Addis Ababa University

College of Natural and Computational Sciences

School of Earth Sciences

CELLULAR AUTOMATA MODEL BASED URBAN SPRAWL MAPPING: A CASE OF MEKELLE CITY, ETHIOPIA

A Thesis Submitted to

The School of Earth Sciences of Addis Ababa University in partial Fulfillment of the requirements for the Degree of Masters of Science in Remote Sensing and Geo-informatics.

By

Berhanu Kidane Wolde michael

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This is to certify the thesis prepared by Berhanu Kidane entitled as “Cellular Automata Model Based Urban Sprawl Mapping: A case of Mekelle City, 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 respect to originality and quality.

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Lists of Acronyms

CA	Cellular Automata
CSA	Central Statistics Agency
DEM	Digital Elevation Model
EMA	Ethiopian Mapping Agency
ETM	Enhanced Thematic Mapper
FBI	Faculty of Business Institute
GIS	Geographical Information System
GPS	Global Position System
ILUD	Integrated Land Urban Development
INSA	Information Network Security Agency
OLI	Operational Land Imager
NUPI	National Urban Planning Institution
RS	Remote Sensing
UN	United Nation
ULULC	Urban land-use/ land-Cover
UNFPA	United Nation Population Fund
USGS	United States Geological Survey
UTM	Universal Traverse Mercator
TM	Thematic Mapper
TVET	Technical and Vocational Education Training

Abstract

In Mekelle city, urban growth and rapid urbanization are recognized facts for urban sprawl. This study aims to study the urban land-use change and modeling for the city. Coupling remote sensing, GIS and Cellular Automata Markov Chain model were applied to analyze the urban land-use urban sprawl, predict its magnitude, trends and spatial pattern; on the city of Mekelle. The data were i) the United States Geological Survey Landsat 4/5 TM and acquired in January 1989 ii) Quick bird image acquired in January 2005 from INSA and iii) Aerial photograph acquired in January 2016 from Mekelle city Integrated Land Urban Development (ILUD). The supervised classification algorithm of pixel-based approach was applied to identify the major urban land-use types in the study area. These were categorized in to 5 classes: built-up, agriculture, vegetation, water bodies and open area. Shannon's entropy approach was used to know the degree of dispersion, direction of built-up area's development and urban sprawl. In addition, Cellular Automata Markov modeling approach was applied to predict urban land-use change between 1989 and 2016. Land-use maps of 1989 and 2005 were used to produce a transition probability matrix for predicated urban land-use maps of 2016. The observed spatial extent increases from 1989 to 2016. That is, built-up, agriculture, vegetation and open area was increased by 17247.1 ha (64.11%), 1107.38 ha (41.29%), 2238.34 ha (8.32%) and 1384.03 ha (5.15%), respectively, while water bodies were declined by 4302.72 ha (-15.99%).This shows that urban sprawl is highest with built-up area. In the analysis that was made to the year 2016, the pattern and tendency of urban growth change for the year 2026 was also predicted. Therefore, the predicted land-use results for the year 2026, shows that the amount of urban land-use will increase by 12% from 2016 to 2026 at the expense of other land-use types. The results also shows the location and growth area for urban expansion of Mekelle which is towards in all directions. The urban sprawl phenomenon under these study areas was of a variable irregular pattern showing the combination of three sprawl patterns: expansion clusters, leapfrog and linear strip or horizontal along highways. This information is expected to support in determining the possible future directions of the city for the next 10 years. The city administration, Mekelle Municipality, urban planner and decision makers give the best solution for rapid expansion of urban sprawl by the help of RS and GIS.

Key words: Mekelle city, Urban sprawl, Remote Sensing, GIS, Cellular Automata Markov.

CHAPTER ONE

1. Introduction

1.1 Back ground

The distinct utmost source of prosperous creation in history has been conversion of rural land in to urban land represents urbanization. This development occurred at a slower rate in earlier periods, and the shape of the city that resulted was dense. Nowadays, urbanization is more rapid (Gorin, 2003). Currently, urbanization is increasing in both developed and developing countries. However, rapid urbanization, particularly the growth of large cities and the associated problem of unemployment, poverty and environment degradation pose difficult challenges in many developing countries. Furthermore, urbanization refers to process by which an increasing proportion of population comes to live in cities by growth and migration of population transformed from predominantly rural to urban area and closely associated with the level of economic activities, land-use/land-cover, population distribution and urban facilities (Medina, 2015). In addition to this, urbanization is an endemic phenomenon that is causing significant town planning and service delivery challenges globally in most developing and emerging economies. According to Abebe (2012), urbanization is the major driving force for population growth, modernization, economic growth and other development, there is an increasing concern about the effects of expanding cities and environment.

Urbanization is a process usually expanding and growing to its surrounding areas at the expense of nearby agricultural farmlands (Shishay, 2011).The process of urban expansion involves both the internal reorganization and outward expansion of the physical structure of urban areas. Such process of urban expansion is a worldwide phenomenon, which could see in the history of all urban centers. Similarly, Ethiopia has a long history of urbanization that developed next to the ancient Egyptian civilization in East Africa: like; Axum, Gonder, Lalibela, Harar. and then finally in the 1880s Addis Ababa has become the capital city of Ethiopia (Shishay, 2011). Currently, Ethiopia, has nine nationally recognized regional states; with each of them having its own capital city. Tigray region is one of these regional states, which is located in the northern part of Ethiopia, and its capital is Mekelle. Mekelle, the capital city (socio-economic and political center) of Tigray regional state is also dynamic experiencing of rapid urban expansion and population growth.

Urban growth is a spatial and demographic process and refers to the increased importance of towns and cities as concentrations of population within a particular economy or society. According to Genemo (2012), the history of urban growth indicates that urban areas are the most dynamic places on the Earth’s surface. Despite their regional economic importance, urban growth has a considerable impact on the surrounding ecosystem. Most often the trend of urban growth is towards the urban-rural-fringe where there are less built-up areas, irrigation and other water management systems. The uncontrolled urban growth and migration to the urban areas results in urban sprawl. Whether, the urban growth is good or bad depend on its pattern, process and consequences.

Sprawl in simple term is just spreading out of a city and its suburbs over more and more rural land at the periphery of an urban area while in reality it is a complex phenomenon that mean different things in different area and conditions (Haregewin, 2005). Urban sprawl refers as an out ward spreading of a city and its suburbs to exurbs, to low density and often all too dependent development on rural land. The rapid urbanization is usually cause by the increase in population in area. The extent of urbanization drives the change in land-use/land-cover pattern. Land-use/ land-cover changes may have adverse impacts on ecology of the area, especially the greenness (Ahasan *et al*., 2015). Urban sprawl is a complex phenomenon and the literature yields a wide range of definitions incorporating aesthetic judgments, unwanted externalities, policy consequences, land development patterns and urban growth rates. According to Bhatta (2010), there are many potential causes of urban sprawl including population growth, transportation facilities, poor urban planning, housing availability and the personal preference of residents. Therefore, urban sprawl is accountable for a variety of urban environmental issues like decreased air quality, increased runoff and subsequent flooding, increased local temperature, deterioration of water quality, etc. if that occurs without plan urban growth, particularly the movement of residential and commercial land to rural areas at the periphery areas, has long been considered as a sign of regional economic vitality (Medina, 2015).

However, the negative side of urban sprawl in developing countries is more severe and intense compared to that of developed countries. That is, the developing countries faced with an unprecedented population growth and potentially threaten vast natural resources. Serious rural to urban migration is also common phenomenon and population increase in bigger cities are accommodated by crowding of existing houses rather than new construction developments. Existing houses are often extended or divided illegally so that they can be rented to migrants and used by extended families (Genemo, 2012). Over the years, urban sprawl has directly contributed to the degradation and decline of natural environment resources. It also reduces farm land and productivity in city leading to social loss and open spaces (Haregewin, 2005). In addition, urban sprawl leads to regional imbalance, such as pulling jobs and people further away from poor communities, increasing in equality.

Recently, the problem of urban sprawl was restricted to the developed world but; it also exists in developing countries although in a different form. For developing countries sprawl is largely a result of necessity people move to the city in search of better employment opportunity (Genemo, 2012). This necessity leads to migration of the people from country side to the cities and commit illegal settlement within and around the jurisdictional boundary of urban areas stretching the size well beyond the limit of the city. On the contrast, sprawl in developed countries is the results of wealthy people's preference to live in the borders of the city. Further, urban growth identification, knowledge rate, quantification and trends of growth helps in determining the changes associated with land-use/land-cover properties and for regional planning with better infrastructure and in environmentally sound system (Medina, 2015). Spatial and temporal technologies in geographical information systems and remote sensing provide cost effective and accurate alternatives to the understanding of landscape dynamics. Change detection techniques based on multi-temporal and multi-spectral remotely sensed data demonstrated a great potential as a means to understand landscape dynamics for example to detect, identify, map and monitor differences in urban land-use patterns over time, irrespective of the causal factors. In this study an integrated approach of remote sensing, GIS, and Shannon's entropy was applied to identify and analyze the patterns of urban sprawl and provide modeling of urban growth, quantitative and spatial information on trends developments of urban area of Mekelle city.

1.2 Statement of the problem

The basic problem is that the rapid urbanization and urban growth have been one of the crucial issues of global change that affect the physical dimension of cities. In current years, settlements which were small and isolated urban center have become large and complex features which is called metropolis. Moreover, population migration from rural to urban areas is one of the most important urban problems resulted from regional imbalances and causes uncontrolled urban growth. The results of uncontrolled urban growth are urban sprawl, environmental damage and formation of informal settlements which suffer from social, economic, and physical problems. Policy makers and city urban planners are increasingly becoming more concerned about urbanization and urban growth since trends and patterns of urbanization have huge effect on socio-economic development. Therefore, understanding the dynamics of urban systems and evaluating the impacts of urban growth on the environment are needed (Hakan *et al.*, 2011).

Ethiopia, one of the developing countries has intensified with the unplanned urban expansion and residential houses sprawl in many of its towns and cities. Mekelle is one of the fast growing urban centers in the Tigray regional state, Ethiopia. The city has a significant spatial expansion, increasing in population growth, physical sizes and developmental activities such as building, road construction, and many other anthropogenic activities. A theoretical framework that has served as a guiding principle in elaborating the city plan has been developed based on the analysis and syntheses of the various planning issues identified by the several studies.

This study concerned that the city has got four master plan. The first was prepared by Italian in 1937 during Italian occupation, the second was prepared during the region of Emperor Haileslase by Italian Architecte called Arturo Mezzedimi, the third one is prepared by National Urban Planning Institute (NUPI) in1993 and the fourth one was by Municipal of Mekelle city in 2006 (Tsige, 2015). However, the city was developing as in glowing-planned manner; it needs additional effort for guiding the active development potential to a desirable direction. According to the Municipal of Mekelle city, the future land-use was proposed based on detailed investigation of relevant spatial factor, current growth trends of city, and socio economic and functional compatibles between various activities. In spite of this, it is observed that the master plan had come short coming both in its implementation and preparation including:

- Absence of clear urban spatial development city plan
- Informal settlements outside the planned areas
- The plan is not in line with rapid growth of the city
- Unclear city administration and planning boundary of existing plan and

- Existing challenging in reserving sufficient area for the different land-use functions, such observed reserved land is almost exhausted and conflict.

Hence, most of the sites proposed for green areas by the master plan are converted to urban land-use types, some of the roads proposed in the master plan are either closed, intruded or diverted. Accurate information on the extent of urban growth is a great interest for the municipalities of growing urban and suburban areas like Mekelle and also for different purposes such as urban planning, water and land resource management, service allocation, etc. Urban sprawl monitoring and prediction are the basic information needed for the future urban planning. Having all these issues in mind, the result from the study can support the city planners and decision makers for monitoring of suitability of the phenomena of urban growth, urban spatial development and environment, leading to better understanding in urban planning and management pattern of urban land-use/ land-cover the city.

1.3 Objectives of the study

1.3.1 General objective

The main objective of this research was to detect, analyze and map urban sprawl expansion of Mekelle city by quantify the patterns of urban growth in different period using high resolution multi-temporal aerial and satellite imageries and Cellular Automata Markov modeling.

1.3.2 Specific objective

- Finding out the trends, rate, and magnitude of urban land changes of years 1989, 2005, and 2016.
- To investigate the degree of urban sprawl in the study area using Shannon entropy approach.
- To build a Cellular Automata Markov model of urban land-change based on the analysis of satellite images.

1.4 Significance of the study

The study will attempt to the major impacts of urban sprawl is a declining amount of cultivated land through the development of infrastructures and various developments strategies. Hence, urban land-use changes studies are important tools for urban or regional state planners and decision makers to consider the impact of urban growth and urban sprawl. The results of the study would provide relevant information to contribute:

- To assist valuable information with contribute in the urban development activities and planning issue to consider the potential of geospatial and Cellular Automata urban land-use modeling tools.
- To deliver information on the dynamic and status of the urban land-use of the area and the use of remote sensed satellite imagery for such analysis for urban planners and decision makers.
- To provides the chance to understand the trends changes of the urban land-use study area.
- To give sustainable and tangible elements for long term bench mark map monitoring and observation relating to resources under currents.
- To the survey of projected analysis of urban sprawl model evaluating the existing urban land-use and its periodic change is to show for the urban planners, policy makers and natural resources managers, the decision makers well implemented to teach up to the ground.

1.5 The scope of the study

Now a days, most of the city of the country have little attention in terms of bodily expansion and energetic population growth which create a burden on a basic source of public service and infrastructural developments. Certain the fact of current and future unmanageable urban growth problems there is a need of decision making and planning to maintain at least some control of urban expansion lead to urban sprawl. Geographical information system (GIS) and remote sensing techniques can help to get up to date information of the urban expansion with frequent coverage and low cost. Hence, this research will investigate the rate of urban land-use changes that occur in the study area over those 27 years (1989 to 2016). Likewise, it was proposed to explore the level of urban sprawl in the study area between 1989 and 2016. The study also includes urban sprawl expansion map to identify the most probably growth area of urban development in the future.

1.6 Organization of this paper

The research paper has been organized in to six chapters and the outlines of each chapter are mentioned below.

Chapter one comprises a general back ground of the research problem. It includes also the main objective and specific objective and significance of the study in which clear information has been provided. Chapter two is devoted to literature review with different definition, concept, and approaches, categorized, trends, causes, impacts, methods and effects of urbanization, urban growth and including application of remote sensing and geographical information system techniques in urban sprawl studies are also reviewed. Chapter three provides materials and methods of the study. The material section includes geospatial data type, source, software and tools utilized to carry out the research. The method section has detail data analysis and techniques. Chapter four is dedicated to the result of the thesis which shows detail findings from analysis of the urban land-use and land cover changes and modeling. Chapter Five is the discussion component of the thesis. The conclusion and recommendations are in chapter six, respectively.

CHAPTER TWO

2. Literature Review

2.1 Basic concepts on urbanization and urban growth

Urbanization and urban growth are two different concepts often found in the literature of urban studies. The distinction should be noted that urbanization refers to proportion of the national population living in the urban areas, and urban growth refers to an increase in urban population size, independent of rural population (Haregewoin, 2005). In contrast, urbanization can be viewed and perceived to mean a lot of things depending on its usage. It can be viewed as a characteristic of social and economic processes and interactions affecting both population and land. Clark (1982), defined urbanization as a spatial and social process which refers to the change of behavior and social relationships which occur in a society as a result of people living in towns and cities (Nduwayezu, 2015). Oguz (2004), argued that urbanization has been increasing since World War II, and has not shown any sign of decline and is likely to continue in to the twenty first century. Fast urbanization has led to a conversion of rural area in to built-up areas and loss of green spaces in cities. These changes in urban land-use concern loss of agricultural, water bodies, vegetation and loss of vacant areas.

According to Lindfield and Steinberg (2012), urbanization is a highly dynamic process that takes place in cities and puts pressure on the urban environment. This is being fueled by population explosion throughout that world. A study by Medina (2015), highlighted that urbanization refers to general increase in population and the amount of industrialization of a settlement which includes increase in the number and extent of cities. It symbolizes the movement of people from rural to urban areas. The development of urbanization is a universal phenomenon taking place the world over, where humans reside. All countries are disposed to these confusing phenomena chiefly responsible due to the increase in population growth, economic and infrastructure initiatives (Sudhira *et al*., 2004). Urbanization is relevant to a range of disciplines, including geography, sociology, and economics, urban planning, and public health. The phenomenon has been closely linked to modernization, industrialization and the sociological process of rationalization (http://en.wikipedia.org/wiki/Urbanization). An extensive variety of urbanization definition have been used in researches ranging from any human modification of the landscape to more precise definition based on density and specified land-use characteristics. In spite of these variations of urbanization drifts or trends are universal. Local factors can speed up or slow down the process, but it cannot be stopped. Similarly, urbanization is not necessarily bad, but the rapid changes bring a lot of economic and social problems that are difficult to achieve. On the other hand, the extent of urbanization the sprawl is one such phenomenon that drives the change in land-use patterns. Some researchers agree that it has an importance of economic development.

However, urban growth is a common phenomenon almost in all countries in the world, presently, the rapid growth and the associated urban land-use/land-cover changes caused by rapid population growth and characteristics of cities and towns of developing countries. On the other hand, urban growth in developed country which is characterized by industrialization, the urbanization process in many developing countries is characterized by demographic change such as, rapid natural population growth and rural-urban migration. This kind of rapid growth make specially poor African countries in capable of supplying services such as land allocation and infrastructure (Zewdu, 2011).This rapid urban growth rate is recognized to population growth in urban resident and rural urban migration. The great population growth which does not match with social economic growth and infrastructure service requirement creates high demand for housing which leads to unplanned and uncontrolled horizontal expansion and contributes to urban land-use changed. Clark (1982) argue that urban growth, is a spatial and demographic process and refers to the increased importance of town and cities as concentrations of population within a particular economy or society.

According to Zewdu (2011) urban population growth will be most important in low income countries, particularly in Africa and Asia. Among Africa countries, East Africa cities will experience urban population growth rates significantly higher than the African average. In descending order, Addis Ababa, Nairobi, Dares Selam, Antananarivo, Kampala and Moqadishu will remain the region’s largest cities in the foreseeable future. Comparing to the world cities, Dare Selam, Kampala, Nairobi and Addis Ababa already rank among the 31 fastest growing urban population.

2.2 Urban sprawl

2.2.1 Definition of urban sprawl

Various researchers defend urban sprawl in different way. The best common definition of urban sprawl is an expansion of urban area to agricultural land caused by high population growth and rural urban migration. This spread of development across the landscape is identified by several researchers as urban sprawl.

- Urban sprawl is urbanization that takes place either in a radical direction around a well-established city or linearly along the high way over a given period of time (Sudhira *et al*., 2004). Obviously, radial and linear are just two types of map patterns that sprawl can take.
- Urban sprawl is considered by leap frog land-use pattern, strip commercial development a long high way, and very low density single use development all of which occur a relatively short period of time (Genemo, 2012).
- Urban sprawl can be described as low density development occurring on the edge or outside of a municipal area that does not follow a specific growth pattern (Tahir, 2012). Urban sprawl is an extent of urbanization mainly caused by population growth and large scale migration (Sudhira *et al*., 2004). Urban sprawl is not considered as increasing of urban lands in a given area.
- Glaster *et al.,* (2007), describes urban sprawl as one of the dimensions of land-use patterns such as low density, continuity, concentration, diversity, proximity and centrality, decentralization from of urban core to the periphery.
- Sprawl in simple terms is just spreading out of a city and its suburbs over more and more rural land at the periphery of an urban area. Early use of the terms suggest that it consumes excessive space in an uncontrolled, disorderly manner leading to poor distribution and loss of open spaces, high demand for transportation, and social segregation (Haregewoin, 2005).
- Urban sprawl may be defined as the scattering of new development on isolated tracks, separated from other area by vacant land (Lata, *et al*., 2001). It has also been described as leapfrog development (Jothimanni, 1977; Torrens and Albert, 2000).

- Bhattta (2010) and Cheng (2008), urban sprawl is a rapid expansion of the built up area in to suburbs in a discontinuous low density and uneven pattern. It has been criticized for its inefficient use of land resources and large scale encroachment on agricultural land and natural covers.
- Urban sprawl is a response to often bewildering (complex) sets of economic, social, political, and physical forces these forces includes municipal fragmentation, the patterns of infrastructure investments and subsidization of infrastructure (Barnes *et al.*, 2001).
- According to Medina (2015), urban sprawl has been considered as aerial extension of urban over the adjacent rural area. Award and irregular spatial growth of a town or city mainly due to increase in population can be termed as urban sprawl.

Generally, within these types of definitions, sprawl appears to be a multidimensional phenomenon. Most authors agree that sprawl is a multidimensional phenomenon. Certain definition agrees that urban sprawl has increasingly become a major issue in the global trend towards urbanization. Faced not only by developed countries but also by developing countries, and by large urban centers and medium and small cities alike, urban sprawl raises social and environmental concerns at the same time that shows a multiplicity of divergent trajectories that somehow challenge the dominance of homogenous characteristics around the world.

This study examined the urban sprawl of Mekelle city, one of the most important historical, cultural, industrial, and commercial cities in northern part of regional states of Tigray. In recent years, Mekelle city has the rapid growth of population and urban area, because of so appropriate natural prerequisites (so desirable lands for agriculture and many water resources), of the development of roads and the construction of housings beside them, immigration (which led to the approach of lands around the city to the city itself (these parts joined to the city boundary), of cooperatives for town building, development and construction of disorganized settlements and urban margin living), and of the ownership issues.

2.2.2 Categories of urban sprawl

Recently, there are numerous definitions of urban sprawl. As noted, they all share the same common thought that urban sprawl is the growth of the urban area outside its border in to the suburbs. In most cases the development is single purpose and car dependent, agricultural and natural land gets lost and patches, enclaves, are created. Also, researchers have created arrangements of the different types of sprawl. As stated, the type of sprawl found in North America and Europe differs. In North America development is not contiguous but spread out, where as in Europe the density is higher but the form is more evenly equally scattered across the region, thus leaving more open spaces (Weijers, 2012).

According to Galster *et al.,* (2001), have classified sprawl in to the following five types which are classified in terms of degree of compactness dispersion and scattering (Figure 2.1).

- Compact contiguous development sprawl forms gradually around the urban area not creating patches and mainly has a high density.
- Linear or strip development the urban expansion along infrastructural works or rivers ripe expansion is continuous but scattered leaving agriculture and natural land open.
- Poly-nucleated nodal development several smaller towns are agglomerated, the sprawl is discontinuous, much lower density than the traditional settlement, physically separated from the urban city of which is sprawled. Creating new larger agglomeration of towns separately from each other (Weijers, 2012).
- The scattered sprawl development uncoordinated discontinuous development away from the historical center core, creating open and vacant land between new built-up areas.
- Leapfrogging sprawl development is the development that leaps frogs over existing barriers. Similarly, leapfrogging is a scattered form of urbanization with disjointed patched of urban land-uses, interspersed with green area. Leapfrog development may be caused by obvious physical limitation such as prohibitive topography, water bodies and wetlands or by more subtle reasons such as differences in development policies between political jurisdictions. (Zewdu, 2011; Weijers, 2012).

