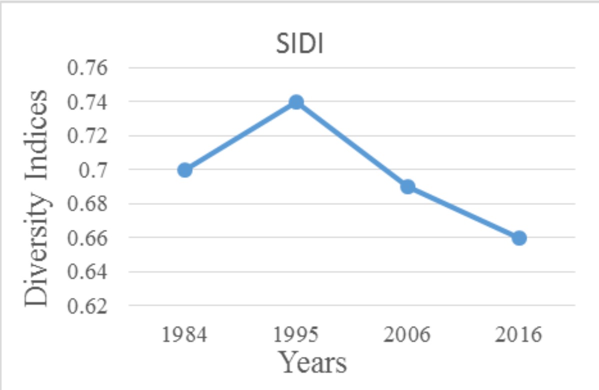
In addition to class metrics, two landscape metrics, Simpson's Diversity Index (SIDI) and Shannon's Evenness Index (SHEI) were selected to check the general structure of the landscape. Both of these indices are composition metrics that range between 0 and 1. Simpson's Diversity Index (SIDI) shows proportional distribution of area among classes and the probability that any two pixels selected randomly, become different patch type. SIDI results obtained from FRAGSTATS range between 0.66 in 2016 to 0.74 in 1955 which means the diversity index is higher in 1995 when all classes have closer proportion of area but decreases in 2016 when built-up area dominates the landscape. The other index, SHEI shows how even the distribution of area among class categories is. Hence, the maximum evenness

(SHEI = 1) is achieved when there is almost equal distribution among patch types. The results obtained for SHEI index are shown in Table 4.8 and the range is between 0.76 (2016) and 0.85 (1995). For both indices the result is a little bit higher for the year 1995 because there is no dominant patch type in this year and the distribution of area among classes is much closer than other years. The graph of both indices (Fig 4.7) indicate a similar shape but the amount is very different and SHEI index is higher than SIDI.

Table 4.8 Landscape Metrics.

Metrics	Indices of Years			
	1984	1995	2006	2016
SIDI	0.7	0.74	0.69	0.66
SHEI	0.81	0.85	0.79	0.76

Landscape metrics measure the pattern of the landscape in a defined boundary. These metrics measure the overall spatial composition and configuration of the landscape.



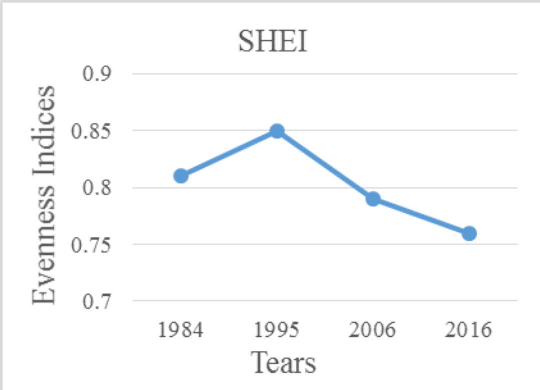


Fig 4.7 Simpson's diversity index and Shannon's evenness index.

4.4 Zonal metrics

Another important method applied for urban sprawl quantification is the use of zonal metric. Zonal metric analysis was conducted to answer the direction, location and amount of urban sprawl in Addis Ababa. This method is mainly applied to measure the spatio-temporal expansion of built-up area. The spatial dimension is addressed by dividing the study area into zones and quantifying direction, location and amount of urban sprawl in the landscape while the temporal aspect addresses the zonal variation through time series analysis of each zone. In order to measure urban sprawl in ZonalMetrics Tool, the categorical maps of each year were divided into 12 pie zones. Zonal metric analysis was conducted to calculate four major indices for built-up area namely, total Class Area (CA), percentage of built-up within each zone (PZ), Total Edge (TE) and Edge Density (ED) per zone for each year. Based on the results obtained, the changes in area, edge length and edge density were compared against each zone and for each focal year. The tool calculates area metrics in hectares and distance indices in meters e.g. Total Edge (TE) but the results for TE are converted into kilo meter and ED is calculated as total edge length (m) per hectare.

Table 4.9 Zonal built-up area and amount of change in hectares from 1984-2016.

	Built-up Area (ha) in Each Year				**Amount of Change (ha)**		
Zones	**1984**	**1995**	**2006**	**2016**	**1984-1995**	**1995-2006**	**2006-2016**
1	203.21	337.25	514.1	1476.16	134.04	176.85	962
2	365.09	354.88	471.09	1612.09	-10.21	116.21	1141
3	1353.59	1443.66	1817.93	1833.17	90.07	374.27	15.24
4	1804.58	2228.97	3207.66	3282.21	424.39	978.69	74.55
5	810.19	1239.44	1641.88	2634.76	429.25	402.44	992.88
6	639.07	822.37	1195.52	4047.08	183.3	373.15	2851.56
7	501.37	952.18	1859.18	2212.25	450.81	907	353.07
8	734.63	1145.66	1728.26	4436.77	411.03	582.6	2708.51
9	1390.15	1938.74	2423.61	5239.23	548.59	484.87	2815.62
10	1654.09	2276.64	3629.89	6155.15	622.55	1353.25	2525.26
11	551.56	834.81	1546.6	2902.06	283.25	711.79	1355.46
12	2065.01	2140.04	2567.75	2971.78	75.03	427.71	404.03

All the indices are computed as an attribute table of statistical layers generated for each year 1984, 1995, 2006 and 2016 but for simplicity, only total area and total edge length metric are mapped based on total built-up area and total edge length of patches.

Class Area (CA) calculated in each year is one the major indices that quantifies the amount of change or urban sprawl per zone. The amount of built-up area in 1984 serves as a base year or reference year to calculate the change in each zone. After running the tool, the total built-up area in each zone was obtained and amount of change in hectare is shown in Table 4.9. In addition, the total area from the attribute table of statistical layers in each year classified into 5 classes and mapped as shown in Fig 4.8. Thus, zones whose total area fall under the same class are represented by a similar color in the map. Even though the amount is different, at the first and second years of analysis i.e. 1984 and 1995, the distribution of CA per zone shows almost similar trend with minor changes. Zone 1 and 2 are classified into the lowest group of built-up area while zone 4, 10 and 12 are zones with the highest built-up area in both years. The result of 2006 showed somewhat a different distribution with zones 4 and 10, in the east west direction representing the highest built-up area. This coincides with the expansion of the city to Alem Bank and Betel area in the west and the Hayat housing project in the eastern part of the city during this period. The amount of CA for the majority of zones fall in the medium class from 1195.52 to 1859.18 while zone 1 and 2 still classified under the lowest class.