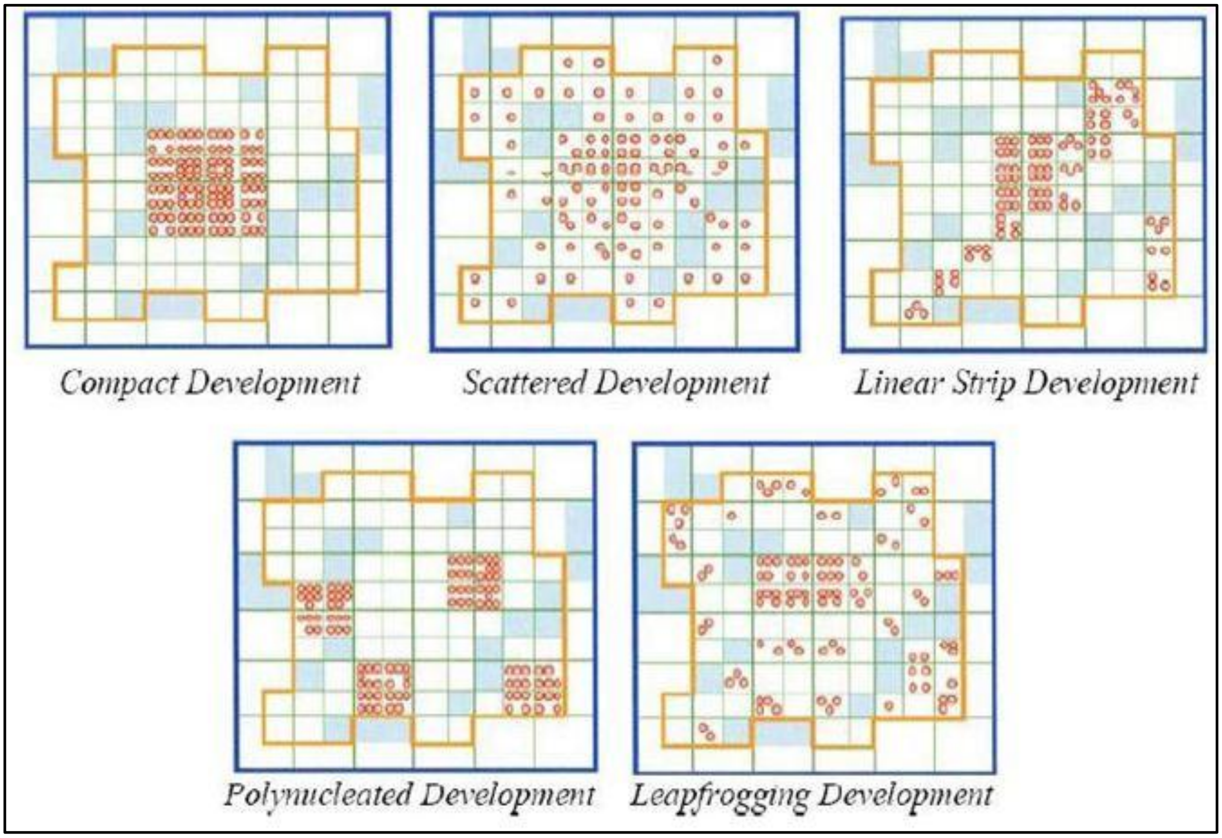


Figure 2.1: Physical form of sprawl (Source: Weijers, 2012).

2.2.3 Characteristics of urban sprawl

Characteristics of urban sprawl implies on a condition of an urban area or part of sprawl at a particular time. According to Burchhell *et al*. (1998), characteristic of urban sprawl in two ways: first residential low-density scattered development and second non-residential scattered commercial and industrial development. Scattered development is a form that is commonly associated with urban sprawl. He further describes ten points that characterize urban sprawl base on a review of research finding:

- Division of governance authority over hand uses between many local governments
- Excessive variances in fiscal capacity of local governments the revenue rising abilities of each are strongly tied to the wealth values and economic activities occurring within their own borders
- Extensive spread commercial strip development along major roadways

- Major reliance upon the filtering process to provide housing for low-income households
- Low residential
- Unlimited outward extension of new development
- Spatial segregation of different types of land-uses through zoning regulations
- Leapfrog development
- No centralized ownership of land
- All transportation dominated by privately owned motor vehicles

Therefore, sprawl suggests a condition characterizing an urban area or part of it at a specific time. Based on descriptions of situations characterizing sprawl in literature and augmented by observation and experience.

2.2.4 Cases of urban growth and sprawl

Mostly, population growth, rise in household income, subsidization of infrastructure investments lie roads, ineffective land-use, excessive growth, social problems in central cities and poor land policies are taken to be the main cusses of urban growth and sprawl (Haregwoin, 2005). Furthermore, urban growth is relatively similar with those of sprawl. In most of the cases they cannot be differentiated since urban growth and sprawl are highly linked. Nevertheless, it is important to realize that urban growth may be observed without the occurrence of sprawl, but sprawl must induce growth in urban area. Some of this caused, for example population growth, in central cities and poor land policies may result in coordinate compact growth or uncoordinated sprawled growth. Whether, the growth good or bad depends on its pattern and process and consequences. These are also some of the causes that are especially responsible for sprawl. They cannot result in a compact neighbored. For example, country living desire some people prefer to live in the rural country sides.

2.3 Effects of Sprawl

Currently, there is a separation between the place of sprawl and the location of its impacts. Once sprawl takes place at the periphery of a certain locality it could have its indirect or direct impact on other parts of the similar locality with its bordering community. Mostly, there are two conflicting idea about the significances or effects of sprawl. While some argue that it is harmful and stress measures that should be taken to combat it, others support and even encourages it. As mentioned, the study presented here does not attempt to resolve the difference options, but the attitude is with those who see sprawl as something harmful, are concerned by it and search for ways for healthier communities.

2.3.1 Negative impact of urban sprawl

Urban sprawl also can have substantial economic impacts on communities through increased cost of services such as emergency response, utility, infrastructure, and public works (Cheng, 2003). Environmental impacts of urban sprawl as pointed out by comprise the loss of arable land to development decreased aesthetic value of the town due to unauthorized developments and elevated air and noise pollution. In spite of the fact that advocates of urban sprawl argue that living in suburban areas outside of major cities is a matter of personal choice and freedom. The negative effect in Ethiopia, the urbanization was increased from 5% in 1950 to 16% in 2000, on average 4.3% per year. Furthermore, it is estimated that by 2025, the World's, African's, and Ethiopians' population rate will reach 58%, 52%, and 32%, respectively (Shishay, 2011).The reason for an optimistic prediction towards the urbanization growth. This negative effect of urban expanding on their peri-urban areas. When choosing your next residence, consider the negative effects of urban sprawl, and their impacts on you, your community and the environment due to undesirable consequences increased air pollution, loss of wildlife habitat, water over consumptions and increased economic disparity.

2.3.2 Positive side of urban sprawl

Sprawl is not always seen as harmful (Haregwoin, 2005). Some organization and planners see sprawl as a sign of economic vitality and not as ecological threat, one positive effects of sprawl is reducing housing costs. Besides that, they may present the various benefits of urban sprawl, such as the short-term economic and employment boost caused by new construction. However, urban sprawl is a growing concern in all of Ethiopia.

2.3.3 Solutions against of urban sprawl

Sprawl, in general, dream about densely populated urban communities with plenty of green spaces, sharp distinctions between city and country side, few cars and lots of public transportations (Haregwoin, 2005). Clearly, the patterns of sprawl in developed and developing countries are strongly different, the solutions proposed are the developing countries specially

Ethiopia, managing urban growth has become one of the most important challenge of the people living on the periphery of the city are mostly rural migrants who have come to the city in search of employment. In rural areas, where the agriculture is most common, the activity often tends to be seasonal and therefore unreliable. The problem that needs to be addressed is, hence, the creation of employment opportunities away from the major urban area. A number of small towns and cities that are closer to the hinter land could develop as potential sources of employment for rural people. This would reduce the burden on large cities and create an alternative source of work, there by addressing the problem of both unemployment and sprawl. In addition, to maximize the effects of new policies, governments should implements them at local levels, ideally at the city level to stop the expansion of cities will be performed.

2.4 Global trends of urbanization

Urbanization is the process of transition from a rural to a more urban society. Statistically, urbanization reflects an interesting proportion of the population living in settlements defined as urban, primarily through the net rural to urban migrations. The level of urbanization is the percentage of the total population living in the town and cities while the rate of urbanization is the rate at which it grows. According to UNFPA (2015), the first urbanization were took place in North America and Europe over two countries, from 1750 to 1950 an increase from 10 to 52 percent urban and from 15 to 423 million urbanites. In second wave of urbanization, in the less developed regions, the number of urbanites will go from 309 million in 1950 to 3.9 billion in 2030. In those 80 years, these countries will change from 18 percent to some 56 percent urban. At the beginning of the 20th century, the now developed regions had more than twice as many urban dwellers as the less developed (150 million to 70 million). Despite much lower levels of urbanization, the developing countries now have 2.6 times as many urban dwellers as the developed regions (2.3 billion to 0.9 billion). This gap will widen quickly in the next few decades. At the world level, the 20thcentury saw an increase from 220 million urbanites in 1900 to 2.84 billion in 2000.

The present century will match this absolute increase in about four decades. Developing regions as a whole will account for 93 percent of this growth, Asia and Africa for over 80 percent. Between 2000 and 2030, Asia’s urban population will increase from 1.36 billion to 2.64 billion, Africa’s from 294 million to 742 million, and that of Latin America and the Caribbean from 394 million to 60 million. As a result of these shifts, developing countries will have 80 percent of the world's urban population in 2030. Africa and Asia will include almost seven out of every ten urban inhabitants in the world shown in (Fig. 2.2).

The impact of globalization on city growth patterns marks a critical difference between past and present transitions. Cities are the main beneficiaries of globalization, the progressive integration of the world's economics. People follow jobs, which follow investment and economic activities. Most are increasingly concentrated in and around dynamic urban areas, large and small. However, very few developing country cities generate enough jobs to meet the demands of their growing populations. Moreover, the benefits of urbanization are not equally enjoyed by all segments of the population. According to UN State of the World Population 2014 report, the majority of people worldwide will be living in cities for the first time in history recording due to referred as the arrival tipping point. In 2014, the level of urbanization significantly different across the countries because of high levels of urbanization at 80%, categorized Latin America and Caribbean and North America. Europe, with 73% of its population living in urban areas is predictable to be over 80% urban by 2050. Africa and Asia remain mostly rural with 40% and 48% of their respective population living in urban areas (UN, 2014). Forthcoming decades, the level of urbanization is predictable to increase in all countries as referred to as major areas, in case of this Africa and Asia urbanizing faster than the rest. Ultimately, these two countries which are expected to reach 56% and 64 % urban by mid-century, respectively, are still projected to be less urbanized than other country of the world.

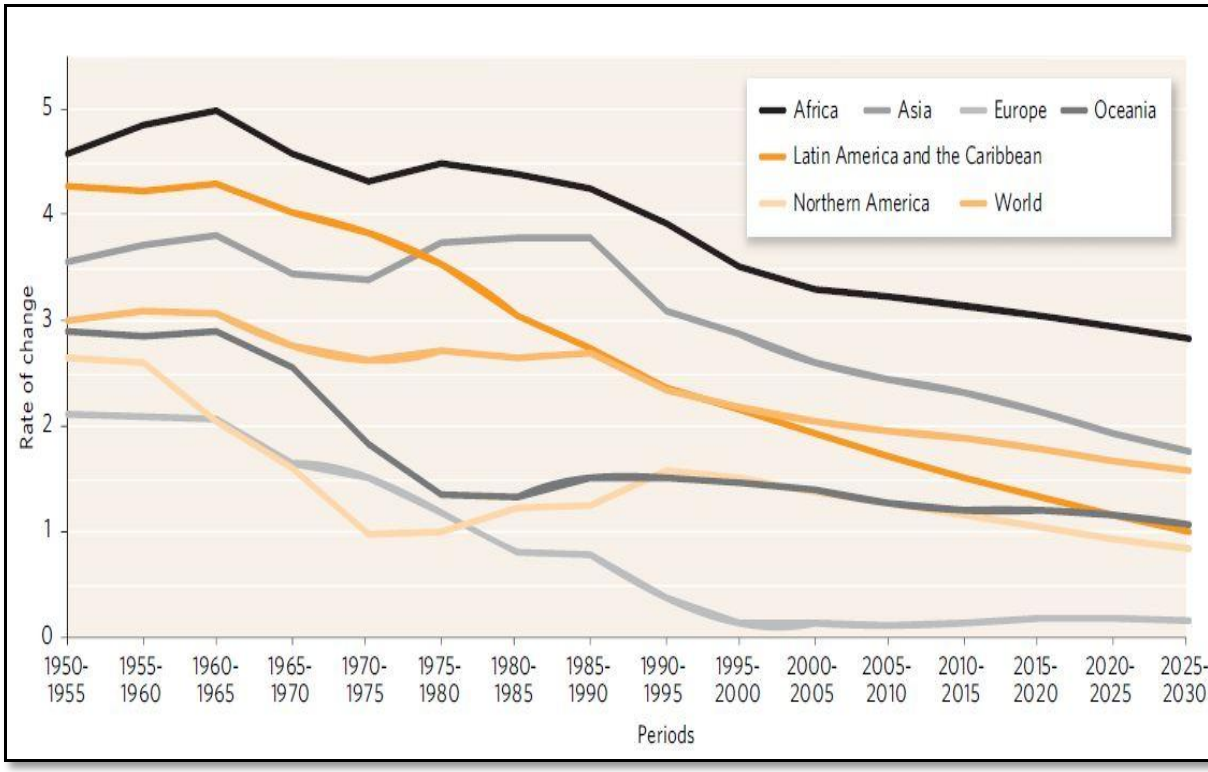


Figure 2.2: Average annual rate of change of the urban population, By Region, 1950−2030

Source: United Nations 2006, World Urbanization prospects; The 2005 Revision.

2.4.1 Trends of urbanization in Ethiopia

Similar most developing countries serious rural to urban migration is a common occurrence. In spite of the fact that urban population growth in Ethiopia is estimated at 6%, as much higher figure compared to other African countries (Haregwoin, 2005). According to Ethiopian CSA, the 1984 census report shows a 46.5% urban population increase over nine year period starting in 1975. The country is one of the least urbanized areas in the Third World. Its economy almost fully depends on agriculture although production and food facility is low due to happen such bad weather conditions and lack of effective technology. Similarly, almost 80% of the population exercise only agriculture and animal rearing as a means to support them. The necessity for housing is not integrated with the need to stop horizontal expansion and hence saving land. Formal and informal settlements are stretching out horizontally from the central in all direction. Commonly, urban sprawl in Ethiopia is a result of population pressure natural births and migration, regional in-balance and unclear planning management (Haregwoin, 2005). Action is consequently needed to deliver for immediate need of the population whereas trying for solutions to overcome mismanagement of land and extra horizontal development.

Generally, as specified that, dissimilar forms, types and level of urban sprawl. The characteristic or dimension can change. The definition above also suggests that sprawl can be defined as a process of development, where you look Mekelle city at the change in patterns of the land and over time.

2.4.2 Trends of Mekelle city expansion

During the data collection, the trends of Mekelle city in 2004 and 2006 of master plan, it has only expanded in west, south and south-east directions (Mekelle Muncipality, 2011). Thus expanded the old Mekelle city in the west of the Endayesus escarpment, Quiha has towards in the south east of the city, Aynalem the south of the city and Adiha the south-west sides of the city connected with Mekelle due to the city expansion. After 2008 master plan, Aynalem, Adiha and Quiha rapidly to sub-cities connect and combine to each other due to the vast urban expansion of the dominant city of Mekelle particularly for the purpose of investments and residential expansion.

2.5 Remote Sensing and GIS Approach in Urban Sprawl

2.5.1 Remote Sensing

Remote Sensing is defined as the science and technology by which the characteristics of objects of interest can be identified, measured or analyzed the characteristics without direct contact. Currently, remote sensing has helped forceful up-date urban growth pattern information for sustainable resources allocation, urban planning and management (Nduwayezu, 2015). The spatial data obtained from remote sensing must be processed and transformed in to information, which can be analyzed, displayed and interpreted in a systematic and quick way. Furthermore, remote sensing gives the ability to good-looking data via the air born and space sensors in a cost effective way and with temporal frequency resulting in multi-resolution, multi-spectral and multi-temporal data which is used for the creation of urban land-use maps (Weijers, 2012). Digital change detection techniques with the help of multi-spectral remotely sensed images which is a great source for extracting and analyzing urban land-use maps show many potential in observing landscape dynamic regardless the causal factors. Increasing improvements in the quality and availability of remotely sensed images makes the land-use maps of a higher spatial resolution for more detail is visible and thus the data becomes more precise the digital change detection with the help of a geographic information system. These digital change detection techniques are becoming more accessible and easier.

Landsat images are accessible from 1972 up-to date in eight successive generations from Landsat one multi-spectral scanner to Landsat eight Operational Landsat Imager (OLI). Landsat six was never operating due to the fact that it did not reach the orbit. As noted, a long time series of data is potentially available for analysis (Nduwayezu, 2015). Currently, remote sensing has been used in grouping with geographical information systems and global positioning system to assess urban land-use changes more effectively than by remote sensing data only (Abebe, 2012).

2.5.2 Geographic Information System (GIS)

Now a days, the development of geographic information system has transformed the collection, analysis and interpretation of data for planning and decision making process especially in urban growth area. Also, the fast expansion of urban area challenges government. Government develops physical plans for the future. To be able to make plans, updated and precise information is needed. They need to know where, how and in what direction the urban area is expanding, in order to make sustainable future plans, resources allocation and infrastructural works (Weijers, 2012). Though, the conventional and traditional survey and mapping technology are too expensive and also time consuming. As a response to this problem on how to monitor urban sprawl with geographic information system techniques emerged. GIS can delivered useful information for the monitoring of the urban land and gives the opportunity to observe, visualize, monitor, urban land-use changes and forecast them. Likewise, GIS is a spatial statistics parameters and indices can be calculated from urban land-use maps, spatial distribution, which characteristics the landscape properties, pattern and the extent of urban sprawl (Sudhira *et al*., 2004). Therefore, GIS can able to handle-in and output of spatial data and non-spatial data (maps, tables, remote sensing and knowledge) with simplifies geographical analysis, simulations, modeling and presentations of urban sprawl.

2.5.3 Remote Sensing and GIS application in urban sprawl studies

Urban expansion and population have advanced at an unprecedented pace over the past few decades. Even though cities occupy only a very small portion of the Earth's total land surface, almost half of the world population lives in urban areas (United Nations, 2000). Urban growth has had increasingly significant socioeconomic and environmental impacts at local, regional and global scales. The fast expansion of urban centers and their peripheries has led, in many cases, to a series of complex problems related to loss of natural vegetation and agricultural land, increased traffic congestion, uncontrolled urban sprawl, water quality and degradation of air. Such impacts affect not only the local environment, but also have consequences for more distant regions. Modify in surface temperature, vegetation cover, air and water quality induced by urban expansion influence the microclimate of the human habitat, as well as climate dynamics and environmental changes at local and regional scales. Urban growth has also significant impacts on the social structure of the cities and their surroundings, in terms of population distribution or urban land-use characteristics. Besides that, local impacts and the emergence of mega cities (with more than ten million people) are considerably influencing the economic, social and political systems on global levels, due to the economic and demographic importance of such cities and their interconnectivity at large scales.

Reliable and efficient characterization of the urban environment provides the basis for urban planning and decision making and facilitates the study of local and regional environmental processes in the broader context of global environmental change and the sustainability of cities and their hinterlands. RS functionalities and geographic information systems can provide timely and accurate information on existing urban land-use increasingly used to characterize urban areas and to monitor urban changes in conjunction with demographic and socioeconomic changes. Thus, RS and geographic information system represent essential tools in any socioeconomic and environmental analysis of urban areas. This section discusses in brief the following uses of RS and Geographic information system in urban sprawl analysis:

- Classification of urban areas
- Analysis of physical characteristics, demographic and socioeconomic patterns of the urban environment
- Identification and delineation of the urban environment
- Monitoring and Measuring physical properties of urban areas (air quality, vegetation etc)
- Measuring changes, urban sprawl and urban growth over time.

2.6 Urban land-use changes

Fast urban growth and associated urban land-use changes caused by fast population growth are characteristics of town and cities (Zewdu, 2011). Urban land-use is a complex and dynamic process that links together natural and human system. Likewise, change detection is the process used in remote sensing to determine changes in the urban land-use properties between different time periods. It has also viewed as the process for monitoring and managing natural resources and urban development because it provides quantitative analysis of the spatial distribution in the area of interest (Genemo, 2011). Moreover, change detection has been applied in different application areas, ranging from monitoring general urban land-use changes. According to Nduwayezu (2015), defined land-cover as the observed physical cover, as seen on the ground through remote sensing including the vegetation (natural or planted) and human constructions (buildings) that cover the earth surface. For example, bare land, water, ice and salt flats. While, land-use express as the way in which, and the purpose for which, human beings employ the land and its resources.

2.7 Cellular Automata Markov Modeling for Urban Sprawl

First of all, the term "model" has been used in different context and in a number of application areas. It is broadly defined as abstraction of reality achieved by simplification of complex real world relations to the point that they are understandable and analytically manageable. Models are used to predict the future state of the urban land-use patterns considering several physical and social-economic elements (Medina, 2015). Furthermore, technological development in the spatial modeling allows examining environmental dynamics and decision-making. Therefore, spatial modeling has more relevance than other methods of modeling. Hence, modeling urban land-use changes helps to understand the process of containing urbanization and informing policy makers to determine the possible future conditions under different scenarios (Nduwayezu, 2015). According to Medina (2015), Cellular Automata models can be used an a planning tool for developing alternative scenarios and the urban planner can take more rational and scientific decisions by looking at the various scenarios generated, thus providing a scientific basis for implementing decisions. Thus, Cellular Automata Markov model is an object that has the ability to change its state based on the application of a rule which relates the new state to its previous state and those of its neighbors. As above mention it, CA combines the concepts of Markov

Chain. Markov Chain Analysis is a convenient tool for modeling urban land-use change when changes and processes in the landscape are difficult to describe. As the most basic level a CA is lattice or regular or an array cell (Nduwayezu, 2015). Now a days, a cell is in one of finite number of allowed states. Cellular Automata is thus composed of five principles elements:

1. Transitional rules: The future state of cells is determined by the transitional rules in a discrete time frame. These are a set of conditions that define the state of change in each cell in response to its current state and that of its neighbors.
2. Neighborhood: The neighborhood is also includes the central cells itself. The two commonly used neighborhoods are a 3x3 cell size Van Neumann and Moore neighborhood. The neighborhood can also extend from their 5x5, 7x7 and 9x9 so on. Similarly, the neighborhood cells acts as immediate area of interest for the central cell.
3. Cell: A cell at any instant of time can be in only one state of a given number of states. The state of all cells in a grid area updated during CA iterations. Also a cell is the sub-unit of the lattice or the regular geometrical grid.
4. State: A state is a variable, which takes different values as each cell. It can be a property, a number or word (0 or 1, urban or non-urban).
5. Lattice: Lattice space can have n dimension, but two-dimensional CA is the most common in urban simulation. Therefore, a regular uniformed and infinite ‘ lattice’ or ‘array’ with discrete variables at each cell.