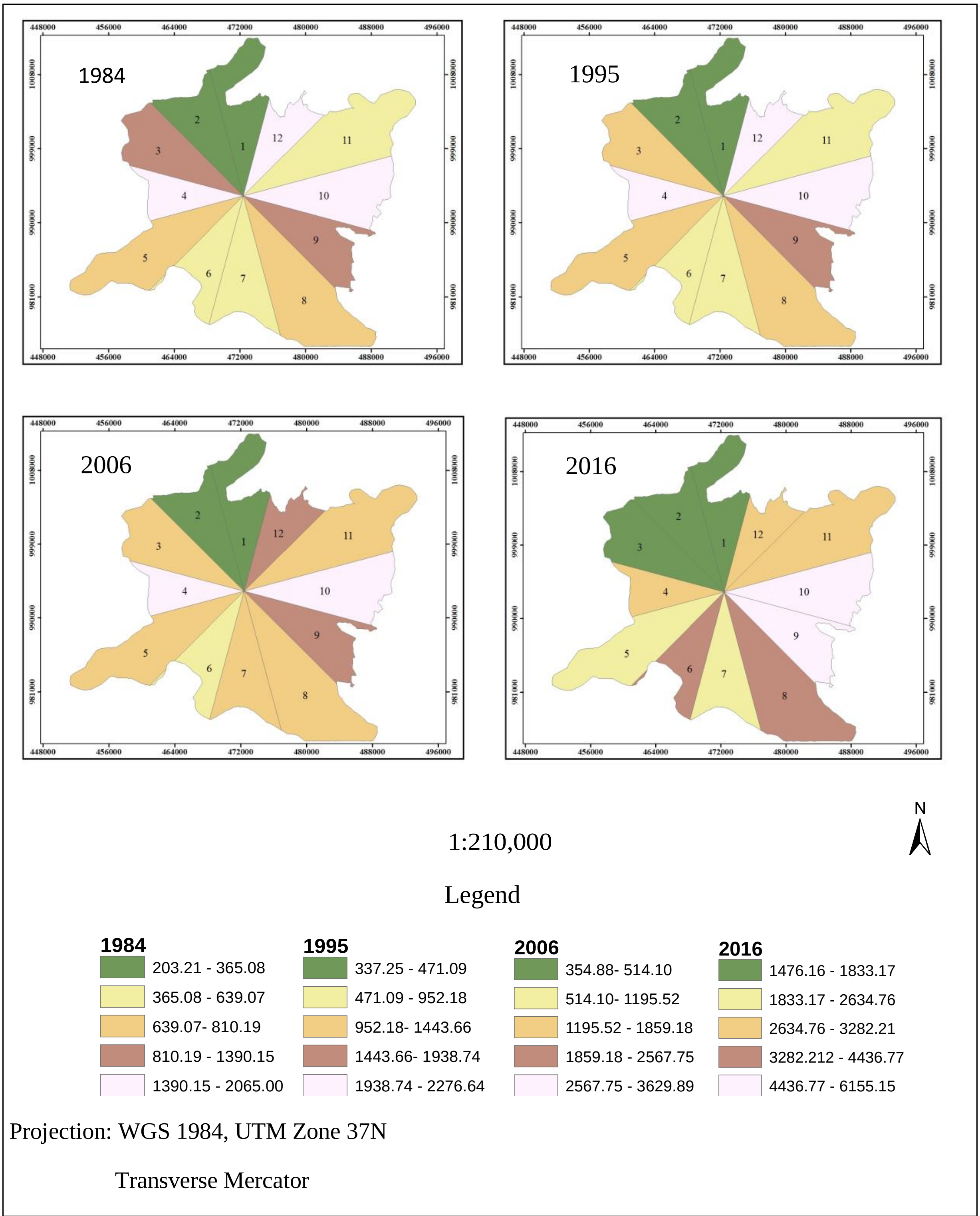


Fig 4.8 Map of built-up area (ha) per zone in each year.

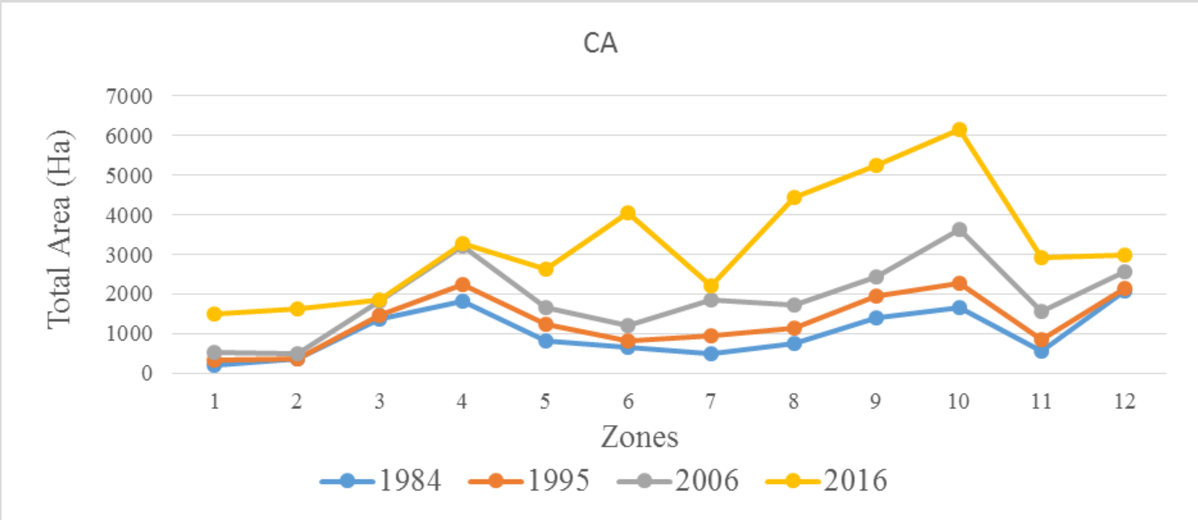
Finally, in 2016 zones with highest built-up area shifted to the eastern and southern direction but zones with lowest built-up area expanded in the northern direction indicating smaller expansion of developed area to the north due to the presence of Entoto hill.

Table 4.10 Percentage of total built-up area per zone from 1984–2016

Years	**Percent of Built-up Area Per Zone (PZ)**											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1984	3.4	6.5	19.8	47.5	9.2	14	8.3	6.5	22.6	20.7	5.1	50.10
1995	5.7	6.3	21.2	58.7	14.	18	15.7	10.2	31.5	28.5	7.8	51.95
2006	8.7	8.4	26.6	84.5	18.7	26.2	30.7	15.4	39.3	45.5	14.4	62.33
2016	24.	28.8	26.8	86.5	29.9	88.7	36.6	39.4	85	77.2	27	72.13

This can be represented graphically as shown in Fig 4.9 Class Area **(CA)** to indicate the growth of urban area in each zone. As the graph clearly shows, the increase of total built-up area in zones from 4–11 in the first two years, 1984 and 1995 show almost a similar pattern but the change for 2006 is a little bit higher and irregular with zone 4 and 10 having the highest CA value of 2228.97 (ha) and 2276.64 (ha), respectively. The total built-up area in 2016 shows a paramount increase in all zones except zone 3 and 4. The line graph of these two zones, remain stagnant in this period. (Fig 4.9**)** and coincides over the graph of 2006, which means there is no if not little urban expansion in this direction in 2016. The graph of CA for the year 2016, increases in other zones with the highest amount for zone 6, 8, 9 and 10 which means urban expansion in this period was towards south-west (Jemo area), south, south-east and east direction of the city. Similarly, the percentage of built-up area in zones (PZ) (Table 4.10 and Fig 4.9**)** also depicts similar pattern of expansion. Zonal metric tool automatically calculates PZ by dividing the total built-up area to the total zone area and multiplying by 100 to convert it to percentage. PZ describes the percentage comprised by built-up area in each zone over study periods. It shows how built-up area grew in each zone in the past 30 years.

Another important indicator of urban sprawl is the amount of built-up area added in each zone at every ten years period. This is calculated by simply subtracting the total built-up area in previous year from the total built-up area in recent year in each zone (Table 4.9**).** The graph in Fig 4.10 shows the total built-up area added to each zone in every ten year. In the first ten years, from 1984–1995, the highest change occurred in zones 7 to 10, while the lowest change occurred in zone 2, 12 and 3. The only exception is Zone 2 which shows a decrease (-10.21) hectares. It is unlikely to see a decrease in urban areas but this might happened due to various reasons change of pixels during classification or polygons might be merged to other categories during raster to polygon conversion. The second study period from 1995–2006 is represented by the red line, and zones which show the highest change are zone 4, 7 and 10 with values of total area 978.69, 907 and 1353.25 in hectares, respectively. This means that the expansion of urban area in this period was in the east, west and southern direction of the city.



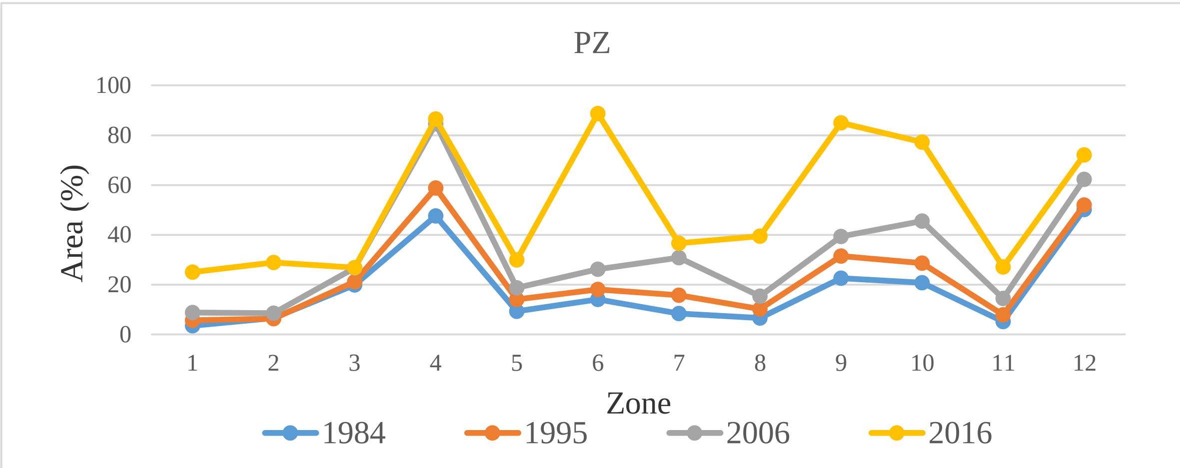


Fig 4.9 Class area and percent in zone of each zone 1984–2016.