2.8 Materials

The analysis of urban sprawling different types of data from different sources in different formats have been used.

2.8.1 Remote sensed satellite data

The best common approach adapted for urban sprawl studies is to understand and visualize the urban growth patterns and changes using classified remote sensing images and data, which enable along GIS techniques detection, monitoring, analyzing and mapping the spatial patterns of sprawl on landscapes (Lata *et al*, 2001;Yeh and li,2001).

During this study, three different images were used. The first is, Landsat (bands 1,2,3,4,5 and 7) acquired (with path 169 and row 059) in January 1989 by the United States Geological Survey

(USGS). The second image, Quick bird image (bands 1,2,3,4 and 5) acquired in January 2005 were obtained from INSA. The last one, Aerial photograph (bands 1,2 and 3) acquired in January 2016 were obtained from Integrated Land Urban Development (ILUD), Mekelle. These images were processed to detect and quantify the amount of urban sprawl and calculate the entropy values. The characteristics of satellite data were described in Table 2.1 and Fig. 2.3.

To study the urban sprawl change over the past 27 years, three images were taken in to consideration. The three images were pre-processed such as projection, masking (clipping to study areas), stacking (creating multispectral image), mosaic (geographic merging), classification that is supervised image classification and post-classification process (detection of the changes in urban land-use and accuracy assessment). ArcGIS software was used for spatial analysis and map making while ERDAS Imagine software was used for image pre-processing and classification. In this study, all data were projected to the Adindan Universal Transverse Mercator (UTM) projection system which is locally used in Ethiopia as standard datum. These data were used to produce the historical land-use/land cover maps of the study area. Having remotely sensed data solves problems related to land-cover information and also provides various changes which occurred on the surface in different land-use classes. A-past from preparing, analyzing and calculating urban land-use data from Landsat imageries, elevation and slope features were generated from Digital Elevation Model (DEM) of 30 m resolution in Arc GIS environment using spatial analysis tools of the surface.

Table 2.1: Characteristics of satellite data.

Acquisition Date	**Sensors**	**Spatial Resolution**	**Number of band**	**Format**	**Source**
01 Jan 1989	Land sat 4/5TM	30 m	7	Geo TIFF	USGS
03 Jan 2005	Land sat ETM+	30 m	7	Geo TIFF	USGS
08 Feb 2016	Land sat 8 OLI	15 m	11	Geo TIFF	USGS
10 Jan 2005	Quick Bird	0.61 m	5	Geo TIFF	INSA
05 Jan 2016	Aerial photograph	0.15 m	3	Geo TIFF	Mekelle ILUD
Instrument:		GARMIN GPS			INSA

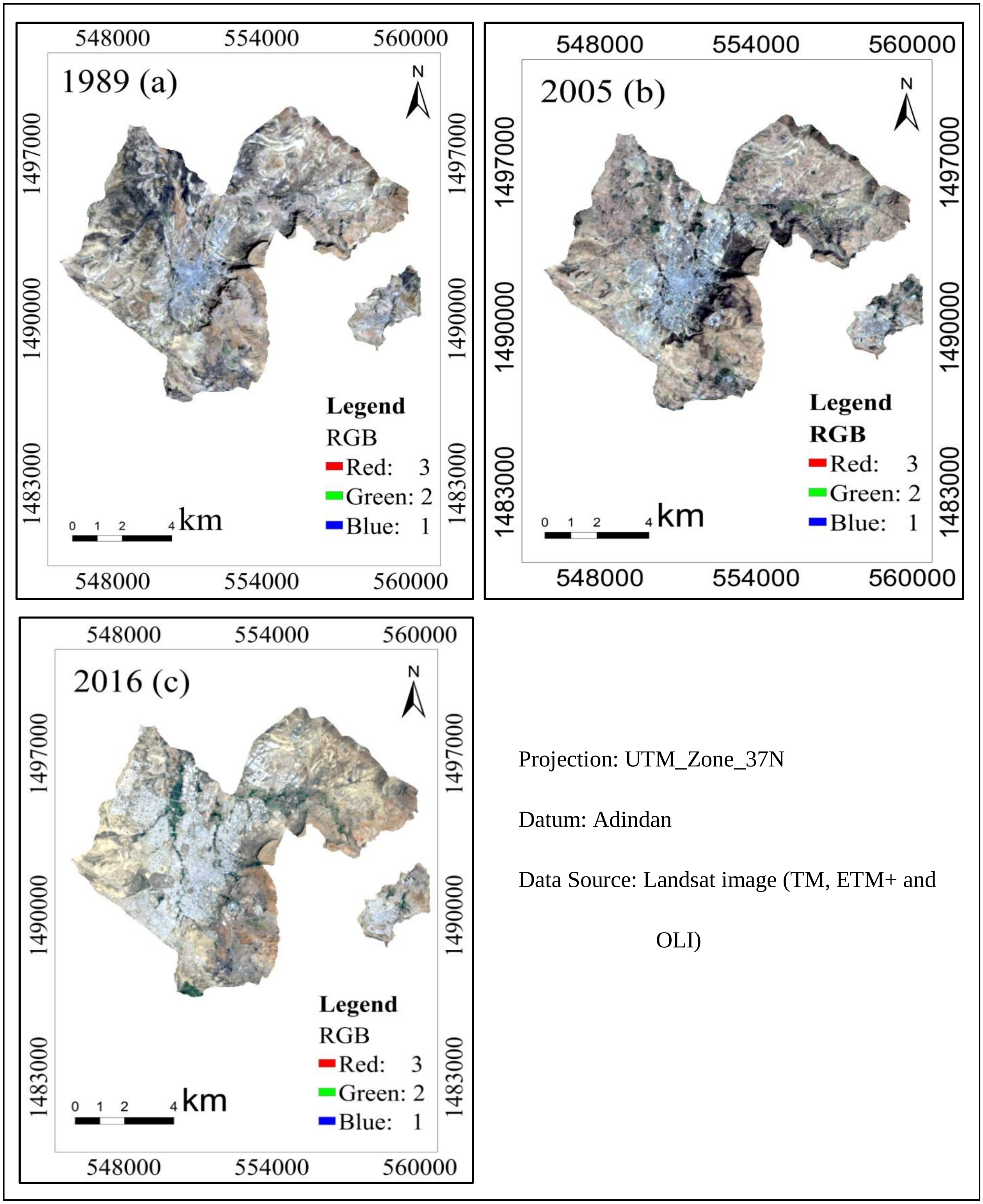


Figure 2.3: True color composite 321: Landsat 4/5 TM (a), Landsat 7 ETM+ (b) and Landsat 8 OLI (c).

Under this study, different bands were composed to recognize the color scene of the features on the image (Fig. 2.3). A true color composite with the visible red (band-3), visible green (band-2), and visible blue (band-1) channels at RGB to create an image that is very close to what a person would expect to see in a photograph of the same scene. Also, true color composite images were created by combining the TM spectral bands that most closely resemble the true color of the features. This explanation depends on the science of remote sensing point of view. On the other hand, band composition under this study was false color composite (4, 3, 2), which eliminates the visible blue band and uses a Near Infrared (NIR) that is band 4 to produce the more interpretable image. Similarly, the study comprised band-1, band-2, band-3, and band-4 to detect urban land-use/land-cover changes of the study area for the years 1989, 2005 and 2016.

2.8.2 Secondary data

Secondary data were collected from different organizations including National Meteorological Agency (NMA), Central Statistics Agency of Ethiopia (CSA), Information Network Security Agency (INSA) and Mekelle City Administration (Table 2.2).

Table 2.2: Secondary data source.

Data Type	Output	Source
Master Plan	Boundary extraction	Mekelle City Administration
Population Data	Extraction of population density and changes analysis	CSA (1965−2007) and Mekelle City Administration
Metrological Data	For description of the study area	NMA (2008−2015)
Digital Elevation Model	Derivation of slope and elevation	INSA

2.8.3 Software used

ERDAS Imagine software used for image classification and interpretation, accuracy assessment. Google satellite down loader software was used to down load Google Earth Imageries. IDRISI Selva Geospatial Monitoring and Modeling System was used for its strength in Cellular Automata modeling of urban land-use/land-cover (Medina, 2015). Similarly, ArcGIS was used to produce a final output urban sprawl maps.

2.9 Methods of data processing

2.9.1 The pre-processing phenomenon

The sympathetic dynamic phenomenon, such as urban sprawl, requires landsat change analysis and urban sprawl pattern. ArcGIS (ESRI) and ERDAS Imagine software have been used to generate different thematic layers. The usual image processing techniques, such as image restoration, resolution merging; for example, Spot 5 m for landsat 4/5 TM, GeoEye 1.85 m for Quickbird, image classification and image rectification have been used for the analysis of satellite images of 2005 and 2016. ERDAS Imagine software has been used for image analysis. First of all, the satellite images are mostly free from atmospheric correction. Second, all the satellite images bands are used for image stacking. Third, image subset and resolution merging of each year was developed by using administration of the boundary. Similarly, satellite images have been studied systematically to determine the probable land-use classes. Spectral profile have been drawn to determine the relative difference in pixel values of different land-use classes in different spectral.

2.9.2 Data processing

In this thesis, different kinds of techniques, methods and analysis were applied to process input data so as to generate the required research output in an efficient and sufficient way with desired quality. In fact, the basic requirement of the active phenomenon of urban sprawl is availability of information on land-use/land-cover change, demographic patterns and urban sprawl pattern, trends and magnitude. Besides, main roads and secondary roads features and urban land-use/land-cover were digitized and extracted from the Quick bird (0.61 m) and Aerial photograph (0.15 m). The methodology of the study is considering the benefits of capability to provide significant information on the nature of changes which arise during the study period (Fig:2.4).

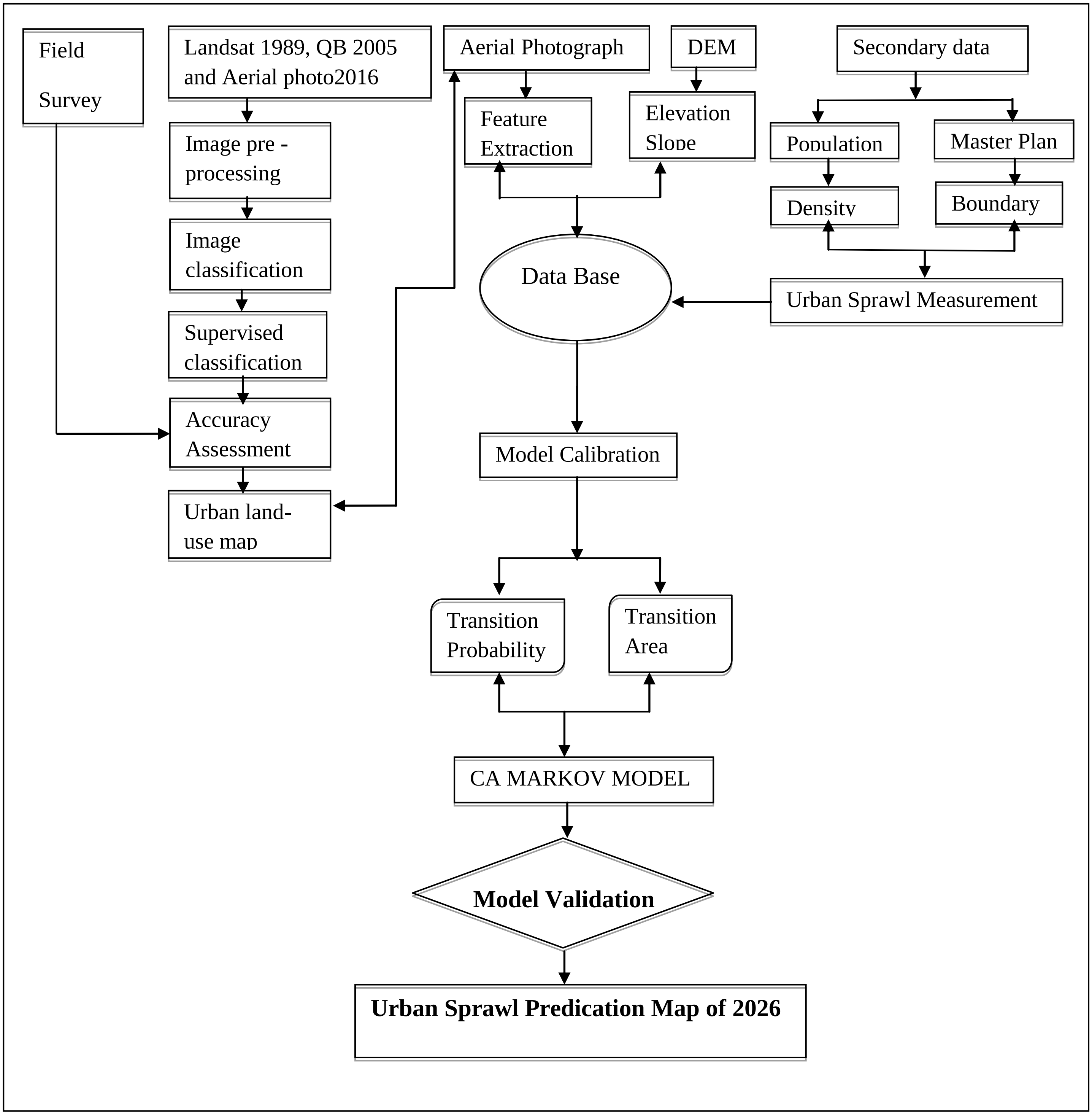


Figure 2.4: Flow chart of overall methodology

CHAPTER THREE

3. Description of the study

3.1 Location

Mekelle is the capital city and commercial center of the Tigray National Regional State in the northern Ethiopia. The city Mekelle was established as a national capital during Emperor Atse Yohannes the 4th era in 1864 E.C and got its urban structure during his reign (Tsige, 2015). The altitude of Mekelle is between 1965 m and 2220 m above sea level. The city is located between latitude 13°24′ 30"−13°36′ 52" N and Longitude 39°25′30"−39°38′ 33" E is situated in the central highlands of Ethiopia (Fig. 3.1). Mekelle is a city in Ethiopia located at 783 km drive north of national capital city, Addis Ababa. The area of the study covered about 9233.23 ha.

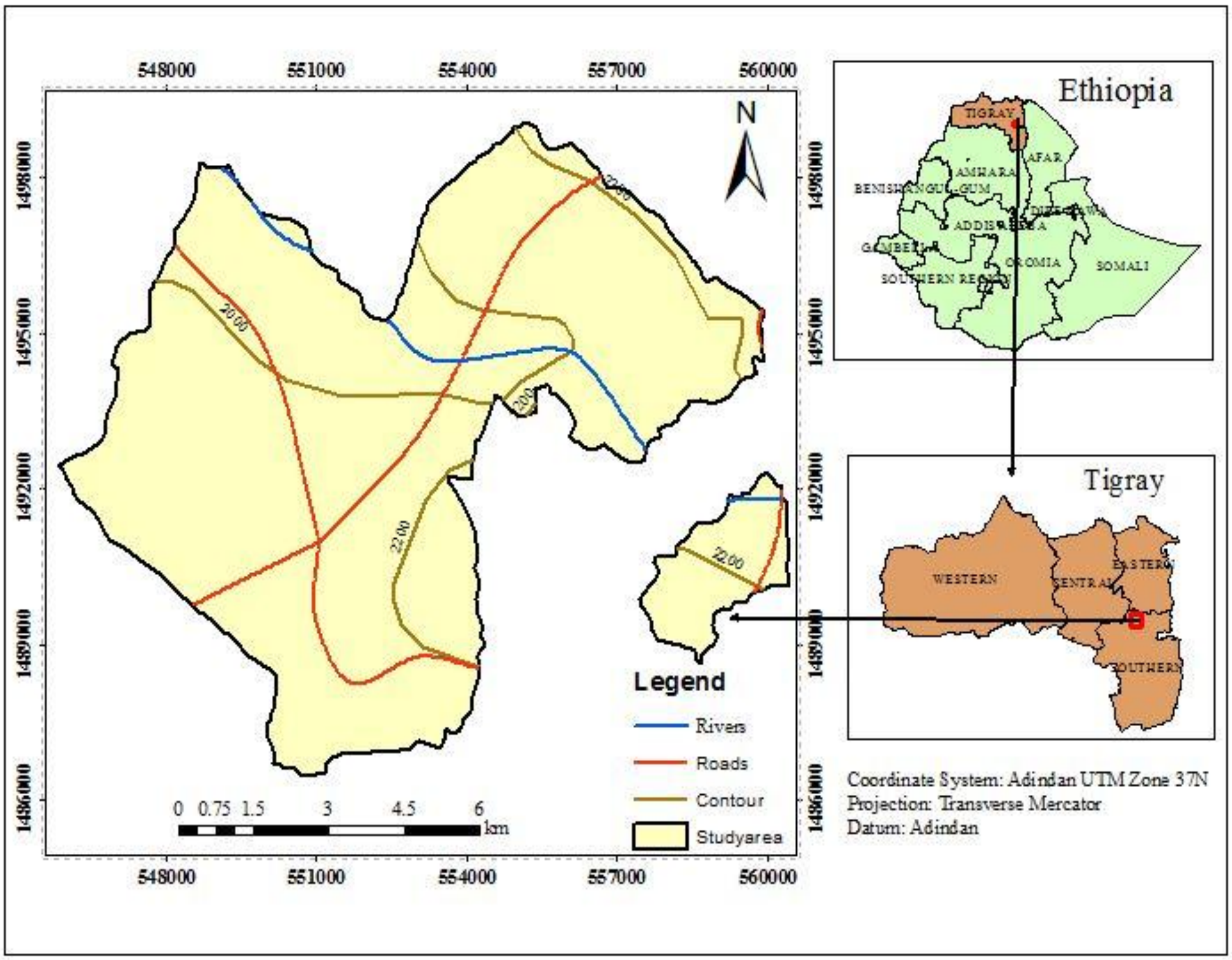


Figure 3.1: Location map of the study area

Boundaries: Mekelle city is surrounded by two countries: the Eritrea to the north and Sudan to the west. In terms of region, Mekelle is surrounded by Afar and Amhara Regional States to the east and south respectively. Likewise, in terms of cities of the region, Mekelle is circled by Adigrate (120 kms) and Maichew (120 kms) and Abbi-Addi (90 kms). It is just 155 kms south from the border with Eritrea. (Source: Google Earth). Mekelle city comprises three scattered settlements. Also, these three parts of the city are disconnected (due to airport, military camp, topography, vast Agricultural land, rugged mountain terrain, and long travel distance), since 2009 they were unified under the city municipal administration is known as Quiha, Aynalem and Adi-ha (Shishay, 2011).

First, the appropriate Mekelle, which comprise area such as the seat of the National Regional Government of Tigray, geographically the appropriate Mekelle is located to the west of the Endayesus escarpment. Second, Quiha is found to the south east of the city. This small town is administratively part of Mekelle. Location of Quiha is bounded by natural and manmade boundaries in North by steep slope, East by a cliff and South by Alula Aba Nega International Airport. Third, Aynalem is one small village to the south of the city disconnected from these two settlements by vast military camps, agricultural land and airport. Last, Adi-ha is another small village to the North of the city in which it is connects with Mekelle due to the city expansion to its plain and extensive farmland in rural and urban fringe. Currently, Mekelle city has unified in to 7 sub cities which might be a leading scenario to transform city of Mekelle in to its metropolitan status. The sub-cities include: Semien, Ayder, Kedmi-Weyane, Hawiti, Adihaki, Hadinet and Quiha. (see the confided seven Mekelle sub-city map for more detail Fig. 3.2).

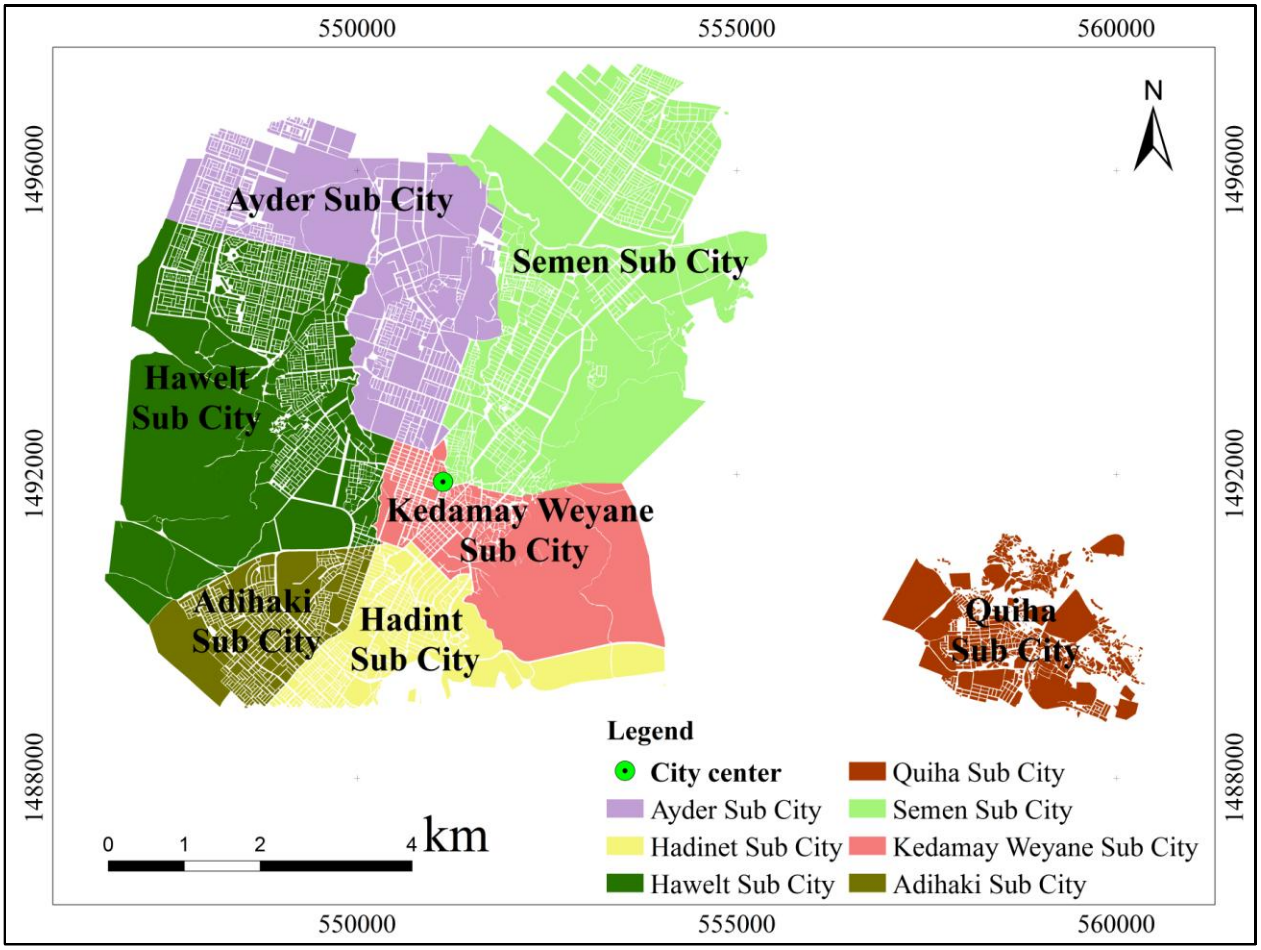


Figure 3.2: The seven sub-cities administration map of Mekelle

Source: Mekelle Municipality (2016).