The lowest increase from the previous ten years was shown in zone 1 and 2 that means the city expanded very small in the northern direction. Urban area grow by leaps and bounds in the last period from 2006–2016 with the maximum development taking place along zone 6, 8, 9 and 10. The major changes of sprawl occurred along zones 6, 8, 9, and 10 where urban area increased more than 2500 hectares in these zones with values of 2851.56 in zone 6, 2708.51 in zone 8, 2815.62 in zone 9 and 2525.26 in zone 10. As a result, huge expansion of Addis

Ababa city and its surrounding areas occurred along these zones. In this period the only small amount of built-up area added to zones 3, 4 and 7. Especially zone 7 which showed highest expansion in the previous ten year, it shows little addition this time which means that development activities shifted to other zones.

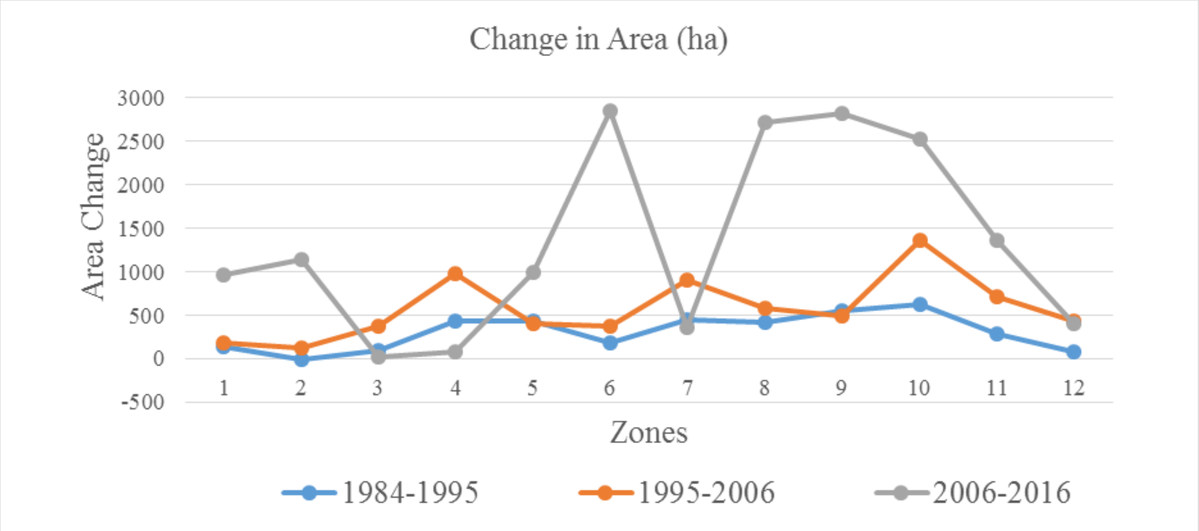


Fig 4.10 Amount of built-up area (ha) added to each zone every ten year.

Table 4.11 Total Edge (TE) length (m) and Edge Density (ED) per zone from 1984–2016.

Zones	Total Edge Length (km)				Edge Density (m/ha)			
	1984	**1995**	**2006**	**2016**	**1984**	**1995**	**2006**	**2016**
1	564.43	549.99	841.42	1063.6	95.52	93.07	142.39	179.99
2	611.84	667.56	755.43	913.54	109.34	119.3	135	163.25
3	414.98	624.09	1115	1567.53	60.78	91.41	163.62	229.6
4	474.97	541.5	698.53	973.43	125.18	142.71	184.1	256.55
5	967.95	1142	1529.1	2236.79	110.02	129.8	173.8	254.24
6	252.73	343.35	434.1	955.86	55.4	75.27	95.16	209.53
7	994.79	1126.5	1230.2	1536.05	164.55	186.34	203.49	254.08
8	1663.9	1820.3	2231.2	3352.57	148.03	161.94	198.5	298.26
9	564.56	624.79	737.96	1356.21	91.62	101.39	119.76	220.09
10	857.76	1004.2	1435.1	2050.96	107.56	125.92	179.96	257.19
11	1394	1333.6	2088.9	2551.61	129.8	124.18	194.52	237.61
12	506.71	513.29	570.52	842.94	122.99	124.59	138.48	204.6

Zonal Metric Tool not only calculates class area (CA) and percent of built-up area in zones (PZ), it also calculates a number of metrics including Total Edge (TE) and Edge Density

(ED) per zone. Total class area (CA) and its percentage per zone tells us only the expansion of urban area but total edge length and edge density are best indicators of the fragmentation of built-up area in the zone. Total Edge (TE) per statistical zone quantifies the total edge length of all patches that belong to built-up area within the zones. It is the aggregate length of boundaries of all patches within the statistical zones. ZonalMetrics Toolbox calculates TE in meter but the result converted into kilo meter (Table 4.11**)** for simplicity. TE is a direct result of the number of patches within the statistical zone. As the number of patches and fragmentation of built-up area within the zone increases, total edge length also increases. Hence, it indicates that zones with highest edge length are more fragmented and highly sprawled than zones with lower edge length in the landscape.

The results obtained show that total edge length per zone increase in all years which means sprawl is increasing through time. The highest increase in TE length is observed in all zone in the year 2016 and this depicts the expansion and fragmentation of the city in all direction. In all the three years 1984–2006, the lowest edge length is shown in zone 6 with values 252.73 km, 343.35 km and 434.1 km for the years 1984, 1995 and 2006, respectively while the highest edge length was observed in zone 8 with values 1663.9 km, 1820.3 km and 2231.2 km for the same respective years. It indicates that zone 6 is more compact while zone 8 is the most fragmented in all the three study years. In the same way, the total edge length in 2016 ranges between 842.94 km for zone 12 and 3352.57 km for zone 8.

The general distribution and spatial configuration of edge length in each year is mapped from the attribute table of statistical layers (Fig 4.11**)**. There is no standardized rule that characterize urban sprawl as high, low, moderate, etc. based on edge length, but increasing trend of edge length in time series analysis shows fragmentation of landscape into patches. Therefore, the classification is simply depending on the data itself and statistical zones are categorized into 5 classes based on total edge length with assigned colors representing the magnitude of edge length for each year. The highest values are represented by the pink and brown colors and the lowest values are represented by green colors on the map. The map on the year 1984 and 1995 shows, only zone 6 is represented on the lowest category of the data. However, as the pink and brown colors indicate, the highest edge length which in turn leads to the highest urban sprawl is towards south, east, south west and north east direction of the city on zones, 5, 7, 8, 10 and 11 along the main road outlets of the city. In fact, this is true for all maps and for all intents and purposes, these are the areas where the city expanded a lot in the past ten and twenty years.