3.2 Urban land-use

Mekelle city is taking as the fast population growth and the appropriateness for different investment opportunities; its area would go increasing and increasing overtime. According to the information collected from Mekelle Municipality, the city of Mekelle constitutes different networks made to be the owner of a lot of facilities and services because of the following physical infrastructures: water supply; health institutions and services including from the private sector; educational institutions including higher learning level, 24 hour electric light and power supply; air service due to the presence of Alula Abanega International Airport; telecommunication services that include internet and cell phone services; a number of financial institutions that give different financial services; a number of road networks that connect the city to different places; an international stadium is also under construction that would be completed soon; and construction of 556 km of rail away is to be constructed to connect the city with the rest of the country in general and Addis Ababa in particular.

3.2.1 Urban land-use pattern

According to the information collection from Mekelle Municipality, the proportion of urban land-use and individual area in hectare are as indicated in the (Table 3.1). The city has urban land-use during 2006.

Table 3.1: Urban land-use pattern of Mekelle city during 2006.

No.	Type of land-use	Area in ha	Gross area	Built-up area
1	Manufacturing and ware house	222.9	2.27	4.1
2	Roads and Transport	1117.7	11.39	20.2
3	Agriculture and forest	4261.2	43.4	-
4	Commercial	277	2.3	5
5	Residence	2723.1	2774	49.1
6	Service	591.9	6.1	10.7
7	Special function and others	691.3	63.3	11.2
	Total area	9885.1	100	

Source: Federal urban planning Institute (2006).

3.2.2 Urban land Use and Respective Area in ha by Local Administration

The land use pattern of the Mekelle City in individual area per hectare by local administration is also described in (Table 3.2).

Table 3.2: Land-use pattern and area in ha in Individual Local Administration.

No.	Sub-city	Manufacturing	Roads	Agriculture	Commercial	Residence	Service	Special function	Total
1	Kedema Weyane	0.66	58.2	190.4	60	185	137	79.7	710.96
2	Hawelti	-	157	201.5	79	410	62.5	409	1319
3	Hadnet	2.7	136.5	801	17.5	561	70.4	0.13	1589.23
4	Adihaki	-	82.2	251	20	276	41	-	670.2
5	Ayder	76	116.4	573	65.8	340	129.5	5	1305.7
6	Semen	136.1	221	2018	24	638	101.5	45	3183.4
7	Quiha	7.4	346.4	226.3	10.7	313.1	50	82.5	1036.6
Total area		222.9	1117.7	4262.2	277	2723.1	591.9	671.5	9866
From gross		2.27	11.39	43.4	2.3	27.74	6.1	63.3	100
From built-up		4.1	20.2	-	5	49.1	10.7	11.2	100

Source: Mekelle Municipality (2011).

3.3 Topography

Mekelle city is positioned at the foot of a steep cliff of Endayesus escarpment on the eastside and steep bedded lime stone cliff on the northern and northeastern side. The altitude varies from 2220 m at eastern side to 1965 m in the northwestern side of the city. The city has an overall tilt from eastern to western and northwestern side. Most streams and tributaries are controlled by this tilt while others are controlled by geological structures and under lying geology. Furthermore, Mekelle is located at the base of a steep cliff of the Endayesus escarpment on the east side. Above the cliff up to Quiha with scattered settlement at a distance of 10 km, north from the center of the city there is also a steep cliff. The altitude of the Ellala area varies from 1960m above sea level at the foot of the escarpment to 2080m.This study area is characterized by topography having the highest elevation of 2220m. As the following elevation map (Fig.3.3), which is extracted from digital elevation model (DEM) of 30m resolution shows that scattered hill of Ellala and the foot of a steep cliff of Endayesus. The topography makes the city to have circular like shape. The slope of Mekelle is between 12 and 15 degree. (Fig.3.4). (*http://www.ethiomedia.com/aurora/9405.html).*

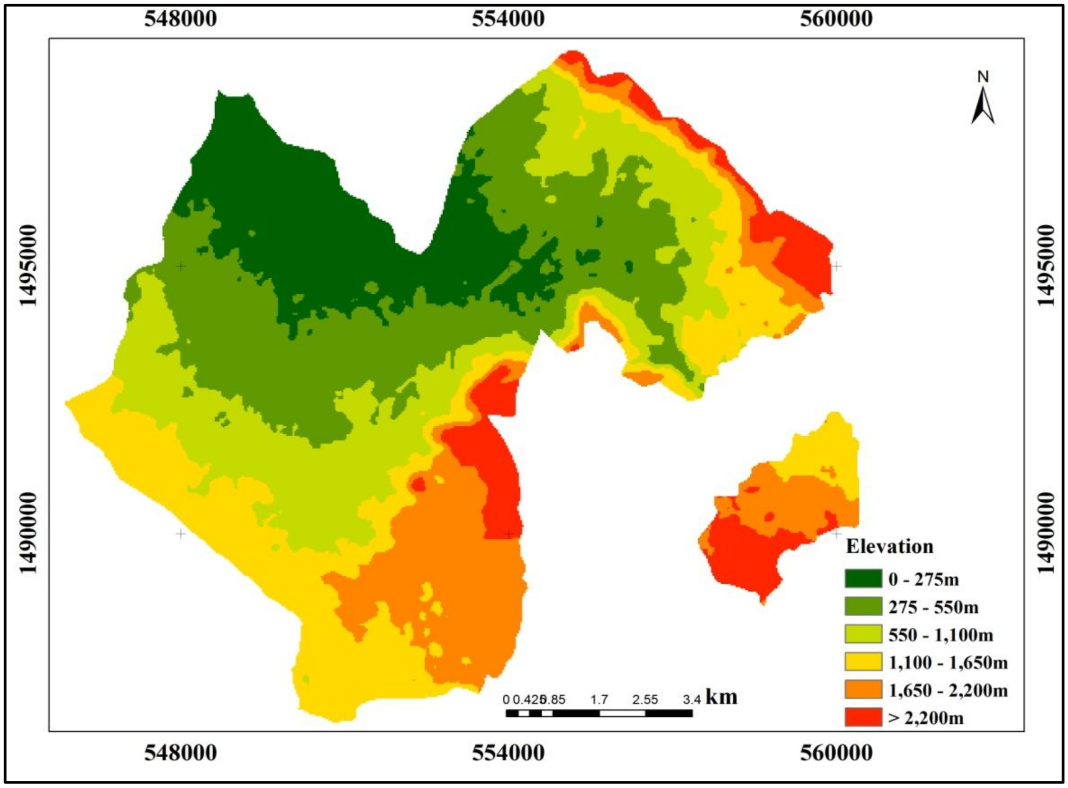


Figure 3.3: Elevation map

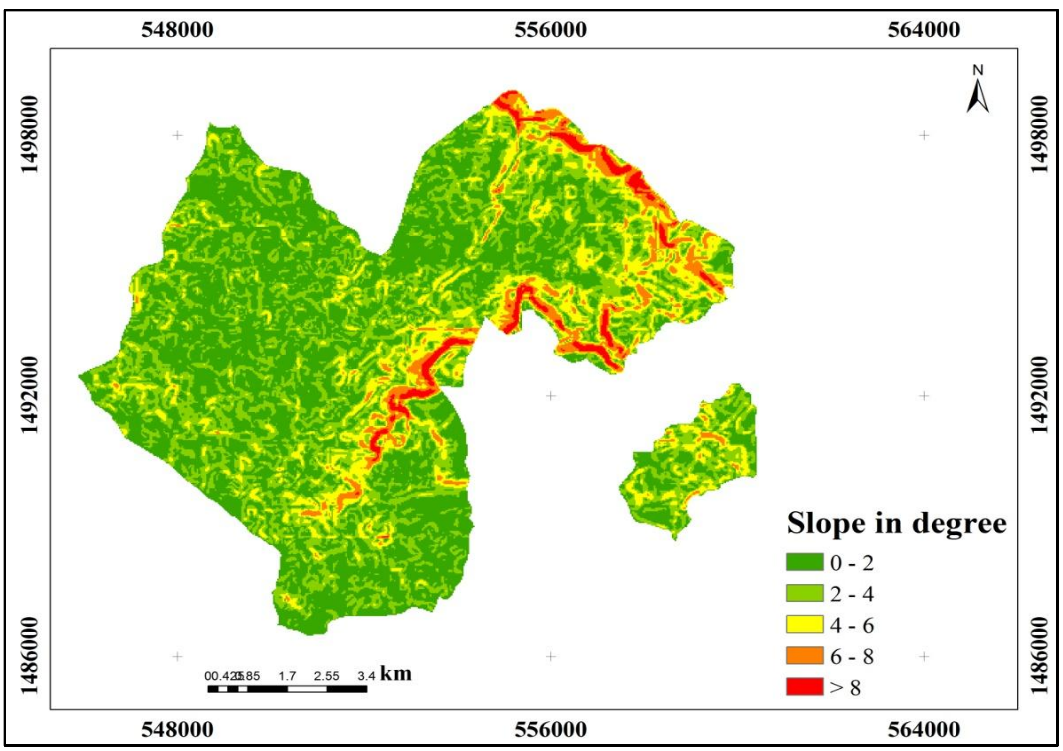


Figure 3.4: Slope map

3.4 Climate

Mekelle city has the climate area is classified as "weynadega" with an effective temperature between 24.1^{o}C and 11.11^{o}C (Ethiopian National Meteorological Agency, ENMA, 1981), which for most of the time is comfortable. It has a moisture index ranging in between 0.25 and 0.5, which indicates moderately dry area. Mekelle lies between 178 mm to 186 mm rainfall region. The mean annual temperature ranges between 5^{o}C and 28^{o}C. According to Gebremedhin (2010), the Mekelle climate has varies mainly according to elevation and slope.

3.4.1 Humidity

Humidity is a ratio between the actual vapor content of the air and the vapor content of air and the vapor contents of air the same temperature saturated with water vapor. The humidity of Mekelle city varies seasonally and timely reading. The highest amount of mean monthly humidity is recorded by the months of July and August during the rain months, as the meantime, the lowest relative humidity is recorded by the month of May. The daily variation of Mekelle mean humidity is expressed by the lowest at 12, the middle at 06, and the highest at 18 Greenwich Mean Time.

3.4.2 Wind

Wind is the movement of air. The winds that blew in special pattern that change with the season is called prevailing winds. From the month of September up to June the wind that blew to Mekelle city is from 110-1630 in the East-West direction. Similarly, from the month of July to August the direction of the wind is from 2100-2500 in the West-East direction. The data collected from Meteorological Agency was analyzed the average the wind that Mekelle has the velocity of 2.97 meter per second. This wind velocity varies in time and space month of February, March and December have the highest velocity with average wind speed per second 4.03, 3.93, and 3.62, respectively. In other hand, the months of August and September are months with low wind velocity of 1.65 and 1.83, respectively. The measurement is taken at 06, 09, 12 and 15 in almost all months the velocity of wind increase from 06 to15 Greenwich Mean Time.

3.4.3 Temperature

Temperature verifies the suitability of a site for settlement and development of various infrastructures. The temperature records were evaluated to determine the average maximum and minimum temperature of the area (Table 3.3 and Fig. 3.5). According to this evaluated the data collected from Meteorological Agency, the area has an annual average maximum temperature 28^{o}C and annual average minimum temperature 5^{o}C. There is monthly variation in temperature. December and November are the coldest months with a mean monthly maximum temperature 14^{o}C and 17^{o}C. In the same way, May, June and July are the hottest months with a monthly mean maximum temperature 24^{o}C, 28^{o}C and 24^{o}C, respectively.

Table 3.3: Mean monthly average Maximum and Minimum temperature during 2008−2015.

Monthly	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Min	9	9	12	11	12	12	13	13	9	8	9	5
Average Max	18	22	22	23	24	28	24	23	18	18	17	14

Source: National Meteorological Agency (2008−2015).

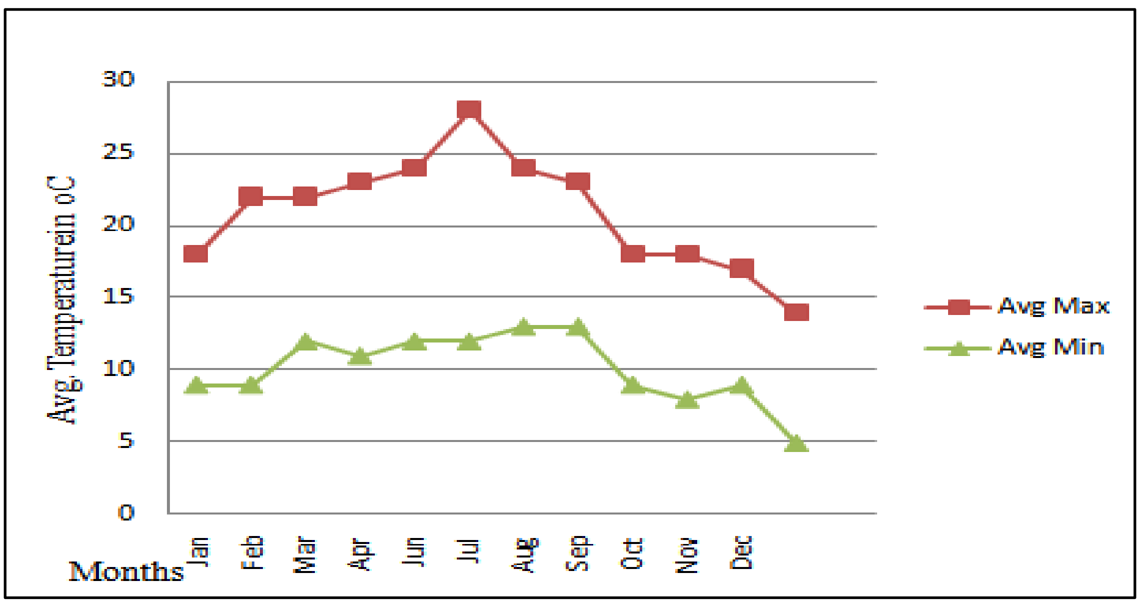


Figure 3.5: Mean monthly average Maximum and Minimum temperature (2008−2015).

3.4.4 Rainfall

Obviously, Mekelle city is found to the North of the Equator, its summer occurs by the months of June, July and August. This summer is characterized to be unreliable and unevenly distributed throughout the year. The variation of rainfall throughout the year, and from year to year, is very important to schedule appropriate formation period for any agricultural sector. From the analysis of metrological data records the area, it has an annual average rainfall of 485 mm/year. Out of this, months of July and August in combination comprise the major share of 364 mm. The amount of rainfall varies from year to year and within months of the year in the study area. (Table 3.4 and Fig.3.6).

Table 3.4: Mean monthly Rainfall Amount (2008−2015).

Monthly	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Monthly RF	1	1	16	24	19	23	178	186	24	4	8	1

Source: National Meteorological Agency (2008−2015).

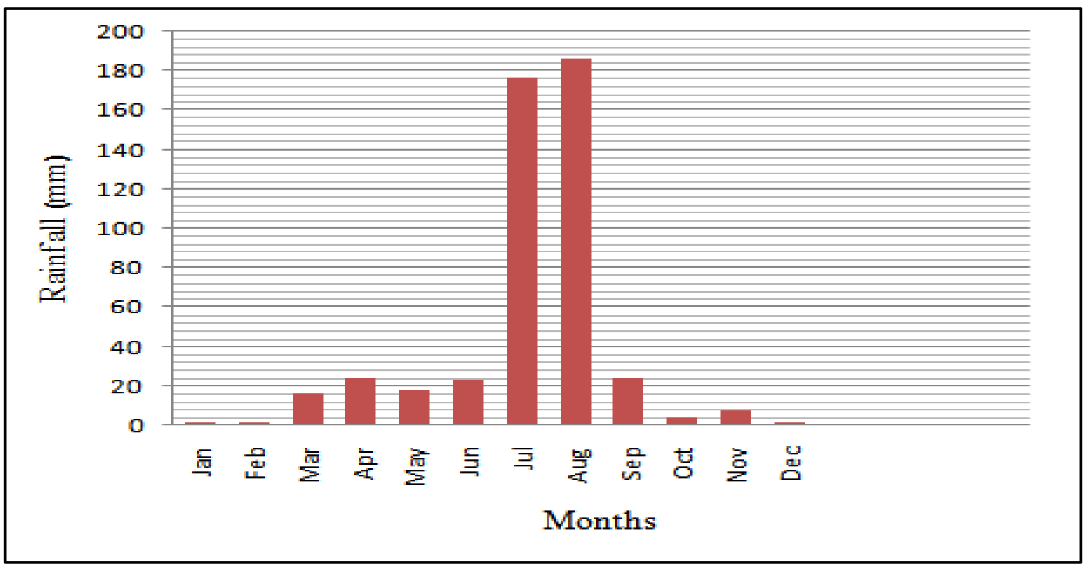


Figure 3.6: Mean monthly rainfall distribution of study area (2008−2015).

3.5 Spatial growth trend of Mekelle city

In the past, Mekelle city has been established as an urban in between 1869−1873, during the reign of Emperor Yohannes the 4th. The city was relatively equivalent to a small village. After

130 years, the city has expanded extremely by overcome many city and small villages surrounding the center of the palace (Mekelle Municipality, 2011). With population raise, the city expanded horizontally. This expansion was on disorganized without systematic extension. Erecting of infrastructure supported this. The compactness of the city became high with no planning. Access routes within settlements were for the foot and donkey or mule path only. Public safety was at a risk with frequent fire accidents. This was mainly focused on the opening of roads and categorizing of urban land-uses. The urban land demand becomes crucial issue for the municipality. The new economic police of the nation and the peace in the country encourage to return back and to invest some investment in the Mekelle city. The city administration urges a new development plan that would support the fast development of the city and expansion area. Currently for this purpose, new project office established and starts to work a strategic master plan is noted as the 2008 master plan was new in its approach as compared with the previous master plans and also allowed its revision every Five years, respectively. The 2008 master plan approach was introducing and adopting with an Integrated Development Planning, which is more participatory, flexible and development oriented. In line with the approach, the major outputs were the local development plans and structure plan and implementation tools such as rule, standards and norms. According to the Mekelle Municipality preparation this plan, was started in 2004 and completed in 2006. It was performed and certified by the city council in 2008 having ten years of valid planning periods. On the other hand, with the rapid and the complex population dynamics and activities growth Mekelle city, the master plan is becoming outdated to guide the development of the city (Table 3.5).

Table 3.5: Urban growth pattern of Mekelle city at different period (1963−2014).

No.	Year	Administrative boundary (ha)	Administrative boundary (km^2)	Source	Physical Change from preceding referenced year
1	1963	240	2.4	Municipality, 2011	Base Year
2	1984	1600	16	1993 plan	567% in 21 years
3	1994	2600	26	Municipality, 2011	62.5% in 10 years
4	2004	10240	102.4	Municipality, 2011	293% in 10 years
5	2006	21000	210	Municipality, 2011	105% in 2 years
6	2014	25995.4	259.9	Estimation	23.8 in 8 years

Source: Municipality (2011), Shishay Mehari, 2011 citing rural linkage/TUDO (2008).

3.6 Demographic characteristics

Demography characteristics express significant messages of multi-dimensional related with economic and social situations. Even if fast population growth is a burden particularly for developing countries as long as their economic progress lags behind, it is not a cause by itself since it is also a fundamental resource for development. The dynamic labor of the population is the determinant factor to run at all technology is introduced whereas high population creates demand for the growth of production of services. According to CSA (2007), the total population of Mekelle city was 215,914 out of these 104,934 males and 110,980 female. This is projected to reach 272,519 people in 2012 out of these 126,818 males and 133,749 females respectively. In addition to this, during the census the number of households of the city was 60,000 taking 4 families per house and the sex composition of the population was found to be 51.4% female and 48.6% male. But according to population estimation of Mekelle city administration the size increasing to 313,332. When population growth trend of Mekelle city compared with a preceding census year (844,040), present urban population increased by 3.2% within six years and the growth rate account about 5.5 per annum (CSA, 2007 and Tigray Bureau of Urban Development 2013). On the other hand, according to CSA estimation, population size of Mekelle city was growing by 6.9% during a period of 1995-2007 and 4.13% till 2013, respectively (Table 3.6 and Fig. 3.7).

Table3.6: Mekelle city estimated population growth trend 1965−2007.

Year	1965	1970	1978	1984	1991	1992	1993	1994	2002	2007
Population size	22,230	28,014	42,130	61,583	49,643	84,129	88,268	96,938	150,000	215,914
Growth rate (%)	0	5.2%	6.30%	7.70%	-3%	23%	2.50%	9.80%	6.80%	8.80%

Source: MUDHC ULGDP II POM Volume I, 20143/4 as estimated by CSA,2013

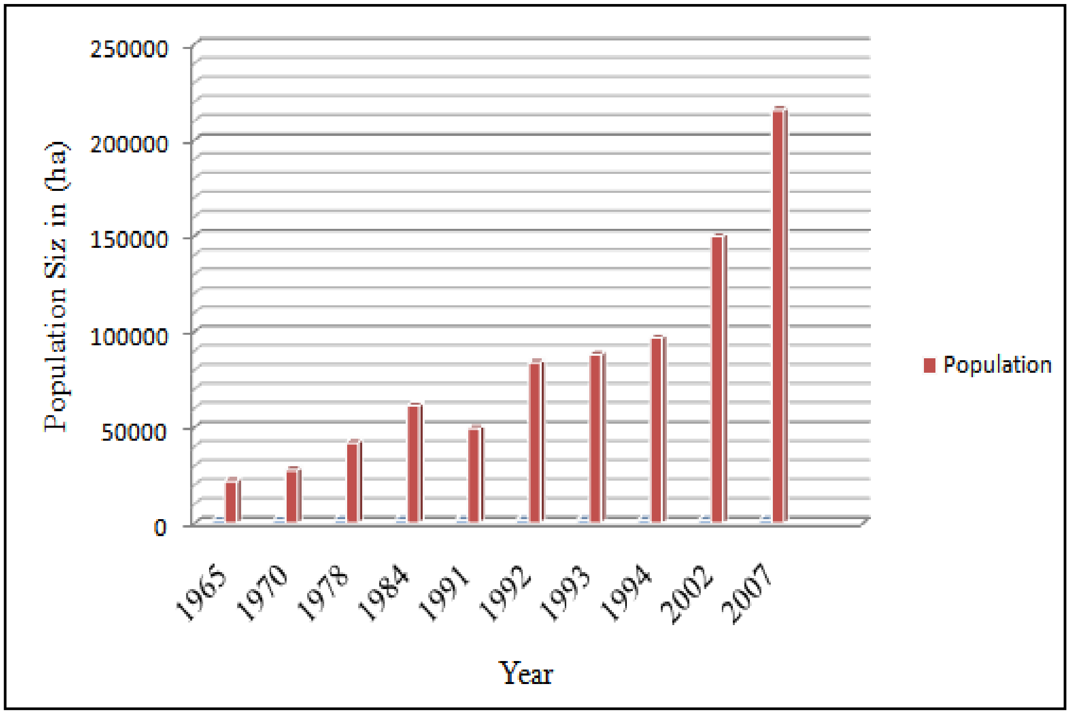


Figure 3.7: Population growth trends between 1965 and 2007

Table 3.7: Distribution and trends of Mekelle city population size by its sub-cities, 2013.

No.	Sub-city	Estimated (2005)	Estimated (2013)	Area in (%)
1	Adi -haki	17000	44051	14.1
2	Ayder	24300	44656	14.3
3	Semein	0	43212	13.8
4	Hadnet	17300	81343	16.4
5	Hawlti	16600	61507	19.6
6	Kedmi-wayane	27200	29274	9.3
7	Quiha	18000	39289	12.5
	Total	212000	313332	100

Source: Mekelle city statistical Bulline and as per CSA July 2013 estimate

3.7 Socio Economic aspect of the study

Mekelle is one of the most important center of the country for principal economic, commercial activity, industral and educational centers. Currently, the city serves as the center for goverment and public corporations and of privately owned industrial and commercial companies. Due to the favorable condition to trade and handicraft associations, the majority of the residents are engaged in micro and small enterprises. The investment projects are on agriculture, induustry, hotel, construcation, transport and social services.

Mekelle city, there are 105 schools with 81 primary and 24 secodary schools of which 75 % are goveremental schools but have only one prepatory school (excluding the Qiuba's Weldo-nigus preparatory school). Similarly, there is 57 pre-primary Education (Kindergarten). Simillarly, there is 32 Technicae and Vocational Education Training (TVET) and one University with three sub branch campusesese.These are Adihaki (FBI), Ayder (healthy) and Aynalem (veterinary) 14 colleges. With consider to the healthy institutions, there are 9 healthy centers, 4 primarly hospital (Private), 4 general hospital and one referal hospital. Besides the education and healthy coverage of the city reaches 85% and 65%, respectively. Also, regarding the economic infrastructure, currently collected data from Mekelle Municipality, the length of asphalt roads covered by 55 km. In the same way, cobble stone roads 23 km, gravel roads 139 km and unclassified and earth roads 93.4 km covered, respectively.

3.8 Data Analysis

3.8.1 Image classification and Urban land-use mapping

Classification is a technique of developing interpreted maps from remotely sensed images which requires a classification algorithms and scheme. The basic necessities for understanding urban sprawl are doing well urban land-use change detection. The amount of urban land-use changes as loss and gain were investigated by mapping the area for all study years through the process of classification. The urban land-use classes applied in this study were adapted from AFRICOVER urban land-use classification scheme which is widely applied in East African Countries (FAO, 2002). Moreover, land-use/land-cover classification scheme and visual interpretation, the following land-use groups (Table 3.8) are described for the study area considering the land-use/land-cover diversity.

Table 3.8: Classified urban land-use/land-cover classes of the study area.

No.	Class Name	Description
1	Agriculture	Rain feed arable lands, cultivated field, irrigated cropland and farming lands
2	Open area	Many of specific land cover classes, bare soil, bare land, open fields and open space or vacant space
3	Vegetation	Natural grass lands, manmade and natural forests, shrubs, woodland, sparsely planted trees and ever green forest
4	Built-up	Discontinuous and continuous urban fabric, residential, commercial, industrial, administrative units, recreation, service, transport, railway and road networks.
5	Water bodies	Artificial lakes and ponds, marshes and rivers

Source: (FAO, 2002 land-use/land-cover classification).

As noted that table 3.8, the five urban land-use categories were identified as agriculture, open area, vegetation, built-up and water bodies. From the objective of analyzing the change and modeling of urban sprawl, the above categories were further classified as built-up and non-built-up land-use/land-cover classes (Table 3.9). Once the land-use categories set up the built-up and non-built-up classification, the accuracy assessment has been validated and performed, the post classification change analysis and the statistics of the rate of changes were done on each the classified of land-use/land-cover groups.

Table 3.9: Description of regrouped urban land-use/land-cover classes.

No.	Class Name	Description
I	Built-up	Comprises industry zone, road networks construction site, commercial, residential and other associated urban land-use/land-cover
II	Non-built-up	Land with permanent crops, farming and fallow fields, rain feed arable lands, natural and manmade forest, sands, rocks, sparsely planted trees, shrubs, natural grass land and wood land

3.8.2 Training sites selection and extracting signatures

The facilitate the image classifying and to come up with a land-use/land-cover map at reasonable accuracy, training areas have been selected based on the information acquired from diverse sources. The choice of point is done by digitizing on-screen for create the area of interest files of training site polygon. Once the training site areas have been digitized, the next step is generating statistical characterizations of each land-use class. Signature file contains different types of information about the urban land-use/land-cover classes it demonstrates. These include the names of the image bands from which the statistical characterization was taken, the maximum, mean and minimum values on each band.

3.8.3 Image Classification

Geographical information system and remote sensing research focusing on image classification has attracted the attention of many researchers and come to a number of studies have been carry out using different classification algorithms. However, image classification is the development of assigning pixels of continuous raster image to predefined urban land-use/land-cover classes. It should be noted that the valuable surface information extraction and analysis is also well performed using image classification. It is time consuming and complex development, and the product of classification is likely to be affected by different factors such as algorithm, classification methods and nature of input data. Moreover, in order to improve the classification accuracy, selection of appropriate classification method is required. This would also enable analyst to detect changes successfully.

3.8.4 Supervised classification

Supervised classification was used, in this study, to cluster pixels in data sets in to classes corresponding to user defined training classes. This classification type requires selecting training area for use as the basis for classification. Of the most common supervised classification techniques, maximum likelihood classifier for parametric rule was applied. Having prior acquaintance with the study area, in the present study, GARMIN GPS provided from INSA was used to collect representative points of various land-use /land-cover classes during the field visit.

3.8.5 Pixel based classification

In this technique, each pixel is classified based on the spatial arrangement of edge features in its local neighborhood. Image classification at pixel level could be unsupervised or supervised. During unsupervised classification, input from the analyst in order to specifying the number of clusters and labeling the cluster is very limited. This technique is associated with the mixed-pixel problem and it may not clearly show the required classes of interest and the detecting changes using this technique may not be effective. Conversely, in supervised classification method such as maximum likelihood and the analyst is responsible for training the algorithm, the result could be effective. The pixel-based processing technique segments the images in to non-homogenous regions based on the neighboring pixels' spectral and spatial properties.

3.8.6 Image classification and validation techniques

Investigation of a number of the literature reviewed and the analyst's personal knowledge revealed that pixel-based classification produces consistent output. This is true not only with common or coarse resolution images but also with very high resolution images (e.g. Aerial photograph and Quickbird). Image analysis technique that considers both the measured reflectance values and neighborhood relations (pixel-based analysis) are available in ERDAS Imagine and ArcGIS software packages. Such pixel-based schemes are essential for urban growth studies respectively.

Under this study, ArcGIS was used to perform mapping operations and sprawl analysis. The ERDAS Imagine software was used to classify the Landsat images, Quickbird and Aerial photograph. It has the capabilities to collect training samples and classify. It also supports different methods to train the algorithm and build up resource, and knowledge-based image classification. The pixel-based classification methods for change detection holds much promise and great potential opportunities for identifying and characterizing of urban land-use change process. A set of stratum random selected pixels which has a true values were used in ERDAS Imagine to conduct the accuracy assessment. Similarly, the Quickbird image and Aerial photograph were used for visualization, interpretation and verification of urban land-use/land-cover classification. The urban land-use/land-cover objects visualization as follow Figure 3.8.

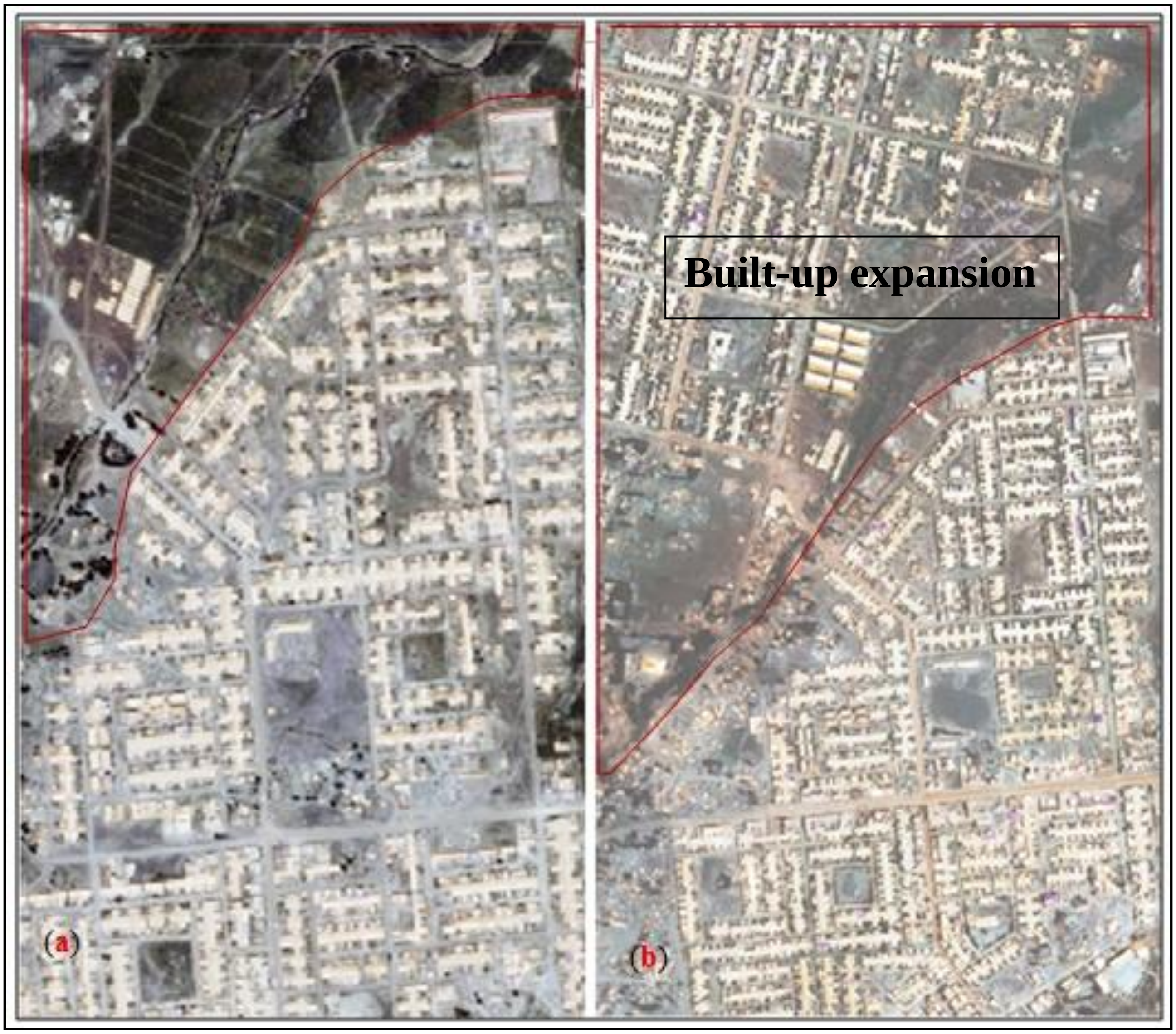


Figure 3.8: Quickbird year of 2005 (**a**) and Aerial photograph year of 2016 (**b**).

3.8.7 Image classification validation

Accuracy assessment is significant for usual photographic remote sensing techniques, with the arrival of more advanced digital satellite remote sensing the necessity and possibility of performing advanced accuracy assessment have received new interest. According to Genemo (2012), accuracy assessment is a development used to validate the accuracy of image classification by comparing the classified map with a reference data. Eventually, accuracy assessment is considered as an integral part of any image classification. This is because image classification using different classification algorithms may classify pixels or group of pixels to the wrong classes.

The best observable types of error that occurs in image classification are errors of omission or commission. In order to use the derived urban land-use maps for further changes analysis, the errors should be evaluated and quantified in terms of classification accuracy. The technique provides some statistical and analytical approaches to examine the accuracy of the classification. Kappa's Coefficient, which is one of the most popular measures in addressing the different between the actual agreements, was also calculated from the error matrix. The reference data used for accuracy assessment are usually obtained from very high resolution (e.g. aerial photograph), high multi-spectral resolution images (e.g. Quickbird).

3.8.7.1 Producer's Accuracy

Producer's accuracy is the possibility of a reference pixel being classified correctly. It is achieved by dividing the number of correctly classified pixels in the category by the total number of pixels of the category in the reference data. It is also known as omission error because it only gives the proportion of the correctly classified pixels.

3.8.7.2 Overall Accuracy

Overall accuracy is computed by dividing the total correct number of pixels summation of the diagonal to the total number of pixels in the matrix (Mas, 1999). Various standard threshold levels were applied to the lower and higher tail of each distribution, in order to find the threshold value that produced the highest change classification accuracy. For this study, results shows that the achieved overall accuracy is the total classification accuracy, which is computed by dividing the total number of pixels summation of the diagonal, to the total number of pixels in matrix or grand total. It can expressed by Xii and Nas:

Overall accuracy = $\sum Xii/N$

where, Xi i= Number of correctly classified pixels, and N = Entire number of pixels in the matrix.
Different standard threshold levels were applied to the lower and higher tail of each distribution made in some empirical studies by different authors':

- According to Anderson (1976), it is noted that a minimum accuracy value of 85% is required for effective and reliable land-cover change analysis and modeling.
- According to Mas (1999), noted that in order to find the threshold value that produced the highest change classification accuracy.
- According to Medina (2015), pointed out that the expected accuracy threshold is usually determined by the users themselves depending up on the purpose of the urban land-cover map, different people use different accuracy levels.
- The value of KC equal to 0.885 which was acceptable according to the United States Geological Survey agency limit i.e.0.85. Based on current study's confusion matrix of all the derived land-use/land-cover map has revealed the overall accuracy levels of more than the minimum accuracy threshold defined by Anderson.

3.8.7.3 User's Accuracy

User's accuracy is the possibility of the pixels in the classified map characterizes that class on the ground (Medina, 2015). It is achieve by dividing the total number of correctly classified pixels in the category by the total number of pixels on the classified data. Table 4.4 illustrates that the value of both the producer and user accuracies of each land-use/land-cover class for the three specified time periods.

3.8.7.4 Kappa Coefficient

Kappa Coefficient is an evaluated agreement used to evaluate the classification accuracy. According to Genemo (2012), it expresses the proportionate reduction in error generated by a classification process compared with the error of a completely random. The assessment of the study area was carried out using aerial photograph and ground truth points from field observations as the major sources of reference data. A set of reference points has to be generated to assess accuracy and stratified random points were generated for each derived maps.

These points were verified the collected ground truth data from the reference of Aerial photograph. The research study also assessed the accuracy of the 1989−2016 classification. A total of 80 (46 for built-up, 12 for agriculture, 10 for forest, 7 for open area and 5 for water) truth ground data were taken and their land-cover were defined from field visual interpretation using very high resolution printed. The points were scattered throughout the area, following are almost stratified random points. The highest amount of points was collected where there is a high concentration of built-up area and the distribution of ground truth data on field verification and vested on the actual ground points (Fig. 3.9).

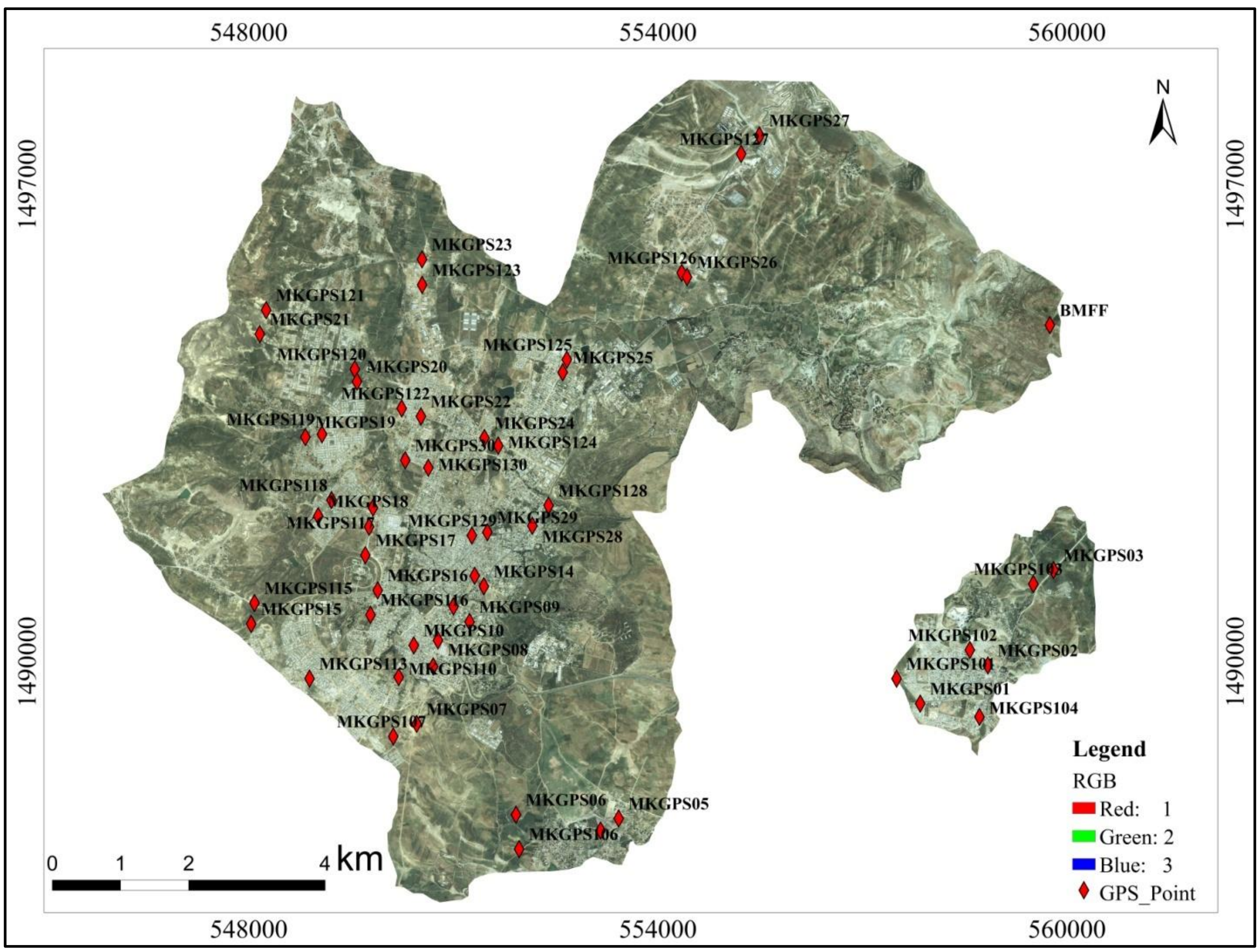


Figure 3.9: Ground truth points (Quickbird image, RGB: 1,2,3 True Color Composite).

3.8.7.5 Sample sites profiles using GARMIN GPS

GARMIN GPS was used for making and recording coordinate points (Appendix 1). Very high resolution to locate the sample sites area vested. Random sampling technique was used to picked five photo samples and capture 80 representative truth ground data and training samples. The area was sub divided into strata based on the interpretation elements tone(color), texture, pattern, shape and size. In each random points in several places were marked, recorded and categorized in to their respective land-use/land-cover classes which were built-up (Plate_2), open area (Plate_3), agriculture (Plate_4), vegetation (Plate_5) and water body (Plate_6). The sample sites were mostly residential with huge industrial developments and community features that have been influencing on peri-urban arable lands. Each of these developments has had somewhat different characteristics as far as sprawl pattern and community features are concerned. Mekelle Municipality office is a sampled as a community feature (Plate_1). The other samples that were considered to represent examples of urban sprawl pattern as expansion, linear, leapfrog and cluster in various sites of the study is shown in Plate_7, 8 and 9, respectively (Appendix 2).

3.9 Urban sprawl measurement using Shannon's Entropy

Shannon's entropy is one of the most commonly used with integrate geographical information system tools. Several attempts have been made to measure sprawl (Yeh and Li 2001; Sun *et al.*, 2007). Entropy means a measure of disorder in a data set. This Shannon's entropy is efficient approach and relatively straight forward to analyze urban sprawl. Similarly, Shannon's entropy is also used to measure the degree of spatial concentration and dispersion of urban sprawl. The entropy value varies from 0 to 1. A minimum value of 0 is obtained if the distribution is maximally concentrated in one region while an evenly dispersed distribution across space gives a maximum value of 1. This gives a clear idea to recognize whether land development is more compact or dispersed. The dispersion of built-up areas from a city centre.

$$En = \sum_i^n \ Pi \log(1/Pi) / \log(n) \quad \text{....................}(4.1)$$

Where; $P_i = Xi/\sum_i^n Xi$ and Xi is the density of land development, which equals the amount of built-up land divided by the total amount of land in the i^{th} zone in the total zone of n zones.