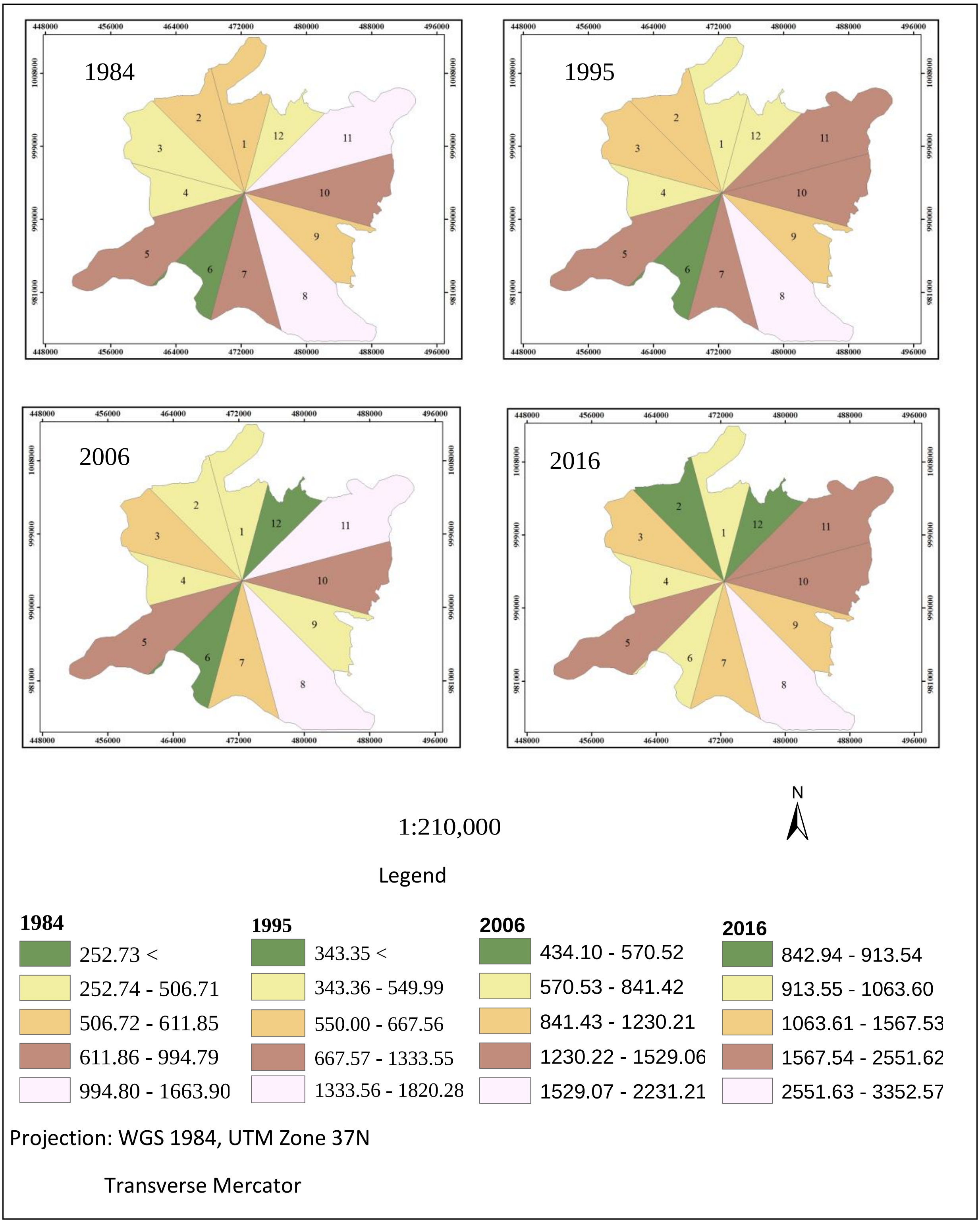


Fig 4.11 Map of total edge length per zone in each year.

In the year 2006, the lowest urban sprawl is on north east and southwest direction on zone 6 and 12. It indicates that there is less development activity in this area or else the new developments are adjacent to the main built-up area with less fragmentation. On the other hand, the highest edge length hence the highest urban sprawl is the same direction with previous years except that it concentrates only along zones 5, 7, 10 and 11. In the final study 2016, there is no change for direction, location and fragmentation of urban patches though the amount is very high at this time. The major change in the year 2016 is that the lower urban sprawl shifted totally to the northern direction on zones 1 and 12. It indicates that not only the spatial expansion of the city is lower in this direction but also fragmentation is also lower in this direction due to the presence of Entoto hill and Eucalyptus vegetation along this line. This can also be presented graphically as shown in Fig 4.12. The graph shows closer similarity with the map in Fig 4.11, indicating the increasing trend of edge length in all years across all statistical zones. The graph indicates the value of edge length at individual zone in absolute terms.

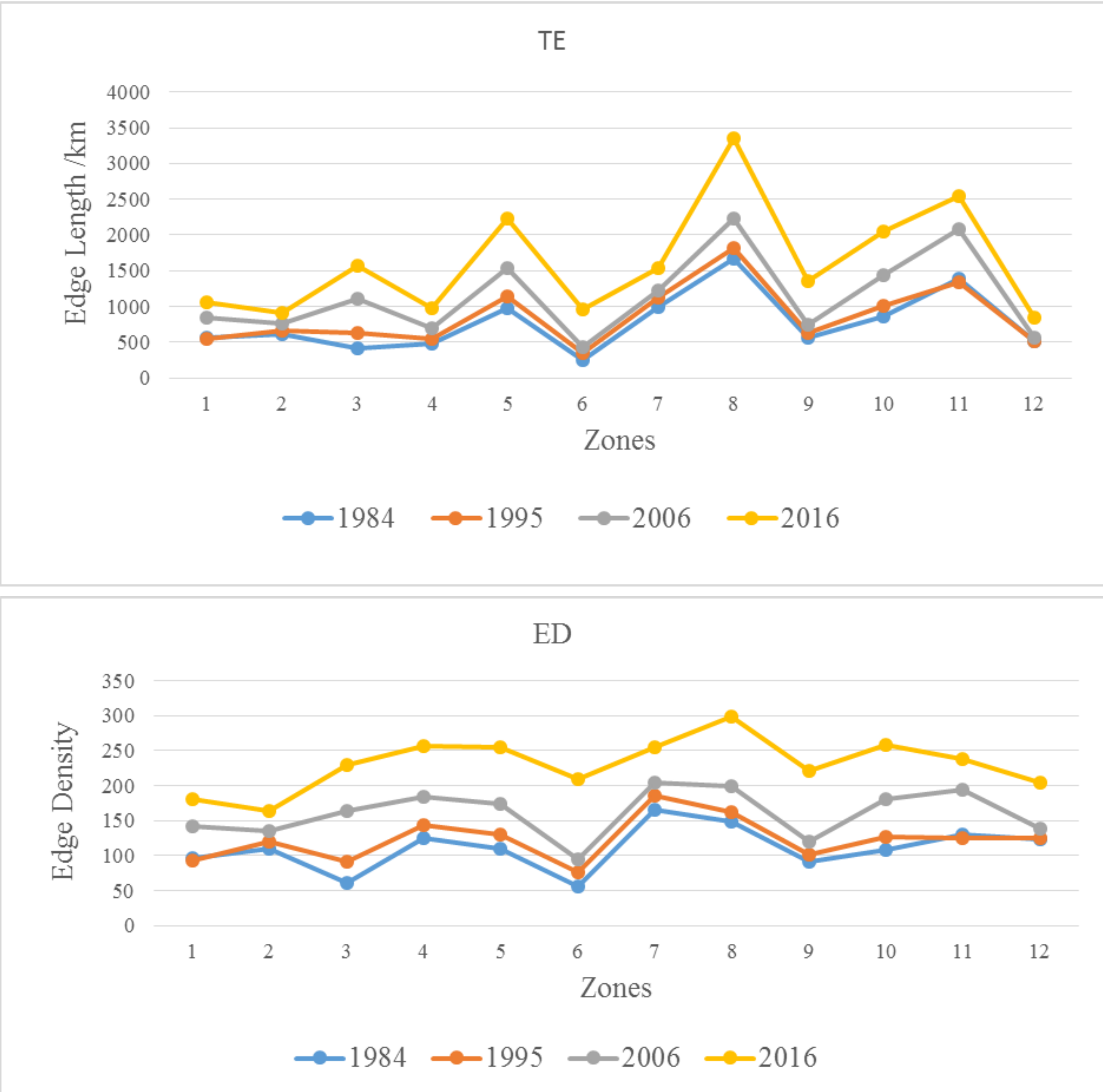


Fig 4.12 Total edge length and edge density per zone.