The number of zones means the number of buffer zones around the city center. Since entropy can be used to measure the distribution of a geographical phenomenon, the difference in entropy between two different periods of time can also be used to indicate the change in the degree of dispersal of land development or urban sprawl (Yeh and Li, 2001).

ΔEn $= En(t+1) - En$ (t)...(4.2)

Where, ΔEn is the difference of the entropy values between two time periods between the years 1989 and 2005, $En(t+1)$ is the entropy value at a time period (t+1) 2005 and En (t) is the relative entropy value at time of 1989. For this study is concerned in the urban land-use/land-cover only, we use the earlier simplified classes of built-up and noon-built up areas of three land-cover maps of the year 1989, 2005 and 2016. By considering the concentric buffer rings, each having a 1km was needed to cover all parts of the sub-city and city respectively. The effort was made to measure the urban sprawling during 1989, 2005 and 2016 years using Shannon's entropy approach. The buffer ring, for example, includes areas outside the study limit, though it is a good approach for measuring urban sprawl, noted that, Shannon entropy is a good approach for measuring urban sprawl. .

3.9.1 Population density and urban sprawl

One of the major driving forces of urban sprawl is population growth with rapid growth of population and migration effects in the city has put great pressure on the demand for urban land spaces. Under this study in order to have more understanding of the situation, the population density of the Mekelle city (persons per hectare) during of 2005 and 2013 will be analyzed. Based on the analyzed result (Table 3.11) in the study area, urban sub-cities of Mekelle has facing to a high population density.

Table 3.10: Population size and density of Mekelle sub-cities.

Sub-city	Pop total 2005	Pop total 2013	Area (ha)	Density 2005 (Person/ha)	Density2013 (Person/ha)
Adihaki	17000	44051	1247.06	13	35
Ayder	24300	44656	872.43	27	51
Semen	0	43212	725.10	-	59
Hadnet	17300	81343	1225.43	14	66
Hawlti	16600	61507	1277.11	12	48
Kadmi wayane	27200	29274	779.41	34	37
Quiha	18000	39289	1177.77	15	33
Total	212000	313332	704.31	118	331

Source: Mekelle city statistical Bulline and as per CSA July 2013 estimate

After computed the population density person/ha, the overall population density results were in the following 2.4 in 1963, 19.79 in 2005 and 47.36 in 2013. This investigation will further discuss in the next chapter of the result part.

3.10 Model calibration for urban land-use

First of all, define modelling; modelling is a significant role for understanding urban land-use change, the impacts, the development plans and decision making process. Nowadays, several researchers used a number of modelling techniques and approaches. Current technological advancement in the spatial modelling for rapid expansion of urban population, energetic urban features and urban areas influence natural and human systems at all geographic scales.

Model calibration is a part of cellular automata. The term CA itself is advanced from the fact that it consists of cells and transition rules which are useful to determine the state of a particular cell. CA is a dynamic discrete system in space and time that operates on a uniform grid based space (Medina, 2015). Alternatively, Markov Chain is a method in which the future state of a system is modelled on the basis of direct proceeding state. Also, Markov Chain describes the probability of land-use/land-cover changes from one period to another by developing a transition probability matrix between time 1 and time 2. According to Eastman (2012), the probabilities may be accurate on a per category basis but there is no knowledge of the spatial distribution of occurrences within each land classes. The CA components of Markov model add the spatial components it allows the transition probabilities of one pixel to be a function of neighbouring pixels to avoid this limitation (Sun *et al.*, 2007).

As a result, CA-Markov is a combination of both CA and Markov chain. These two modelling tools are termed as geo-simulation techniques used to produce land-use/land-cover predictions. Geo-simulation refers to the process of land-use change between two points in time and extrapolating this change to the future (Medina, 2015). Under this study employed a CA-Markov chain analysis integrated with raster based remote sensing and geographic information system to explore land-use spatial pattern, magnitude and dynamic of the city of Mekelle. Model calibration analysis in the case of CA, the first method is developing a transition probability matrix for each urban land-use/land-cover classes. A transition probability matrix is the probability that each land-use grouping will change to every other grouping; for example, the probability of changing from vegetation class in the time of 1989 to open area and other urban land-use/land-cover classes in 2005. This research developed between 1989 and 2005 (Table 4.5) to predict land-use/land-cover of 2016 and between 2005 and 2016 for modelling of 2026 using an input for projecting urban land-use/land-cover change in 2026.

3.10.1 Model implementation and validation

CA-Markov model of IDRISI Selva has been used to compute transition area and project each urban land-use in 2016 based on the urban land-use classes of 1989 and 2005 (Fig 3.12). The module uses the following elements to determine the location of changes:

a) Transition area matrix

The transition area matrix is used to predicate the future urban land-use change probabilities; the transition area matrix of 1989−2005 was used to predict the 2016 urban land-use categories. Therefore, the input 2005−2016 transition area matrix was used for predication of the 2026 urban land-use.

b) Base urban land-use image

The base land-use image is used to predicate the 2016 urban land-use map is that of 2005 urban land-use map. For this predication of the time 2026, actual urban land-use map of 2016 is used to the base urban land-use image.

c) Contiguity 5*5 filter

A contiguity 5*5 filters are considers as the predicated land-use change to be within two pixels of the edge including the diagonal. Including all these inputs, the module determines number of pixels that must undergo in each transition. The following map presents the actual and predicted land-use maps for the year 2016.

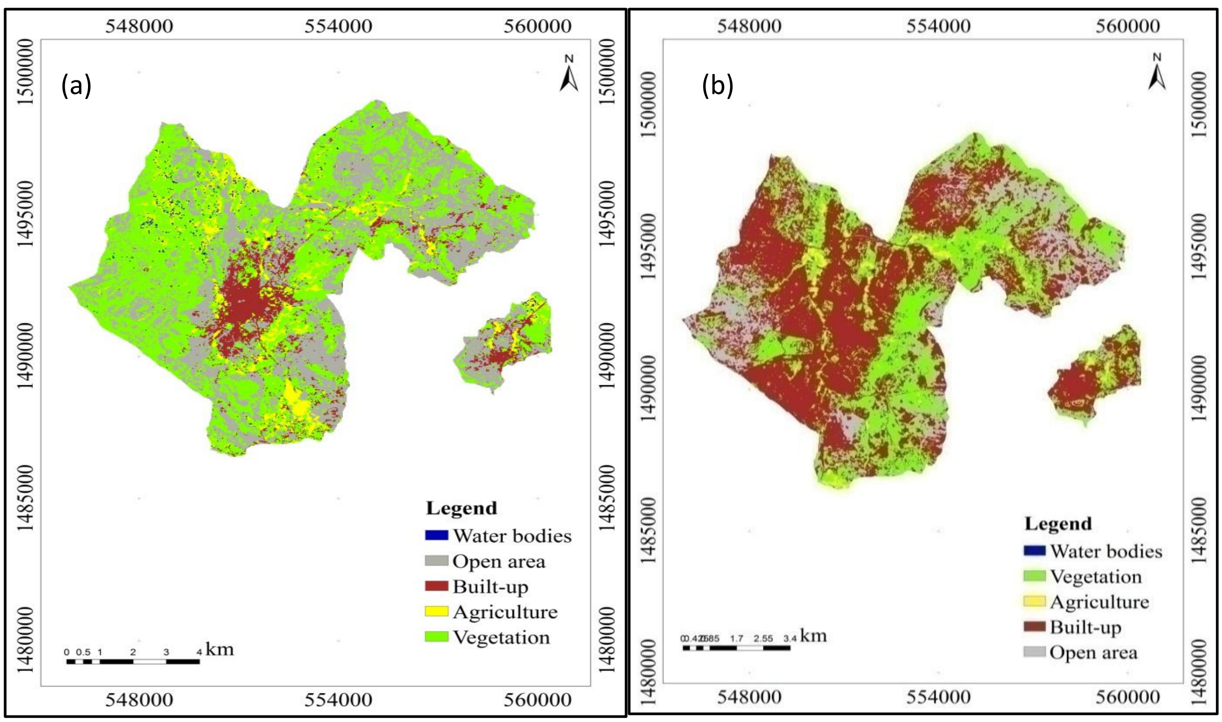


Figure 3.10: Actual urban land-use of 1989 (a) and Predicted urban land-use map of 2016 (b).

Figure 3.12 reveals that the evaluation between actual urban land-use and simulated maps are different urban land-use classes have shown a comparable result of area coverage (Table 3.12) and (Fig 3.13). For example; the area of water bodies in actual land-use map is 42.05 ha and 2.0 ha in predicated land-use. Obviously, the actual urban built-up is 776.86 ha and predicated urban built-up class illustrates as 4547.6 ha. This show that the actual water bodies and agriculture is converted in to built-up area.

Table 3.11: Actual and predicated land-use/land-cover maps of 2016.

Class Name	Actual area (ha)	Predicated map area (ha)
Built-up	776.86	4547.6
Agriculture	5012.62	449.75
Vegetation	4571.93	2118.6
Water bodies	42.05	2.00
Open area	3274.70	2049.6

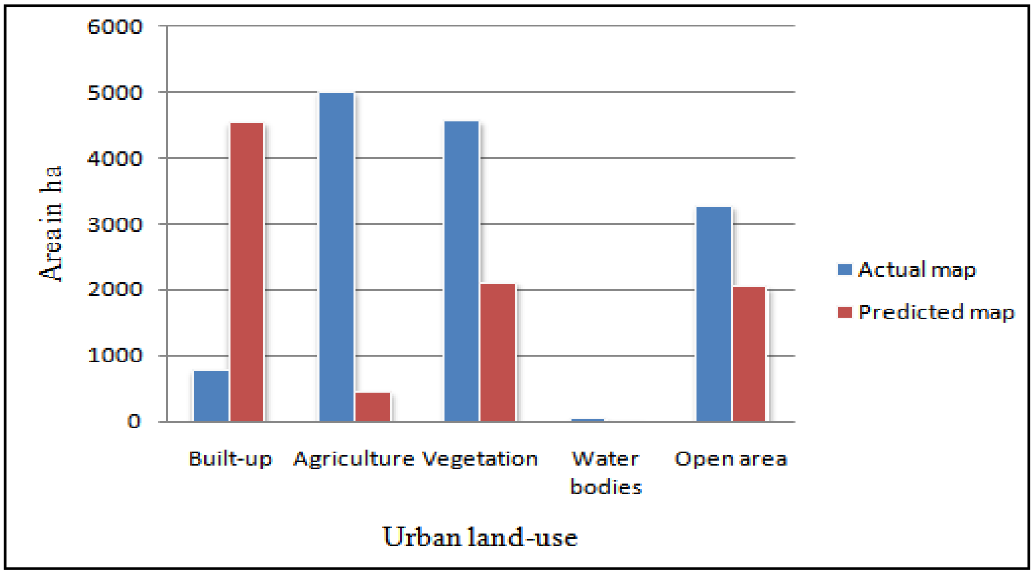


Figure 3.11: Comparison between actual and predicated land-use maps of 2016

3.10.2 Model validation

Model validation is an important step in the modeling land-use process. The technique to quantify the predicative power of the model used is comparing a result of the predicted map to a reference map one considering as more accurate at time of predication.

CHAPTER FOUR

4. Results

4.1 The detecting urban land-use/land-cover change detection pattern

This study started from classification, both land-use/land-cover classes (built-up, agriculture, vegetation, water bodies and open area) have different spectral reflectance property and pattern (Fig. 4.1).

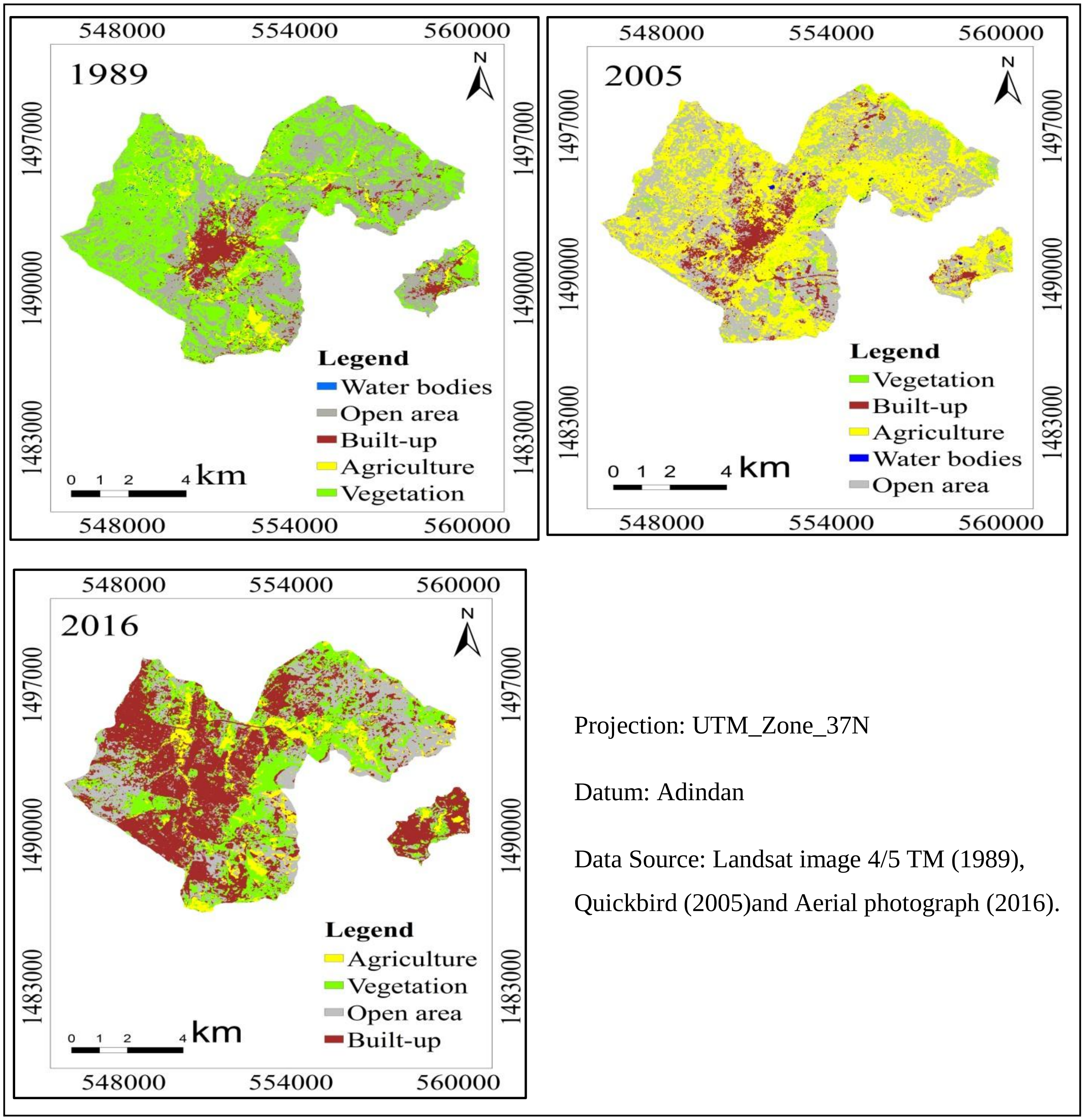


Figure 4.1: Urban land-use/land-cover maps

Accordingly Table 4.1 and Fig 4.2, built-up is the most dominant urban land-use class occupying more than 60% of the total area and shares the largest portion 6.08% in 1989, 44.36% in 2005 and 66.20% in 2016. On the other hand, open area is the second largest portion in the area during 1989 (35.49%), 2005 (30.0%) and 2016 (17.32%). This shows that the declining pattern occurs in the area. Similarly, another extremely declining pattern of land-use class is water bodies which is less than 2% of the total and share the least portion 49.55 % in 1989, 10.80% in 2005 and 1.00% in 2016.

Table 4.1: Comparison of the area of urban land-use in year 1989−2016.

	Area in ha and percentage during					
	1989		2005		2016	
Class Name	Area (ha)	Area (ha) in %	Area (ha)	Area (ha) in %	Area (ha)	Area (ha) in %
Built-up	561.56	6.08	4580.95	44.36	17808.68	66.20
Agriculture	42.05	0.46	385.75	3.74	1149.43	4.27
Vegetation	776.86	8.42	1146.64	11.10	3015.20	11.21
Water body	4571.93	49.55	1115.29	10.80	269.21	1.00
Open area	3274.70	35.49	3099.13	30.00	4658.73	17.32
Total	9227.10	100	10327.75	100	26901.25	100

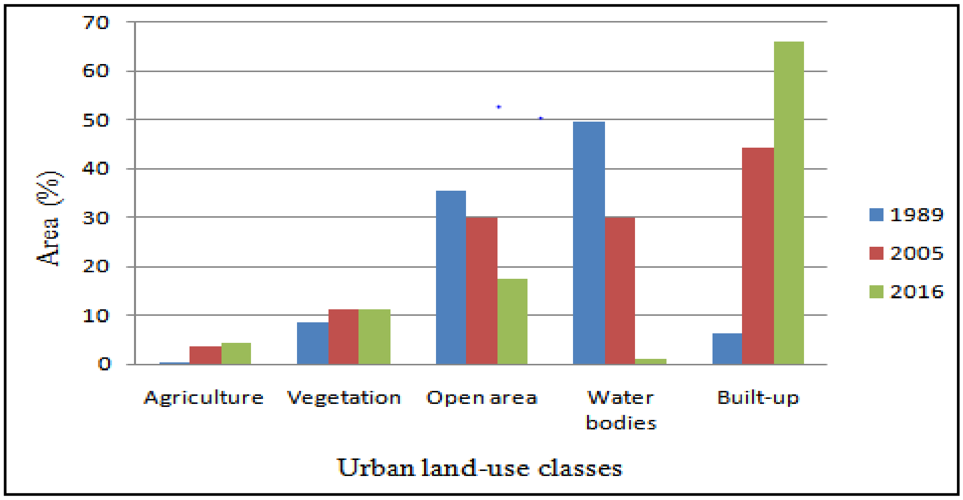


Figure 4.2: Urban land-use change in the study area from 1989,2005 and 2016

In order to observe the nature and spatial extent of the urban land-use/land-cover maps were also categorized in two broad classes. This categorized of shows the comparisons of urban land-use of built-up and non-built up areas in the different periods (Fig. 4.3).

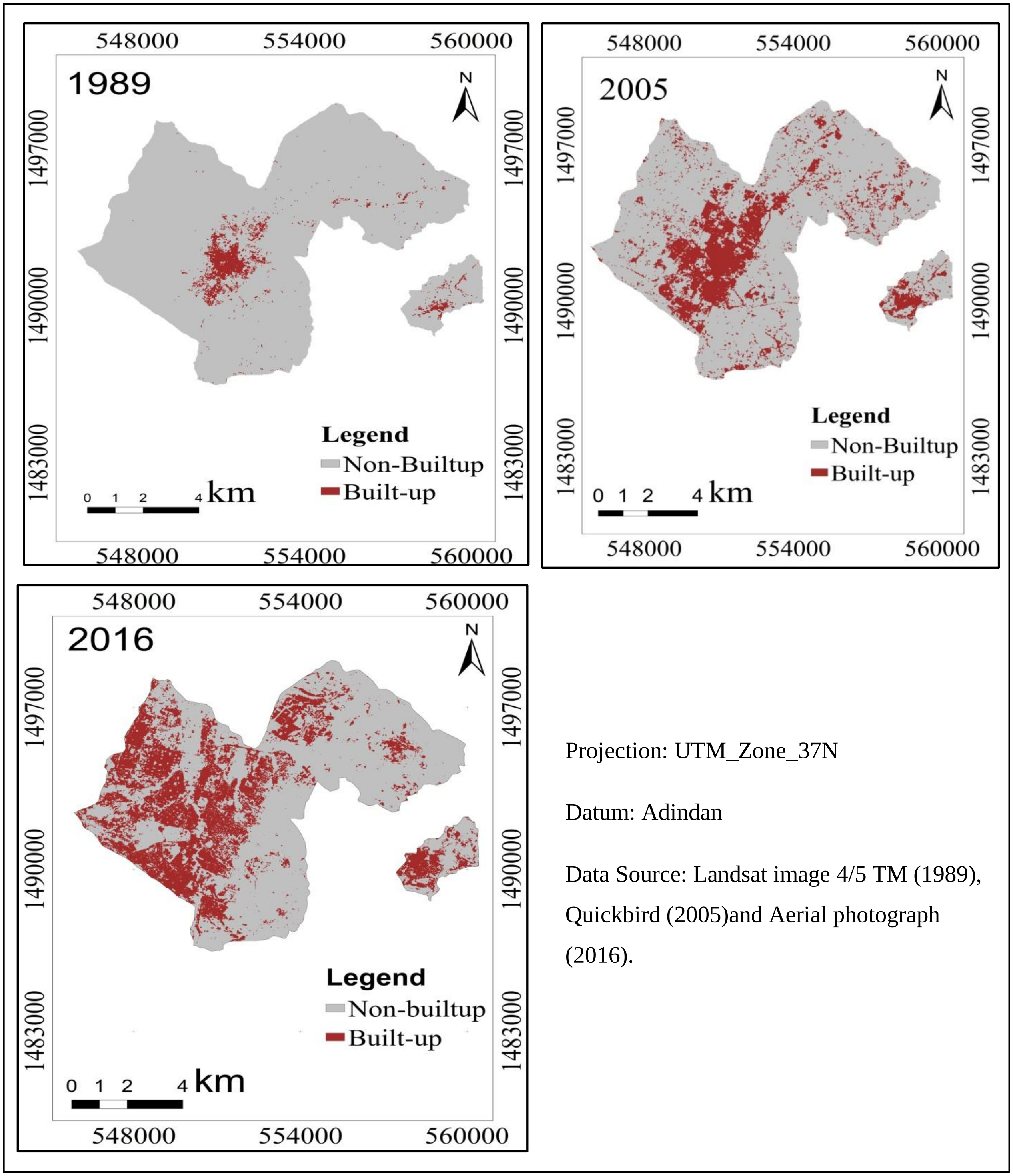


Figure 4.3: Urban land-use of built-up and non-built up map

4.1.1 Trends of urban land-use expansion rate

Under this study the results of classification (Table 4.2) in the period's 1989−2005 water bodies and open area were radically decreased. Specially, water bodies decreased by -3456.64 ha (-37.46%) during these 16 years. This could be due to a shortage of rain and the water also disappear. Areas under agriculture and vegetation covered by 343.69 ha (3.72%) and 369.78 ha (4.00%). On the other hand, built-up area increased by 4019.39 ha (43.56%).