Edge Density (ED) per zone is another index that shows urban sprawl. Generally, ED is a function of total edge length and the total area of the zone. It is calculated in ZonalMetrics Toolbox as the total edge length (m) divided by the area of the zone, and described per a user defined extent of land i.e. 1, 100 or 1000, hectares. For this study ED is calculated edge length (m) per hectare. Therefore, ED quantifies the amount of edge length per hectare of land at individual year across all zones in the urban landscape. Like TE, ED has a similar relationship with fragmentation of a landscape, as the subdivision of a landscape into smaller patches increases ED also increases. As the graph in Fig 4.12 shows, ED for the years 1984 and 1995 is almost in a similar pattern with smaller increment per hectares in 1995.

However, the level of ED increased in most statistical zones in the year 2006 with the exception of zone 6 and 9 which have a lower ED value of 95.16 and 119.76 m per hectare (Fig 4.12**)**. The result in 2016 is very clear and bold that ED increased a lot and the line graph of 2016 appeared higher than previous years. The value of ED per statistical zone is greater than 200m per hectare except two zones i.e. zone 1 and 2. This indicates that urban sprawl and fragmentation of urban landscape occurred in all direction in the year 2016. The highest value of ED in most statistical zones in 2016, shows greater similarity with the values of CA and TE in 2016.

To summarize the location and directional expansion of the city in the year 2006 and 2016, zonal built-up area was mapped with sub-city and surrounding towns. Administratively, Addis Ababa is divided into 10 sub-cities: Arada, Gulele, Addis ketema, Kolfe keranyo, Chirkos, Lideta, Yeka, Bole, Nefas Silk Lafto and Akaki Kaliti. There are also five surrounding Oromia towns: Sululta, Burayu, Sebeta, Akaki and Legetafo-Legedadi areas.

The amount of built-up area in hectare categorized into five major classes (Fig 4.13 and Fig 4.14). The map shows the location of statistical zones and the distribution of built-up area in each zone. In 2006 (Fig 4.13), highest built-up area was found in zone 4 and 10 in the east-west direction. To the west, Zone 4 is located in Kolfe keranyo sub-city and the expansion of the city in this direction is associated with the growth of Alem Bank and Betel areas in this period. In the eastern direction, the zone with highest built-up area (Zone 10) is found in Bole sub-city associated with new developments in Hayat area. In 2016 (Fig 4.14), the highest built-up area as represented by the pink and brown colors shifted in eastern and southern directions along zones 6, 8, 9 and 10. The expansion in Zone 6 is towards Nefas Silk lafto sub-city associated with new developments in Jemo area at this time. In the southern direction, highest built-up area is found along zone 8 in Akaki Kaliti sub-city and Akaki area.

In the east, the major changes observed along zone 9 and 10 in Bole and Akaki Kaliti sub-cities indicating highest growth of the city. This is mainly due to the establishment of industries and condominium sites in these areas.

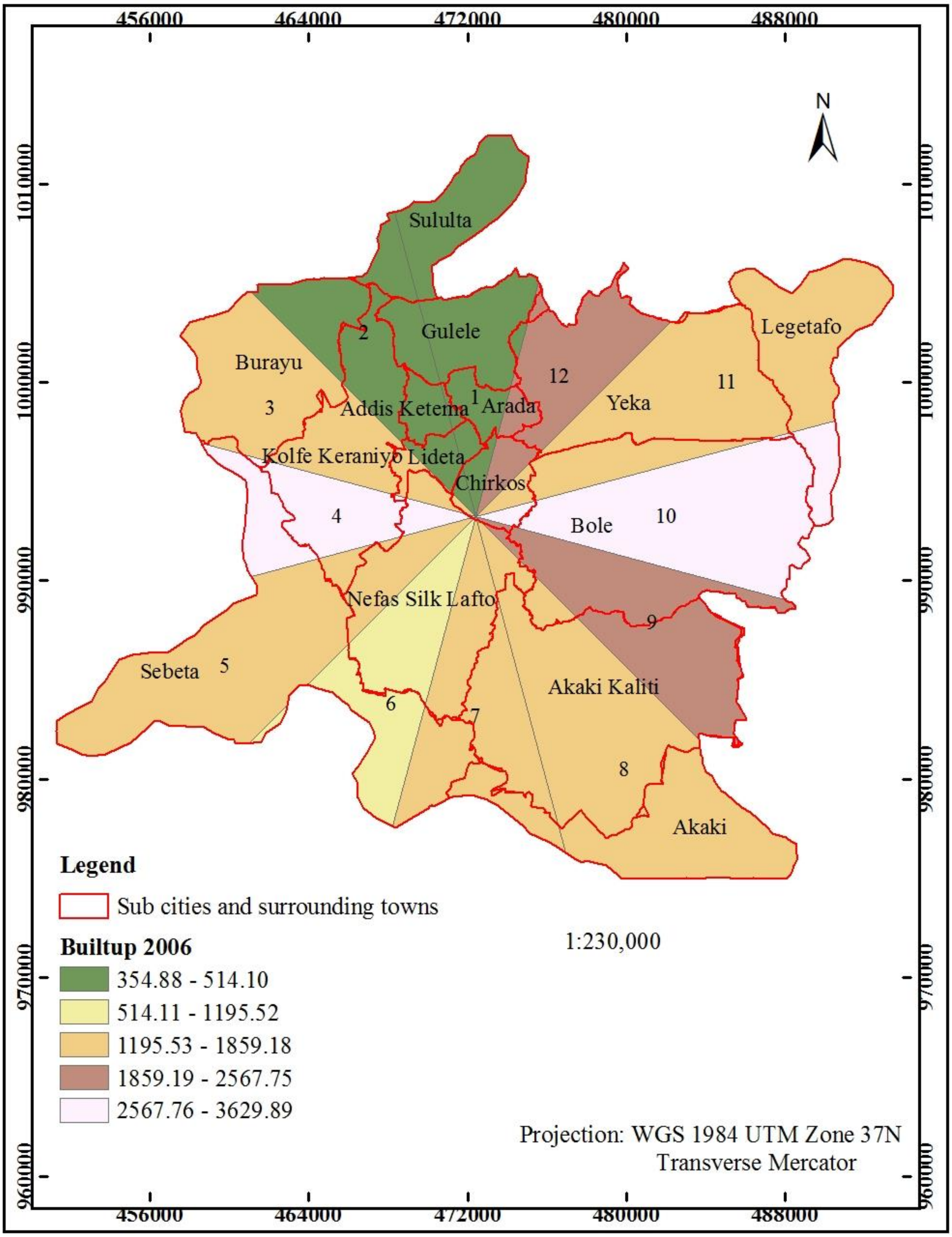


Fig 4.13 Zonal built-up area expansion with sub-cities and surrounding towns for 2006.