Recognition of urban land-use for a period of 2005−2016 during these 11 years, the area under vegetation, open area and agriculture were increasing by 1868.56 ha (18.09%), 1,559.60 ha (15.10%) and 763.69 ha (7.40%) whereas water bodies decreased by -846.08 ha (-8.19%). Specially, built-up was significantly increased by 13227.73 ha (128.08%). This shows that the area under built-up increased significantly indicating urban sprawl.

The change detection from 1989−2016 showed during these 27 years, built-up, vegetation, open area and agriculture areas were increased by 17247.12 ha (64.11%),1107.38 ha (41.29%), 2238.34 ha (8.32%) and 1384.03 ha (5.15%) while water bodies decreased by -4302.72 ha (-15.99%). The change of urban land-use areas in periods 1989−2005, 2005−2016 and 1989−2016 are computed in (Table 4.2 and Fig 4.4).

Table 4.2: Urban land-use classes and rate of change during 1989−2016.

	Rate of Changes (%)					
	1989−2005		2005−2016		1989−2016	
Class Name	Area (ha)	Area (ha) in %	Area (ha)	Area (ha) in %	Area (ha)	Area (ha) in %
Built-up	4019.39	43.56	13227.73	128.08	17247.12	64.11
Agriculture	343.69	3.72	763.69	7.40	1107.38	41.29
Vegetation	369.78	4.00	1868.56	18.09	2238.34	8.32
Water bodies	-3456.64	-37.46	-846.08	-8.19	-4302.72	-15.99
Open area	-175.57	-1.90	1559.60	15.10	1384.03	5.15

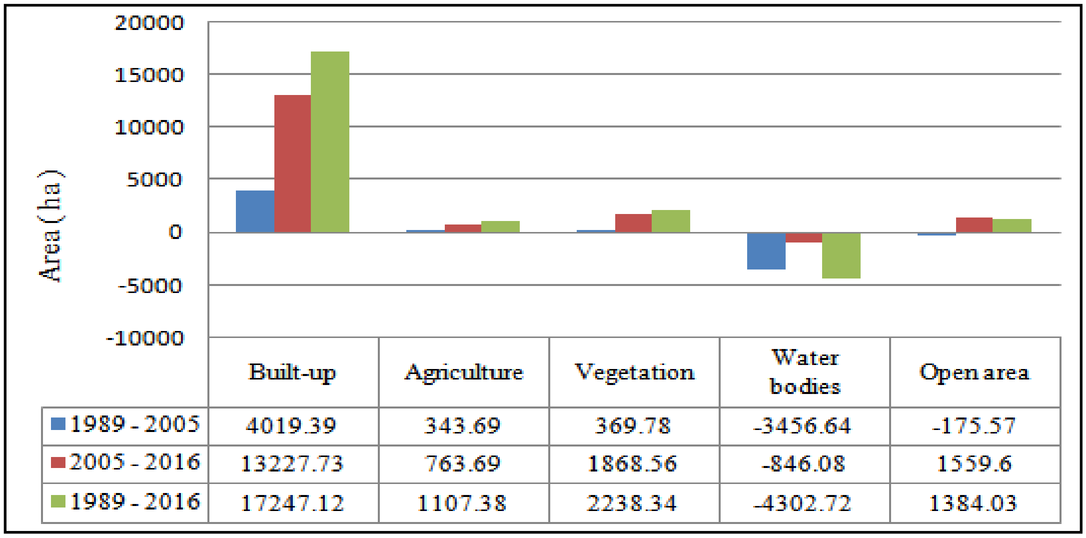


Figure 4.4: Urban land-use changes during1989−2005,2005−2016 and 1989−2016

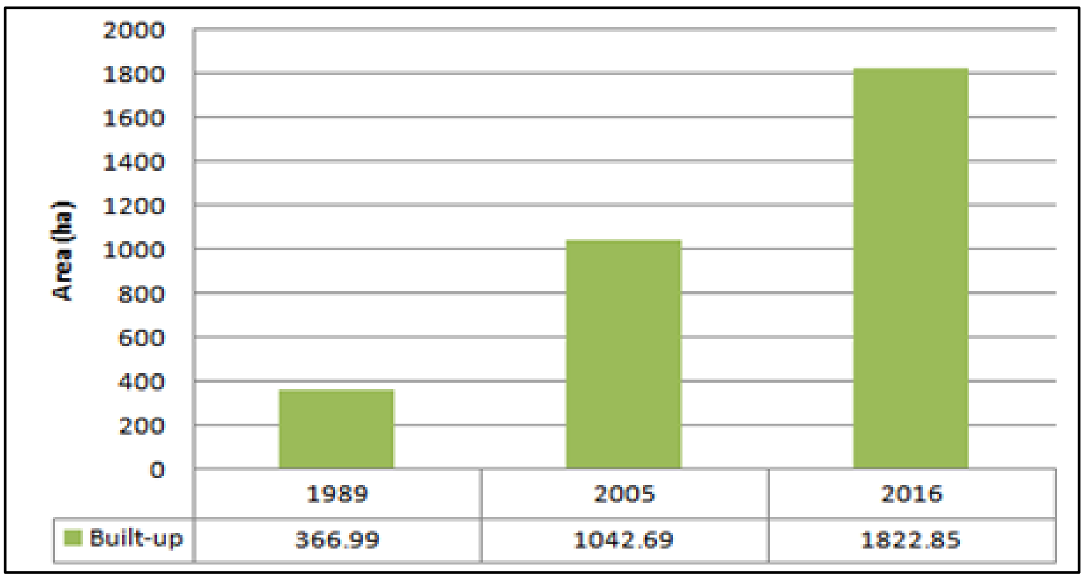


Figure 4.5: The built-up urban land-use trends in Mekelle city

The trends show that the amount of urban growth and its increment during 1989−2016 has increased considerably during this time (Fig. 4.5). That is, 675.7 ha increment from year 1989 to 2005 and 780.16 ha increment from year 2005 to 2016. Approximately, the area doubled from 1989−2005 to 2005−2016. The average annual growth rate from 1989 to 2016 was 4.19 ha. Groundwork results from the multi-date visual change detection indicate that urban land-use had changed extensively over the period from 1989−2016 clear observation incident of urban sprawl phenomena in the study area. Besides, the change detection of time series analysis of urban land-use shows that the dynamic change of spatial structure in different periods. The dynamic change of spatial structure is an important indicator that can reflect the dynamic change of urban spatial expansion (Fig.6). The formula of dynamic change rate of urban sprawl adapted from Feng Li (2012) was computed (Appendix 3). A higher rate of dynamic change indicated a faster speed of sprawl. Hence, this method is very important to compare the rate of urban sprawl for the same area between two separate periods. For example, the rate of expansion between 1989−2005, 2005−2016 and 1989−2016 is computed as follow:

I. Built-up change rate the period 1989−2005

BU= 44.74 %

II. Built-up change rate the period 2005−2016

BU= 26.4 %

III. Built-up change rate the period 1989−2016

BU= 113.8 %

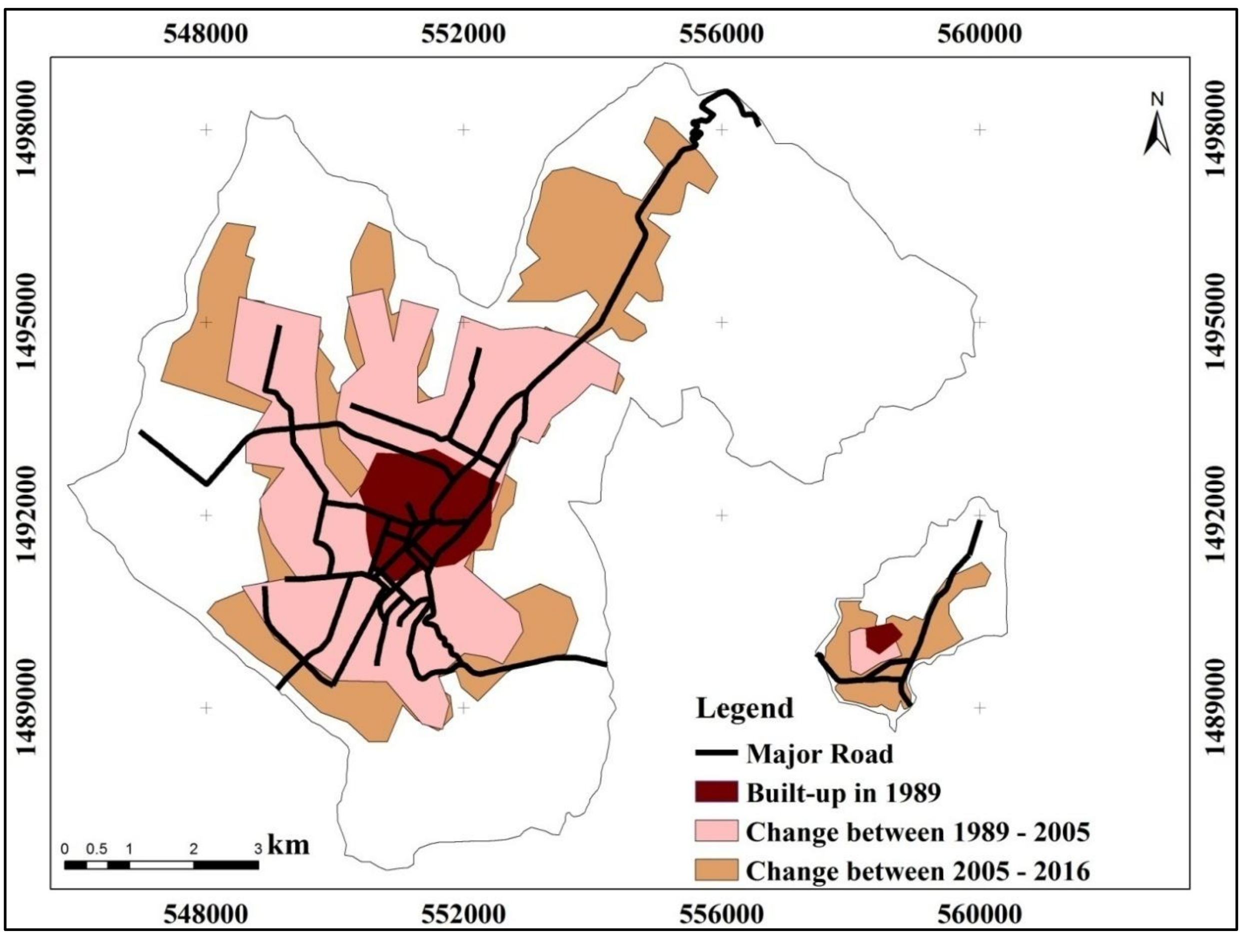


Figure 4.6: Built-up area boundaries changes between 1989, 2005 and 2016

From the above results, built up change rate calculation between consecutive periods shows that the rate of built-up area expansion was high (44.7 %) between 1989 and 2005. During this early period of the measurement, much of the non-built areas have been rapidly converting to the built-up area. In the middle period the built-up expansion rate between 2005 and 2016 is also found to be relatively medium (26.4%). Compared to another periods the rate of built-up expansion between 1989 and 2016 was very rapid rate (113.8%). The trend of built-up area expansion assessed here complies with the urban land-use category derived from the computed class.

The magnitude of the changes occurred in the peripheries of the existing built-up areas. Some of the observed types of change exposed by the study were urban sprawl expansion and densification development. The city of Mekelle has been expanding in almost all directions having different pattern of urban sprawl; linear strip and compact were observed. Between 2005 and 2016, there were remarkable extension trends in all direction of the city, for example; Ayder and Semen sub cities were forms linear strip sprawl expansion, Quiha, Adihaki, Hawelti and Hadinet were forms compact sprawl expansion. While, Kedamay weyane sub-city was almost silenced extension trends among the rest of six sub cities. Thus, built-up expansion the result of the increase population because of a big demand for land by the high number of industries, schools and offices built during last 27 years. As per the result, it is possible to see not only built-up are use change but also provides an estimate of the extent of magnitude or direction of the urban sprawl changes in this study area. (Fig. 4.7).

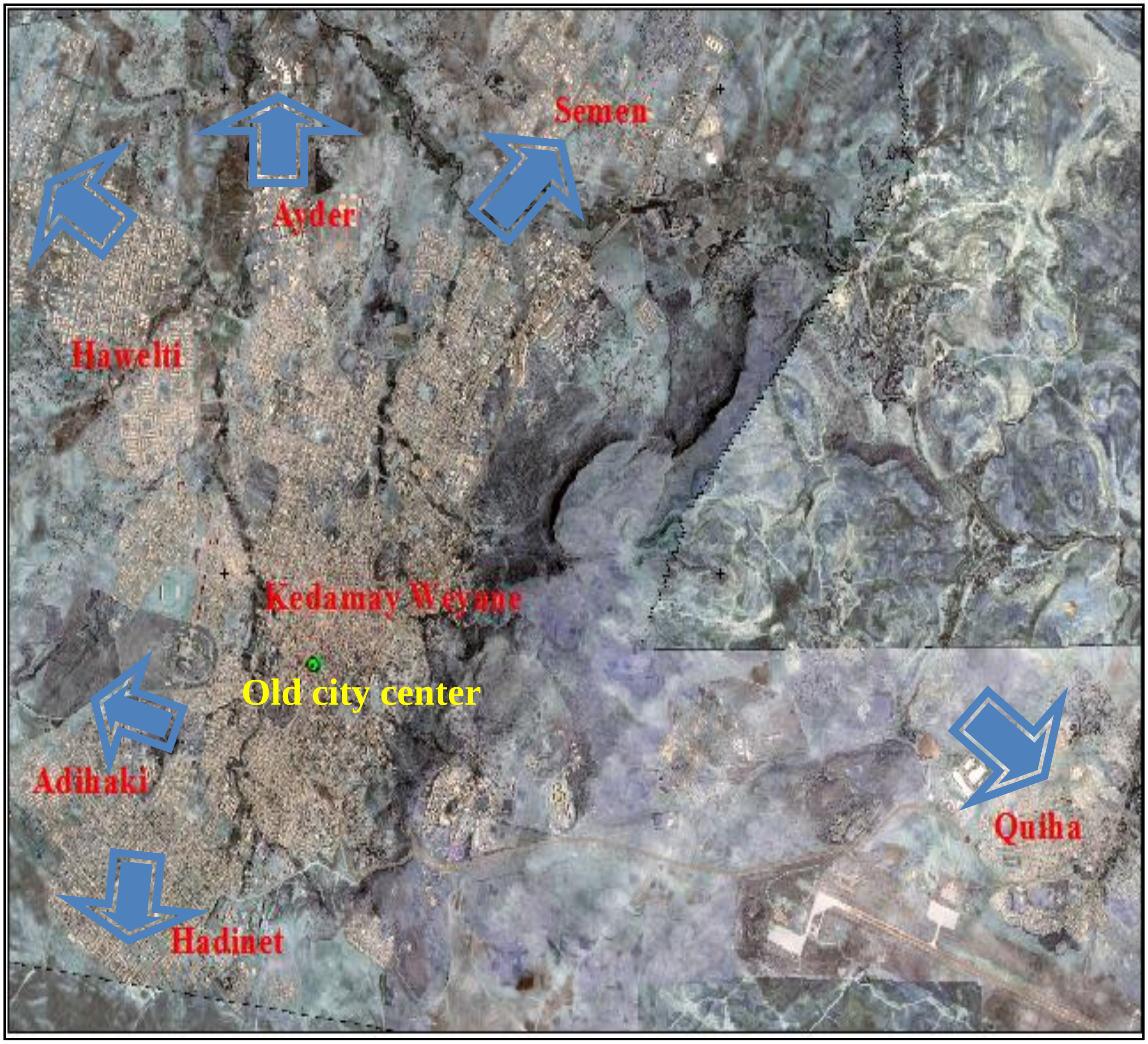


Figure 4.7: Urban sprawl expansion direction of 2016 (Source: mosaic Aerial photograph 2016).

4.1.2 Accuracy assessment of urban land-use mapping

The accuracy is essentially a measure of how many ground truth pixels were classified correctly. An error report containing the error matrix and accuracy report summarizing the agreement and disagreement are produced. The ground truth data were utilized in the classification report as the independent data set from which the classification accuracy was compared. An overall accuracy of 87.89%, 85.33% and 90% was achieved with a Kappa coefficient of 0.81, 0.80, and 0.83 for the three time series of satellite images (Landsat TM 4/5 1989, Landsat ETM+ 2005 and OLI 8 2016), respectively (Table 4.3).The overall accuracy is a similar average with the accuracy of each class weighted by the population of test samples for that class in the total training or testing sets. Thus, the overall accuracy is a more accurate estimate of accuracy. The Kappa coefficient represents the proportion of agreement obtained after removing the proportion of agreement that could be expected to occur by chance. The kappa coefficient lies typically on a scale between 0 and 1, where the latter indicates complete agreement, and is often multiplied by 100 to give a percentage measure of classification accuracy.

Table 4.3: Accuracy assessment results.

Satellite Data	**Classified image**	**Overall accuracy (%)**	**Kappa statistics**
Landsat 4/5 TM	1989	87.89	0.81
Landsat ETM+	2005	85.33	0.80
Landsat 8 OLI	2016	90.00	0.83

The Kappa statistic incorporates the off-diagonal elements of the classification error matrices and represents agreement obtained after removing the proportion of agreement that could be expected to occur by chance. The producer's accuracy and user's accuracy for individual land classes presented in table 4.4. The producer's accuracy ranges from 92-98% for 1989, 70-99% for 2005 and 96-99% for 2016, while the user's accuracy for 71-96% for 1989, 80-98% for 2005 and 80-100% for 2016, respectively.

Table 4.4: Producer's and User's accuracy from landsat data.

Class Name	**Accuracy % 1989**		**Accuracy % 2005**		**Accuracy % 2016**	
	Producer	User	Producer	User	Producer	User
Built-up	98.00	96.00	94.00	98.04	96.97	86.49
Agriculture	94.00	89.00	70.00	80.00	98.70	86.67
Vegetation	92.00	71.34	80.00	93.00	97.92	89.20
Water bodies	97.00	91.00	99.00	90.73	98.96	99.10
Open area	94.00	89.00	94.00	92.00	99.06	98.72

4.1.3 Urban Sprawl Measurement Using Shannon's Entropy

This study is interested in the urban land-use only, we use the earlier simplified classes of built-up and non-built up area of three land cover maps of the year's 1989, 2005 and 2016. In view of a 1 km concentric buffer rings around city center to cover all parts of urban area to measure the urban sprawling during 1989, 2005 and 2016 using Shannon's Entropy approach. The result of buffer ring was as follow in Figure 4.8.

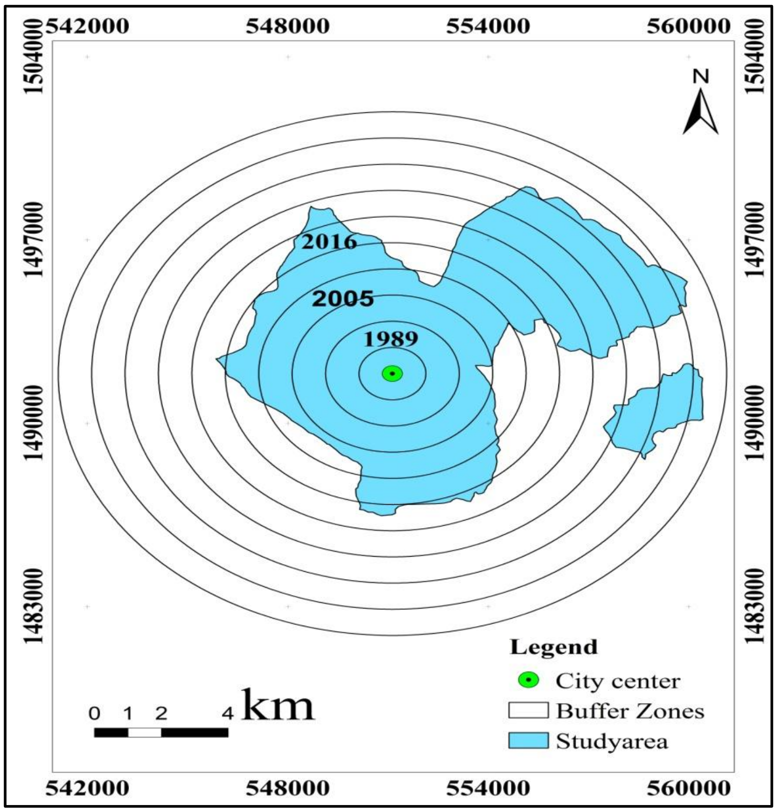


Figure 4.8: Buffer zone around the city of Mekelle center

The dispersion of built-up areas from a city centre leads to an increase in the entropy value. The formula used in order to calculate Shannon's Entropy from the equation 4.1.

$$En = \sum_{i}^{n} Pi \log(1/Pi) / \log(n) \quad \text{.....(4.1)}$$

Where; $P_i = Xi/\sum_{i}^{n} Xi$ and Xi is the density of land development, which equals the amount of built-up land divided by the total amount of land in the i^{th} zone in the total zone of n zones. the result of Entropy values are shown in Table 4.5.

Table 4.5: Shannon's Entropy values during 1989−2016.

	∆En, Entropy		
	Time series of three years		
Mekelle city	1989	2005	2016
	0.18	0.30	0.63

Accordingly (Table 4.5) are shown the result of Entropy 0.18 in 1989, 0.30 in 2005 and 0.63 in 2016. This show that the highest dispersed development is 0.63 in year 2016, Medium dispersed development in the year of 2005 by 0.30 and small dispersed development in the year of 1989 in Figure 4.9. Urban sprawl increasing during 2005 and 2016 high entropy values also make known that land development was spreading over the urban periphery and to the surrounding rural area.