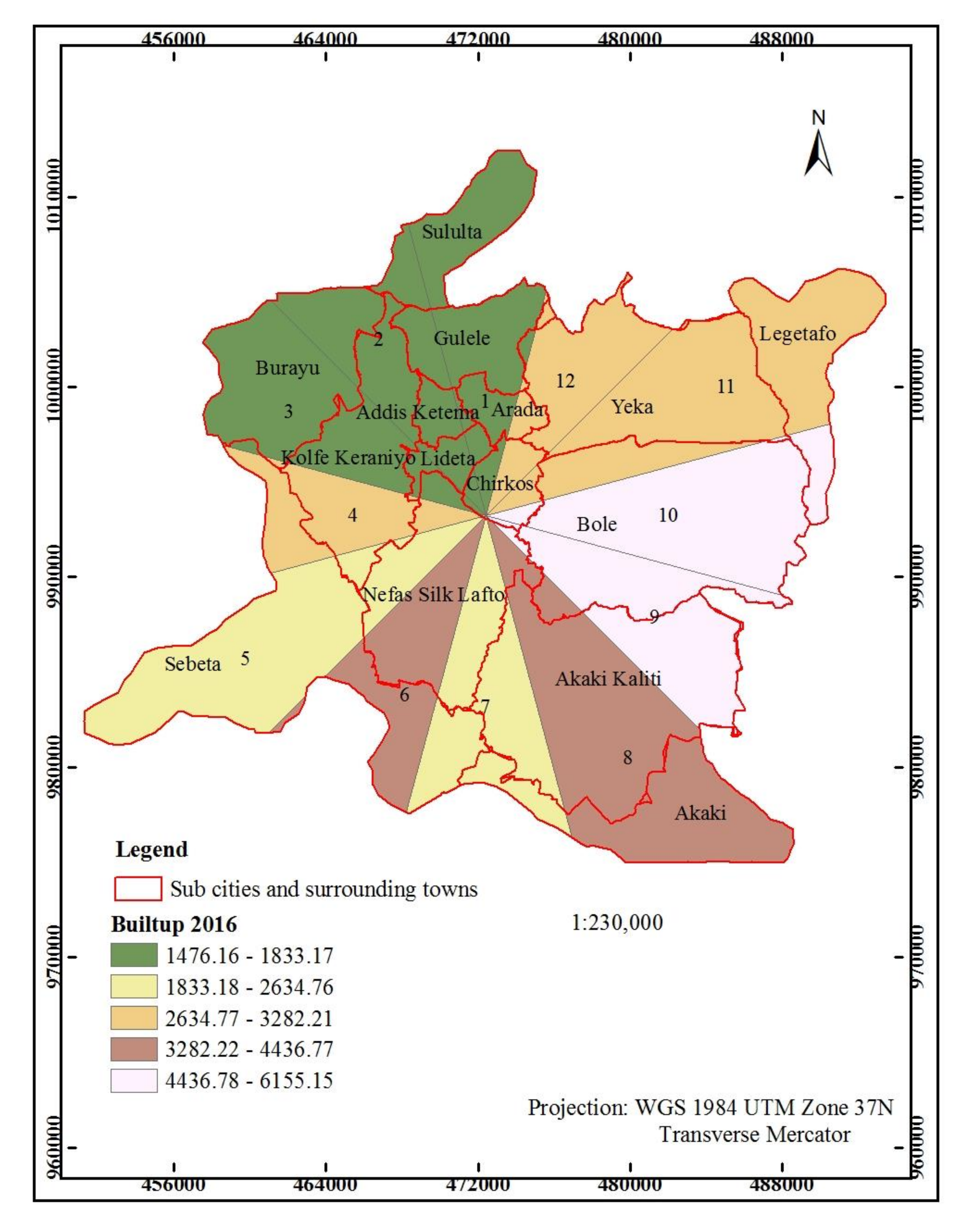


Fig 4.14 Zonal built-up area expansion with sub-cities and surrounding towns for 2016.

CHAPTER FIVE

5. Conclusion and Recommendations

5.1 Conclusion

The main objective of the study was to detect, assess and measure the spatial composition and configuration of urban sprawl in Addis Ababa city and its surrounding areas using spatial and zonal metrics indices. In order to meet the objective, four distinctive years- 1984, 1995, 2006 and 2016 were selected. Then, satellite images were acquired and processed to generate categorical maps that can serve as an input. The methodology applied involves three main phases. The first part was image preprocessing, classifying, and generating categorical maps. The second phases was selecting appropriate spatial metric indices, calculating indices, urban growth change detection and characterizing urban sprawl of the study area. The last phase was generation of zonal statistical layers and calculating area and edge metrics to quantify the location, amount and direction of urban sprawl at zonal level. In order to accomplish all the activities, GIS and remote sensing software programs together with other zonal and spatial metric tools were used in an integrated approach. The final results were summarized in three main themes change detection, spatial and zonal metrics.

Change Detection: post classification change detection analysis was conducted to map the lay of the urban environment in land-use/cover categories. As such four major land-use classes were selected and the area covered by each category was calculated for each study years. Built-up area or Class Area (CA) was calculated in hectare from categorical maps and the results were found to be 12,218 in 1984, 15,981.6 in 1995, 22,513.3 in 2006 and 38,801.4 in 2016. In other words, the percentage of built-up area (PLAND) comprised about 15%, 22.83%, 27.53% and 47.46% for the years 1984, 1995, 2006 and 2016 out of the total study area, respectively. The major contributors for the growth of urban area are agricultural and green areas which decreased 61% and 30% only from 2006–2016, respectively. Similarly, the barren land/open spaces also contributed a lot, though it waxes and wanes through time. This is a major important indication that Addis Ababa is growing on the expense of agricultural and green areas. Hence, we are kissing fertile agricultural area in the landscape for good. In addition to the spatial expansion of built-up area, the dynamic growth rate is **2.80%,** for 1984–1995, **3.72%,** for 1995–2006 and **7.24%** for 2006–2016 time periods. The growth is one of the highest in the world, and this indicate that the presence of rapid and unprecedented urban growth in Addis Ababa city, particularly true in the past ten years.

Spatial Metrics: selected spatial metrics indices show the presence of urban sprawl in Addis Ababa and its surrounding areas. In this respect Number of Patches (NP) are important indicators for subdivision of built-up area into pieces. The number of patches obtained from this study are 621, 476, 574 and 840 in 1984, 1995, 2006 and 2016, respectively. The increasing number of patches indicate that built-up area was sprawling increasingly except in the year 1995 that shows lower number of patches and merging of patches to the main built-up area. Largest Patch Index (LPI) in percentage also show a growing trend from 8.77% in 1984 to about 35.76% in 2016. This is a good indication that largest patch is growing more and more in size forming a continuous urban agglomeration at the city center. That is, while the number of patches increase at every year leading fragmentation of the fringe areas, the largest patch is growing bigger and bigger at the center.

Zonal Metrics: Class Area (CA) per zone at the first and second study periods 1984 and 1995 shows similar pattern but CA was the highest in three zones, 4, 10 and 12 with values 1804.58, 1654.09 and 2065.01 hectares for the year 1984 and 2228.97, 2276.64 and 2140.04 hectares for the year 1995 in respective order of zones. In 2006 the location of maximum built-up area increased in the east-west direction in zone 4 and 10 with values 3207.66 and 3629.89 hectare, respectively. CA was lowest to the north direction of the city in zone 1 and 2 in all study periods adding zone 3 in 2016. However, in 20016, urban expansion shifted completely to the east and south direction in zone 9 with value of 5239.23 hectares and zone 10 with value of 6155.15 hectares. This is the areas where the largest agricultural land is found in the landscape which means the city expansion is on the expense or loss of agricultural areas.

The result of Edge length in each study period show increasing trend in all zones. The lowest edge length is observed in zone 6 with values 252.73 km in 1984 and 343.35 km in 1995. Zones with the highest edge length are observed to the south, south west, north east and south direction of the city with zone 8 being the highest edge length in all study periods. This indicates that urban sprawl to the south along the outlet to Debre Zeyte road is the highest in all years as area is the location of most industrial establishments along the road. The results of Edge length in 2016, show a different pattern of distribution with zone 8 being the single highest edge length value of 3352.57 km and zone 5, 10 and 11 in the south west , east and north east direction being the second largest edge length of 2236.79 km, 2050.96 km and 2551.61 km, respectively. On the contrary, the lowest edge length is observed in the north directions in zones 1, 2 and 12 with values 1063.6 km, 913.54 km and 842.94 km, respectively. This indicates that urban sprawl in this direction is the lowest due to the presence of Entoto hill and the protected eucalyptus forest.

5.2 Recommendations

This portion is committed to the recommendation part of the paper. The deals with urban growth change detection, satellite image utilization, urban planning, and spatial metrics method.

- The results of the study show that, the pace of urban growth in Addis Ababa and surrounding Oromia towns is rapid, especially in the last ten years with a growth rate of 7.24%. This causes unprecedented, unplanned and rapid expansion of the city that will continue in the coming decades. Moreover, studies indicate that all the master plans formulated so far to guide urban development activities suffered from lack of proper implementation. Therefore, it is time for city planners to plan ahead and cope up with the pace of urban growth with proper implementation.
- It is also indicated that the city is sprawling in the east, north east, south and south west direction along the major road outlets and towards fertile agricultural areas with a quantified spatial expansion. As such a considerable amount of agricultural and green areas decreased in the past ten to twenty years. Therefore, in order to mitigate loss of agricultural areas and the impact of urban sprawl on urban ecology, city planners must look inside and vertically to accommodate infill development and ensure proportionate horizontal expansion of the city.
- The use of satellite images for urban growth change detection has been successful to show the spatio-temporal expansion of urban areas. Due to lack of high resolution data, the researcher made use of different satellite image fusion- SPOT-5 and Landsat images to get a better spatial resolution out of it and facilitate feature extraction. However, if availability of high resolution data source such as IKONOS and QuickBird is possible, future studies can also be made based on these images to get spatial metric indices less than 5m resolution.
- Like in other parts of the world, the application of spatial and zonal metric method successfully quantified urban sprawl by calculating number of patches, ED, LPI, LSI, AI and other landscape metrics. It is also possible to conduct researches to find out the major driving forces of urban sprawl in an independent research using different methodology.

REFERENCES

Angel S, Parent J., Civco, D. L., and Blei A. M. (2011). *Making Room for a Planet of Cities*. Policy Focus Report, Lincoln Institute of Land Policy, Cambridge, USA 72 pp.

Anderson A. R., Hardy E. E., Roach J. T. and Witmer R. E. (1976). *A Land Use and Land Cover Classification System for Use with Remote Sensor Data, A Revision of the Land Use Classification System As Presented in U.S. Geological Survey Circular 671*. United States Government Printing Office, Washington. 41 pp.

Antos, S. E., Lall, S. V. and Gracia, N. L. (2016). The Morphology of African Cities. Social, Urban, Rural and Resilience Global Practice Group, World Bank, 51 pp.

Batty, M. (2004). What Is Urban Sprawl? Concepts and Perceptions, Final Seminar of the SCATTER Project Brussels.

Baudot, Y. (2005). Geographical Analysis of the Population of Fast-Growing Cities in the Third World. *Taylor and Francis*, *GISDATA* **9:** 208–224.

Besussi, E., Chin, N., Batty, M. and Longley, P. (2010). *The Structure and Form of Urban Settlements*. London, 30 pp.

Bowyer, D. (2015). Measuring urban growth, urban form and accessibility as indicators of urban sprawl in Hamilton, New Zealand. Lund University, Sweden.

Buettner, T. (2014). Urban estimates and projections at the United Nations: the strengths, weaknesses, and underpinnings of the world urbanization prospects. *Spatial Demography* **2:2** 2164–7070.

Cabral, P., Augusto, G., Tewolde, M. and Araya, Y. (2013). Entropy in urban systems. *Entropy*, **15:** 5223-5236.

Caicedo, J. F. (2015). *Growing or filling the city? Taking the debate on densification South. Is the densification approach an appropriate urban development policy for Latin-American cities? A Colombian case study*. Bogota, Colombia 75 pp.

Cheng, J. (2003). *Modelling Spatial & Temporal Urban Growth*. Febodruk BV, Enschede, the Netherlands, 214 pp.

Conway, D., Mould, C. and Woldeamlak Bewket (2004). Over one century of rainfall and temperature observations in Addis Ababa, Ethiopia. *International journal of climatology*, **24:** 77–91.

Central Statistical Agency (CSA) (2013). *Population Projection for Ethiopia* 2007–2037. Addis Ababa, 173 pp.

Demographia (2016). *World Urban Areas (Built-Up Urban Areas or Urban Agglomerations) 12th Annual Edition*, 112 pp.

Ding, L., Hwang, J. and Divringi, E. (2016). *Gentrification and Residential Mobility in Philadelphia.* Federal Reserve Bank of Philadelphia, Philadelphia 50 pp.

Eastman, J. R. (2003). *IDRISI Kilimanjaro Guide to GIS and Image Processing*. Clark University Worcester, MA, USA, 306 pp.

European Environment Agency, (EEA) (2006). *Urban Sprawl in Europe the Ignored Challenge*. Copenhagen, Luxembourg, 60 pp.

European Union Regional Policy (EU) (2011). *Cities of tomorrow challenges, visions, ways forward*, 116 pp.

Ewing, R. and Hamidi, S. (2014). *Measuring Sprawl*. Smart Growth America, University of Utah, 46 pp.

Ewing, R. Pendall, R. and Chen, D. (2002). *Measuring Sprawl and its Impact*. University of Utah 55 pp.

Freire, M. E. Lall, S. and Leipziger D. (2014). *Africa's Urbanization: Challenges and Opportunities, the Growth Dialogue*. Washington DC, USA, 44 pp.

Frey, W. H. and Zimmer, Z. (1998). *Defining the City and Level of Urbanization*. Population studies center (PSC) University of Michigan. , 41 pp.

Gao, J. (2002). Integration of GPS with remote sensing and GIS: Reality and prospect. *Photogrammetric Engineering & Remote Sensing*, **68:5** 447–453.

Galster G., Hanson R., Ratcliffe M., Wolman H., Coleman S. and Freihage J. (2001). Wrestling Sprawl to the Ground: Defining and Measuring an Elusive Concept. *Housing Policy Debate*, **12:4** 681–717.

George Washington University (2014). *Addis Ababa Spatial Determinants of Growth*. Elliott School of International Affairs, 50 pp.

Gezahegn Aweke Abebe, (2013). *Quantifying Urban Growth Pattern in Developing Countries Using Remote Sensing and Spatial Metrics: A Case Study in Kampala, Uganda*. Enschede, 108 pp.

Gilbrook, M. J. (2014). *Using Land Cover Mapping and Landscape Metrics to Evaluate Effects of Urban Development on Ecological Integrity in Florida.* University of Central Florida Orlando, 295 pp.

Gillanders, S. N. (2009). *Multitemporal Remote Sensing of Landscape Pattern Dynamics Resulting from Mountain Pine Beetle Infestation and Timber Harvest*. The University of British Columbia, Vancouver, Canada. 129 pp.

Gurin, D. (2003). *Understanding Sprawl a Citizen's Guide*. The David Suzuki Foundation. Vancouver, Canada, 29 pp.

Handy, S., Paterson, R., Song, J. Rajamani, J., Jung, J., Bhat, C. and Kockelman, K. (2003). *Techniques for Mitigating Urban Sprawl: Goals, Characteristics, and Suitability Factors*. University of Texas, Austin, USA, 120 pp.

Jat, M. K., Garg, P. K and Khare, D. (2008). Monitoring and modelling of urban sprawl using remote sensing and GIS techniques. *International Journal of Applied Earth Observation and Geo-information*, **10:** 26–43.

John Hopkins University (2006). Urbanization measurement and trends, module 9A, 48 pp.

Knaap, G., Song, Y., Ewing, R. and Clifton, K. (2005). *Seeing the Elephant: Multi-Disciplinary Measures of Urban Sprawl*, Maryland, USA, 46 pp.

Kupfer, J. A. (2012). Landscape ecology and biogeography: Rethinking landscape metrics in a post-FRAGSTATS landscape, progress in physical geography. *University of South Carolina*, USA, **36:3** 400–420.

Laurent, E. (2006). *Methods for Generating Patch and Landscape Metrics*. Biodiversity and Spatial Information Center. North Carolina State University, St Louis, 35 pp.

Levin, N. (1999). *Fundamentals of Remote Sensing*. Tel Aviv University, Tel Aviv, 225 pp.

Levy, D. K., Comey, J. and Padilla, S. (2006). *In The Face of Gentrification: Case Studies of Local Efforts to Mitigate Displacement.* The Urban Institute, Washington, DC, USA. 100 pp.

Li, F. (2012). *Investigation of Urban Sprawl on The Basis Of Remote Sensing Data---A Case Study in Jiangning*. Nanjing City, 125 pp.

Lo, L. P. and Yeung, K. W. (2005). *Concepts and Techniques of Geographic Information System*. Prentice-Hall of India Private Limited, New Delhi, 492 pp.

Lu D., Mausel P., Brondizio, E. and E. Moran, E., (2004). Change detection techniques. *Int. J. Remote Sensing*, **25:12** 2365–2407.

Maclean, M. G. and Congalton, R. G. (2013). PolyFrag: a vector based program for computing landscape metrics. *GIScience & Remote Sensing*, **50:6** 591–603.

Marcus, H. G. (1994). *A History of Ethiopia*. University of California Press, Los Angeles · Oxford, 163pp.

Mason J. P. (1989). The role of urbanization in national development: bridging the rural-urban divide, U.S. Agency for International Development, USA, 58 pp.

Mathema, S. (2013). *Gentrification an Updated Literature Review*. Poverty & Race Research Action Council, Washington DC, 38 pp.

McGarigal, K. (2015). *Fragstats Help*. University of Massachusetts, Amherst, USA, 182 pp.

McGarigal, K. and Marks, B. J. (1994). *FRAGSTATS Spatial Pattern Analysis Program for Quantifying Landscape Structure*. Forest Science Department, Oregon State University, Corvallis 134 pp.

Meeli, R. (2013). *GIS Assessing Traditional And Modern Agricultural Land Use/Land Cover Change: A Case Study 1959-2005: Rekijoki, Somero*. University of Turku, SW-Finland 100 pp.

Megahed, Y., Cabral, P., Silva J. and Caetano, M. (2015). Land cover mapping analysis and urban growth modelling using remote sensing techniques in Greater Cairo Region, Egypt. *ISPRS Int*. *J. Geo-Inf*. 2015, **4:** 1750–1769.

Melesse, A. M., Weng, Q., Thenkabail, P. S. and Senay G. B. (2007). Remote sensing sensors and applications in environmental resources mapping and modelling. *Sensors*, **7:** 3209–3241.

Mesfin Tadesse Bekalo (2009). *Spatial Metrics and Landsat Data for Urban Land-Use Change Detection in Addis Ababa, Ethiopia*. Universitat Jaume I, Castellon, Spain, 89 pp.

Mikyas Tesfaye Aragaw (2011). Urban open space use in Addis Ababa: the case of Meskel square. Addis Ababa University, 55 pp.

Minwuyelet Melesse (2005). City Expansion, Squatter Settlements and Policy Implications in Addis Ababa: The Case of Kolfe Keranio Sub-City Working Papers on Population and Land Use Change in Central Ethiopia. Addis Ababa University, 29 pp.

Moir, E., Moonen, T. and Clark, G. (2014b). What are future cities? Origins, meanings and uses. Government Office for Science, London, UK, 100 pp.

Mulu Eshete (2015*). Public Transportation System: the Case of Addis Ababa*. Addis Ababa University, 117 pp.

Mundia, C. N & Murayama, Y. (2013). Modeling spatial processes of urban growth in African Cities: A case study of Nairobi City. *Urban Geography*, **31:2** 259–272.

Ofem, B. I. (2012). A review of the criteria for defining urban areas in Nigeria. *J Hum Ecol*. **37:3** 167–171.

Ramachandra, T.V., Bharath, H. A. and Sowmyashree, M. V. (2014). *Analysis of Spatial Patterns of Urbanization Using Geo-informatics and Spatial Metrics*. Indian Institute of Science. Bangalore, Karnataka, 50 pp.

Reis, J. P. Silva, E. A. & Pinho, P. (2015). Spatial metrics to study urban patterns in growing and shrinking cities. *Urban Geography*, 1938–2847.

RUAF Foundation (2010). *The Growth of Cities in East-Africa: Consequences for Urban Food Supply*. Leusden, the Netherlands, 34 pp.

Rui, Y. (2013). *Urban Growth Modeling Based on Land-Use Changes and Road Network Expansion.* Stockholm, Sweden, 110 pp.

Rutledge, D. (2003). *Landscape Indices As Measures Of The Effects Of Fragmentation: Can Pattern Reflect Process*? New Zealand Department of Conservation, Wellington, New Zealand, 26 pp.

Satterthwaite, D., McGranahan, G. and Tacoli, C. (2010). Urbanization and its implications for food and farming. *Phil. Trans. R. Soc. B.* **365:** 2809–2820.

Spence, M., Annez, P. C. and Buckley, R. M. (2009). *Urbanization and Growth. Commission on Growth and Development.* Washington, DC, USA, 290 pp.

Singh, A. (1989). Digital change detection techniques using remotely-sensed data. *J. Remote Sensing*, **10:6** 989–1003.

Sudhira, H. S. (2008). *Studies on Urban Sprawl and Spatial Planning Support System for Bangalore*. India, 186 pp.

Torrens P. M. (2008). *A Toolkit for Measuring Sprawl, School of Geographical Sciences*. Arizona State University, Tempe, USA, 32pp.

Tsai, Y. (2005). Quantifying urban form: compactness versus 'sprawl'. *Urban Studies*, **42:1** 141–161.

United Nation, (UN), (2014). *World Urbanization Prospects The 2014 Revision Highlights*. Department of Economic and Social Affairs. New York, USA, 32pp.

United Nations Environment Programme (UNEP) (2014). *Building Urban Resilience Assessing Urban and Peri-urban Agriculture in Addis Ababa*. Ethiopia, 58 pp.

United Nations Environmental Program (UNEP) (2003). *Groundwater vulnerability mapping of the Addis Ababa water supply aquifers, Ethiopia.* Scientific report, Addis Ababa 80 pp.

United Nations Human Settlements Programme (UN-Habitat) (2011). *State of the World's Cities, Bridging the Urban Divide*. London, UK, 244 pp.

United Nations Human Settlements Programme (UN-Habitat) (2016). *Urbanization And Development: Emerging Futures, World Cities Report.* Nairobi, Kenya, 262 pp.

United States Environmental Protection Agency (EPA) (2001). *Our Built and Natural Environments a Technical Review of the Interactions Between Land-use, Transportation, and Environmental Quality,* Washington DC, USA, 102 pp.

United States Environmental Protection Agency (EPA) (2013). *Our Built and Natural Environments: A Technical Review of the Interactions among Land-Use, Transportation, and Environmental Quality*. Second edition, Washington DC, USA, 139 pp.

Urban and Regional Development Plans Formulation & Implementation, (URDPFI), (2014). *Guidelines*. Vol. I, India, 603 pp.

Wagner, H. H. and Fortin, M. E. (2005). Spatial analysis of landscapes: concepts and statistics. *The Ecological Society of America*, **86:8** 1975–1987.

Ward, D., Phinn, S.R., and Murray, A.T. (2000). Monitoring growth in rapidly urbanizing area using remotely sensed data. University of Queensland, *Association of American Geographers*, **52:3** 371–386.

Weber, C. (2005). Urban agglomeration delimitation using remote sensing data. *Taylor and Francis*, **9:** 131–145.

Weijers, D. (2012). *The Suitability of GIS Methods for Analyzing Urban Sprawl, and the Influence of Scale.* Enschede, the Netherlands, 93 pp.

World Bank (2015). *Enhancing Urban Resilience*. Addis Ababa, Ethiopia, 46 pp.

Wray, C. Musango, J. Damon, K. and Cheruiyot, K. (2013). *Modelling Urban Spatial Change:a Review of International and South African Modelling Initiatives*. GCRO Occasional paper, South Africa, 83 pp.

Yongqing, X. (2010). *Urban Compaction and its Impacts on Urban Development in China: A Case Study of Beijing.* University of Hong Kong, 269 pp.

Young, A. (2014). No pain, no gain? Rapid urban growth and urbanism in Addis Ababa. (http://www.urbanafrica.net/urban-voices/pain-gain-rapid-urban-growth-urbanism-Addis- Ababa/ accessed on 12/27/2016).

Yu, M. (2013). *To Analyze Urban Sprawl Using Remote Sensing: A Case Study of London.* Ontario, Canada. 101 pp.

Yusuf, B. Sileshi Tefera, and Admit Zerihun (2009). *Land Lease Policy in Addis Ababa*. A ddis Ababa Chamber of Commerce and Sectoral Associations, Addis Ababa, Ethiopia, 140 pp.

Zuk, M., Bierbaum, A. H., Chapple, K., Gorska, K., Loukaitou-Sideris, A., Ong, P. and Thomas, T. (2015). *Gentrification, Displacement and the Role of Public Investment: A Literature Review*. Los Angeles 76 pp.

DECLARATION

I hereby declare that the work in its entirety is my own work, except explicit citation and acknowledgement is given for published and unpublished sources. The document has not been summited to the university or any other institution for any purpose.

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CERTIFICATE

This is to certify that the thesis entitled "Urban Sprawl Mapping and Land-use Change Detection Using Spatial Metrics Method: A Case Study of Addis Ababa City and Its Surrounding Areas" is bona fide by Sewunet Shiferaw under my guidance and supervision. This is the actual work done by the candidate for the partial fulfillment of the award of the Degree of MSc in Remote Sensing and Geo-informatics from Addis Ababa University in 2017.

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