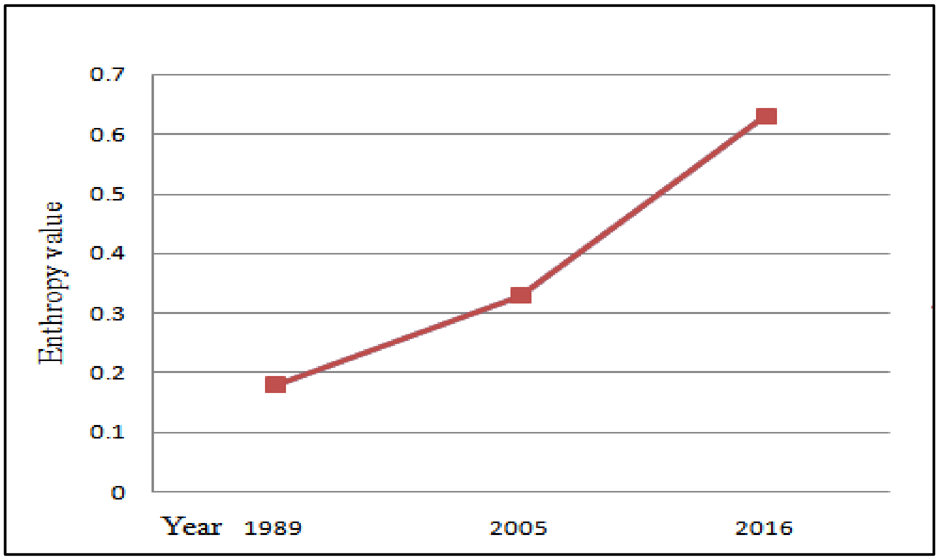


Figure 4.9: Entropy value of Mekelle city during 1989, 2005−2016

4.1.4 Population density and urban sprawl of Mekelle

In order to better understand the situation, the population density accelerates the demand for land and the dynamics in urban land-use change. In this study, the main focus about the relationship between urban sprawl and population density. Also, the driving forces behind the sprawl could be several among the major factors is population growth particularly in the period after the year of 1994. Population growth can affect economic, environmental, social and other positive and negative aspects. The city of Mekelle has categorized in to seven sub-cities namely; Adihaki, Ayder, Semen, Hadnet, Hawlti, Kadmi wayane and Quiha have facing high population density (118 persons per ha in 2005 and 331 person per ha in 2013). This implies that there is high pressure upon the existing built-up area during 2013 population density in (Fig 4.10).

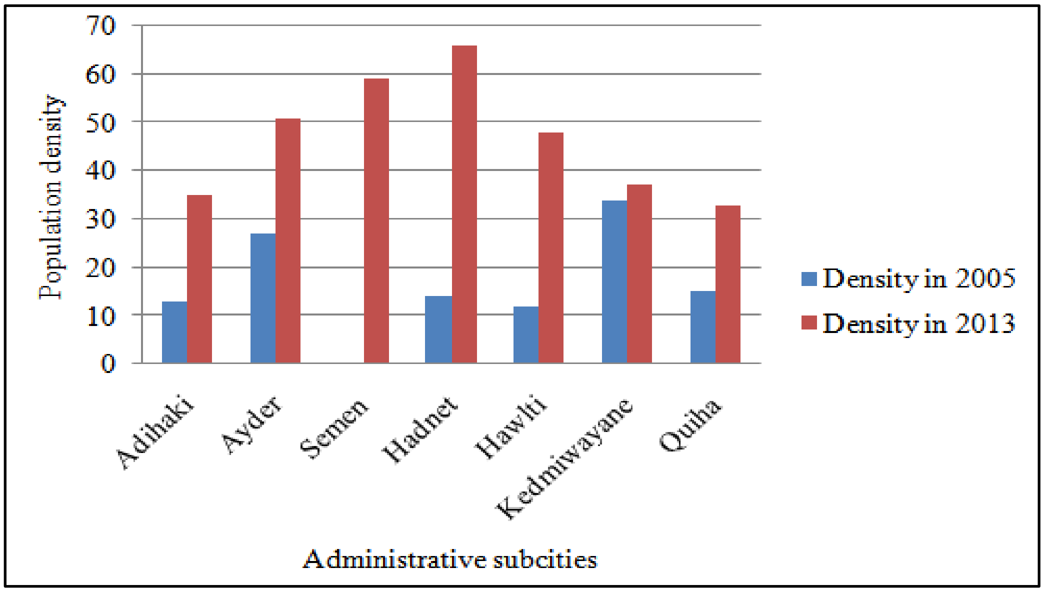


Figure 4.10: Population density in 2005 and 2013

4.1.5 Urban land-use modeling

Markov Chain Analysis which helps describes the output in table format during the application of a transitions area matrix. It is a number of pixels that are expected to the probability change each urban land-use/land-cover type to every classes of land-use/land-cover from the year of 1989 and 2005 to projection the year of 2016.The result of a transition probability matrix in Table 4.6 The same steps are applied from the year of 2005 and 2016 for projection of the year 2026 result in a transition probability matrix in Table 4.7.

Table 4.6: Transition probability matrix for the projection of 2016 urban land-use.

		2005				
	Class Name	Built-up	Agriculture	Vegetation	Water bodies	Open area
1989	Built-up	**0.6500**	0.0000	0.1017	0.0105	0.0000
	Agriculture	0.2572	**0.0714**	0.0000	0.0023	0.5228
	Vegetation	0.0000	0.0000	**0.0400**	0.0002	0.1759
	Water bodies	0.5999	0.0000	0.0000	**0.0105**	0.1683
	Open area	0.2764	0.0000	0.0000	0.0000	**0.0998**

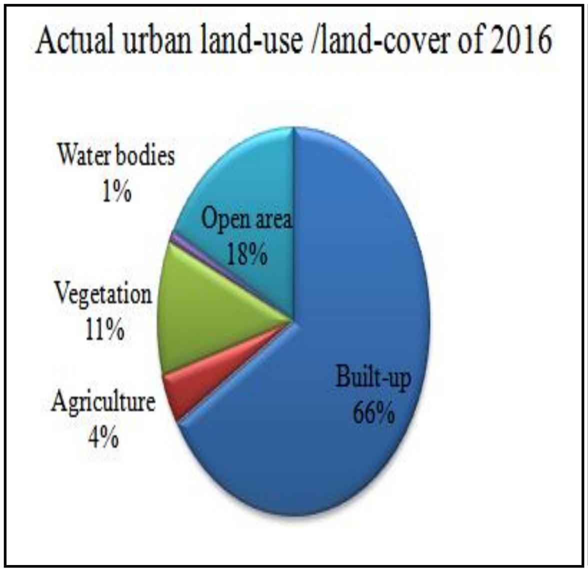
Table 4.7: Transition probability matrix for the projection of 2026 urban land-use.

		2016				
	Class Name	Built-up	Agriculture	Vegetation	Water bodies	Open area
2005	Built-up	**0.6900**	0.0000	0.1017	0.0105	0.0000
	Agriculture	0.2501	**0.0613**	0.0000	0.0023	0.5228
	Vegetation	0.0000	0.0000	**0.0200**	0.0002	0.1759
	Water bodies	0.5999	0.0000	0.0000	**0.0004**	0.1683
	Open area	0.2764	0.0000	0.0000	0.0000	**0.0897**

The necessary transition area matrix file was computed from the urban land-use 1989 and 2005 using Markov Chain model in IDRISI Selva and it was validated with existing urban land-use map of 2016. The off-diagonal elements indicate the expected probability of change between the two periods from the existing 1989 to 2005 new classes. The result involved that from Table 4.6 and Table 4.7 the projection transition probability matrix shows that water bodies and agriculture were converted in to built-up area while vegetation and open area converted in to non-built up area. In this study, the model resulted in the built-up area increasing from the actual and predicted projection transition matrix while water bodies and agriculture were disappeared and declined time to time due to the physical factor of climatic, landscape, topography population density and anthropogenic activities. In general, The comparison between the actual urban land-use/land-cover from the year of 2016 and the predicted urban land-use/land-cover the year of 2026 in Table 4.8. The result in simulated urban sprawl map of 2026 shown in (Fig 4.13).

Table 4.8: Urban land-use/land-cover comparison between 2016 and 2026.

Class Name	**Area (ha) in 2016**	**Area (ha) in %**	**Area (ha) in 2026**	**Area (ha) in %**
Built-up	17808.68	66.20	22201.07	78.10
Agriculture	1149.43	4.27	600.15	2.10
Vegetation	3015.20	11.21	2430.35	8.54
Water bodies	269.21	1.00	176.54	0.62
Open area	4658.73	17.32	3049.08	10.73
Total	26901.25	100	28457.19	100



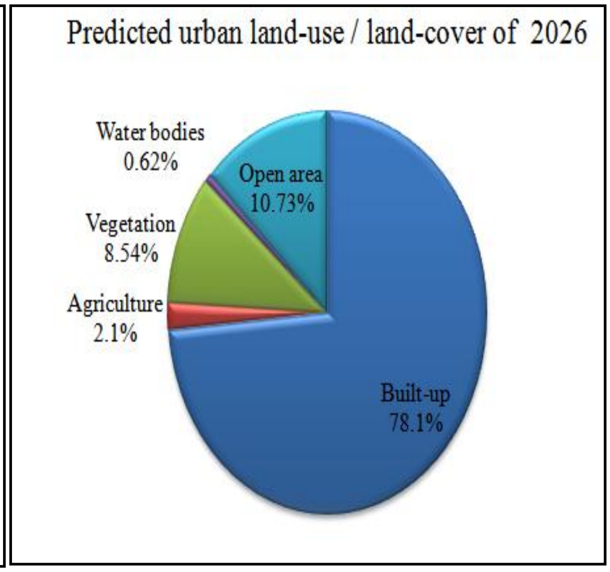


Figure 4.11: Comparison of urban land-use/land-cover between 2016 and 2026

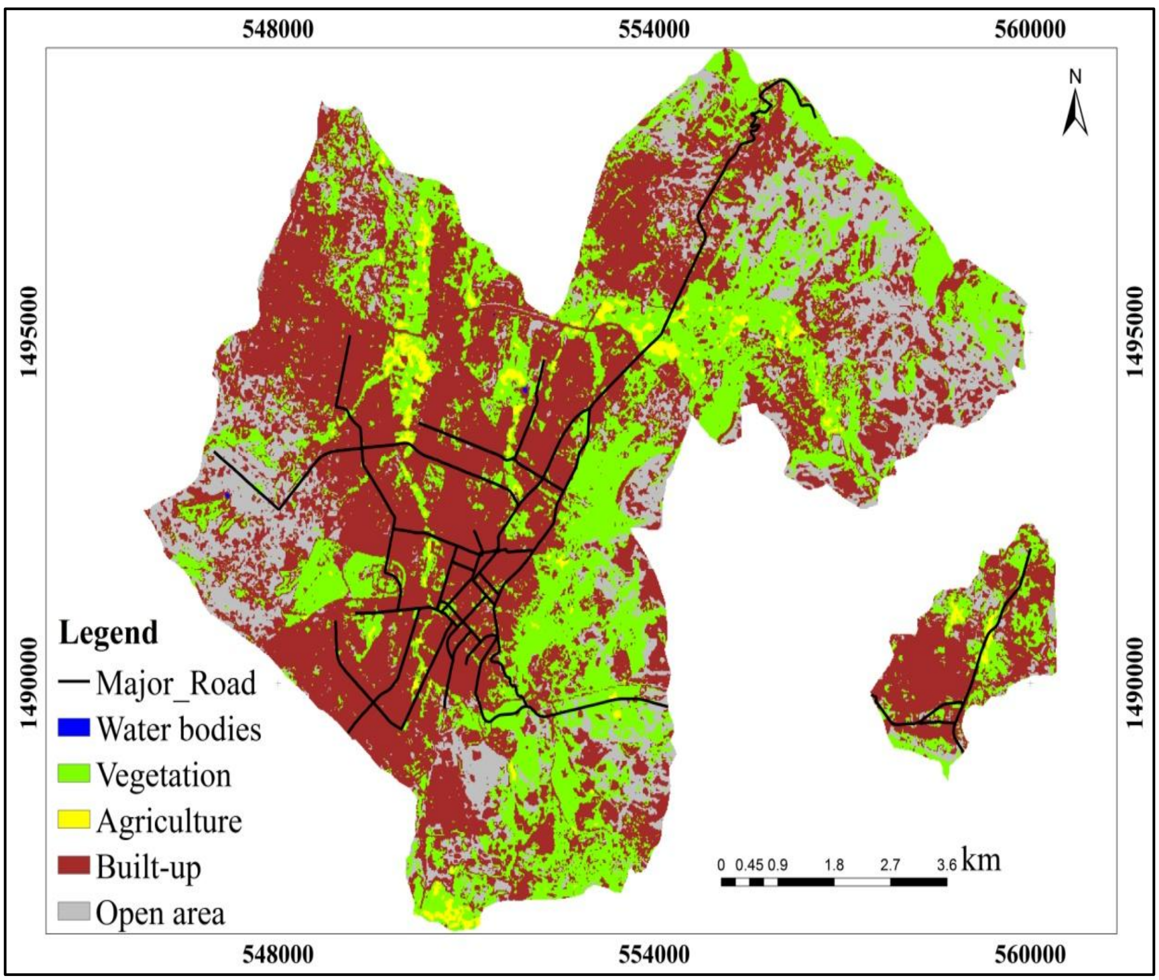


Figure 4.12: Actual urban land-use/ land -cover map of 2016

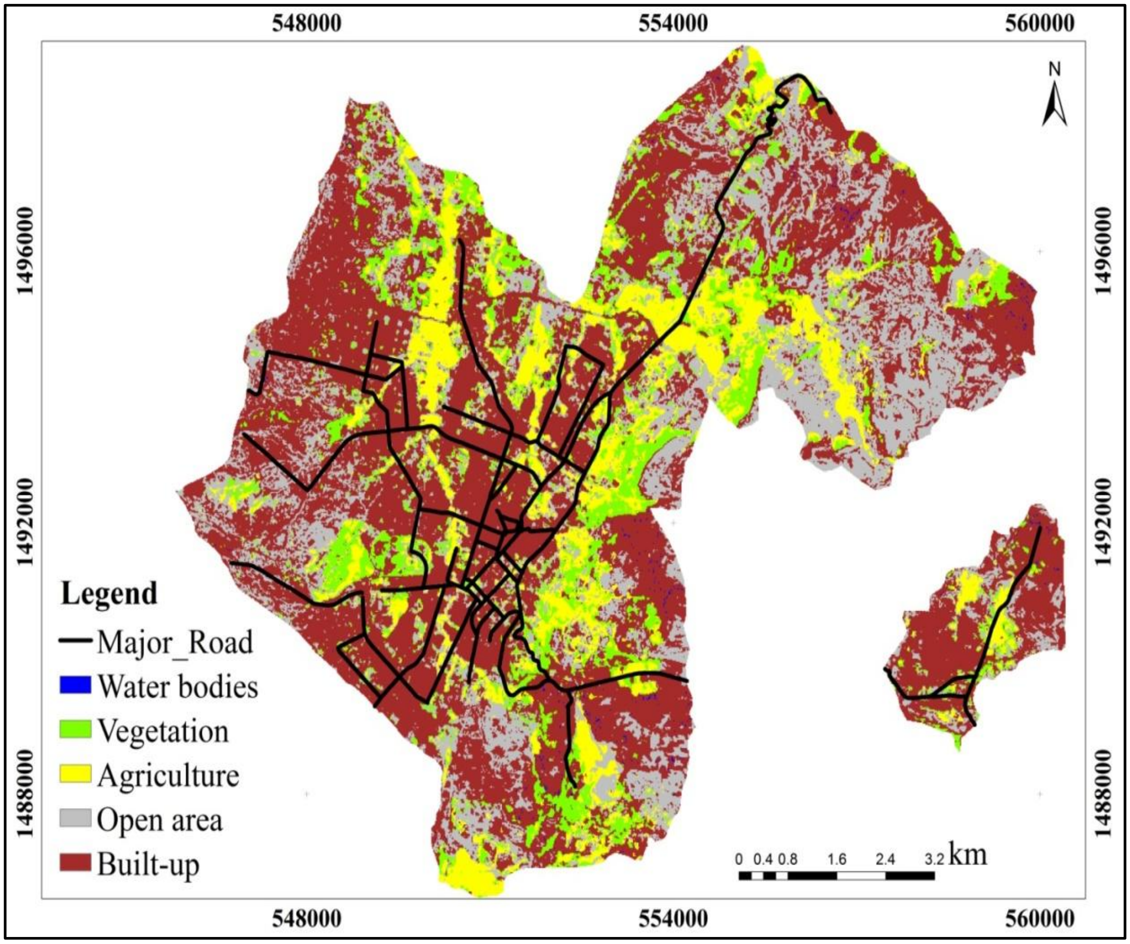


Figure 4.13: Predicted urban sprawl map of 2026

The assumption of the modeling is to show the urban land-use/land-cover change plays a significant role for understanding the impacts, dynamic urban built-up features, rapid expansion of urban sprawl and discontinuous urban areas affect the natural and human system at all geographic scales. The land-use/land-cover change projection transition pixel matrix for 1989, 2005 and 2016 of Mekelle city indicates that water bodies accounts for the highest percentage loss and converted to urban land-use. This is an indicator of increased urban sprawl due to urban expansion, population growth and urban extent too.

CHAPTER FIVE

5.1 Discussion

Remote sensing application of image analysis is used to for mapping and monitoring urban land-use. It can provide spatially reliable datasets that cover large areas with high level of details temporal frequency and helps to estimate different surface features. Similar studied by Nduwayezu (2015) modeling urban growth in Kigali city Rwanda, more appreciate the explanation and the application of remote sensing for urban sprawl. He has well done the modeling urban growth and in Rwanda city. This research, helps to easily understand urban growth is result in urban sprawl.

Landsat data (30*30 meters cell size resolution) lacked the capability to capture patterns on a micro level scale of change and some sort of the difficulty based on the urban land-use/land-cover classification group has resulted in misclassification of one urban land-use into another (Genemo, 2012). In order to overcome this problem, field observation were repeatedly done to verify actual urban land-use/land-cover. On the other hand, using high resolution remote sensing data (1 m resolution of IKONOS, 0.61 m resolution of Quickbird, 0.41 m GeoEye and 0.15 m Aerial photography), which improve and clear the pattern comparison, there is no misclassification during the classification of urban land-use/land-cover classes and model performance. Currently, Landsat imageries were used for preparing land-use/land-cover maps only not used for predicating urban sprawl. In addition, very high resolution aerial photography images were used for verification of training sample sets like prepare and predicated the urban sprawl maps.

The rapid population growth of the world has resulted in uncontrolled disorganized growth in the fringes of urban areas without the awareness and consent of both concerned cities and bordering rural administrative bodies. Also, Zewdu (2011) explained that about the fast population, Ethiopia being the third most heavily populated countries in Africa has been a victim of this phenomenon, particularly, the horizontal and leapfrog expansion of urban areas often infringe on arable lands on the border. I agree with this idea. This is particularly true in Mekelle city where agricultural and water bodies are disappearing each year, converting to built-up areas. Moreover, because of the lack of appropriate land use planning and the measures for sustainable development, uncontrolled urban growth has been creating severe environmental consequences.

Urban sprawl is primarily detected by estimated urban growth in several ways. Similar studies by different researcher have been explained by different title of urban sprawl. First, the study done by Shishay has well thought-out the impact of urban built-up area expansion on the livelihood of farm households, in the peri-urban area of Mekelle city (Shishay, 2011). Second, Genemo has made clear that the town of Shashamane urban expansion toward leap frog, compact and linear or horizontal direction expansion with good urban sprawl susceptibility analysis, a case study of Shashamane town (Genemo, 2012) and Third, Medina Arab has explained about the current expansion of urban sprawl, a case of Hawassa (Medina, 2015).

Clearly, different research gave direction for several ways to measurement urban forceful while the result of the above research have less due to the direction no implemented with a proper manner. In contrast, my research is new and practical can solve the expansion of urban sprawl in the city of Mekelle.

This study area has under gone the degree of urban sprawl using Shannon's entropy, which measure the spatial concentration and dispersion of a geographic variable integrated with remote sensing and GIS tools to calculate sprawl (Genemo, 2012). The distribution is maximally concentrated in one region, the lowest entropy value is obtained where as an evenly disperse distribution across space give a maximum value. Dispersion of built-up area from a city center led to an increase in the entropy value. This shows that a clear idea to visualize whereas the urban land-use/land-cover development is towards a more dispersion/compactness. As noted in previous chapter an increase in the entropy value of Mekelle city, clearly shows that there is an increase in urban sprawl and highly dispersed expansion of horizontal sprawling. Urban land-use have been converted in to built-up areas due to the increase in urban activities. There is a big demand for land by the high number of offices, schools, industries built (Ayder) during last 27 years. For now, the sprawl of urban land-use of an area is also to observe a change in size, shape and configuration of the built-up development.

The model predicts the future land-use pattern only on the basis of the known land-use patterns of the past and a number of change drivers to better understanding of the change. Then, CA-Markov model useful under this study considers all the input land-use/land-cover classes for simulation, more emphasis was given to only on urban land-use/land-cover change analysis and modeling (Medina, 2015). Therefore, modeling of urban land-use/land-cover change plays a significant role for understanding the impacts, development plans and decision making process.

Additionally, urban sprawl is taking place around the world. Currently, the negative environmental and social effects of urban sprawl have been understood by different city planners and researchers. Smart growth is a policy oriented strategy for fighting urban sprawl (Freilich, 1999) and is mainly based on the achievement of higher residential densities (Gemeno, 2012). Being with ongoing urban sprawl and strong population growth, the city of Mekelle needs to consider smart growth policies to encourage the effective and efficient use of newly developed urban land-use of established land.

The linear strip and compact sprawl built-up expansion area in Mekelle is the displacement of farmers, excessive use of natural resources and unfair farmland compensation system. Besides, these impacts of urban land-use stress on the farm households affected their livelihood sources of incomes (Shishay, 2011).This study noted that, the expansion of the built-up areas is predominantly at the expense of water bodies, agricultural and vegetation.

Furthermore through the CA model, the newly expanded built-up area is allocated to discrete geographic space based on estimated land-use/land-cover patterns over the past two decades. The newly increased urban land-use/land-cover is mostly likely to expand around the edges or vicinity of already established city center or sub-city centers (Medina, 2015). Built-up area; such as building and road network planning could make a great contribution to direct the distribution of newly urbanized land-use/land-cover.

In the future few years till 2026, the urban land-use/land-cover in city of Mekelle is expected to keep on expanding mainly along a north-east axis (Endayesus).

CHAPTER SIX

6.1 Conclusion and Recommendation

6.1.1 Conclusion

This study is devoted to model urban sprawl by coupling RS, GIS and satellite imagery and CA-Markov model. These were applied in Mekelle city to determine the urban expansion and predict future urban sprawl pattern in study area in the next 10 years. The major finding are summarized as follows.

Firstly, generate a consistent set of Landsat imageries maps of Mekelle city during the period of 1989, 2005 and 2016 together with very high resolution aerial photograph (0.15 m). Pixel-based approach by maximum likelihood method was applied to classify Landsat images. As the purpose of the study was to look at built-up urban land-use only, from the urban land-use maps, built-up area were visualized and extracted. A number of built-up pixels in each time span were quantified and the built-up area of each year was derived. With Landsat images classified, a remarkable trends and sprawl pattern was observed in urban area in Mekelle city, the rapid trend was accelerated between 2005 and 2016 while it continued at a moderate pace at 1989. The finding revealed that urban areas expanded mainly towards in all directions, for example; the Northern, Eastern, Southern and Western directions. The study has been carried out to investigate the overall urban land-use changes occurred from 1989 to 2016 and modeling with special emphasis to extent of urban sprawl.

The major changes have exposed that in the study area, the first the largest urban land-use/land-cover class is occupied by water bodies, which covers 49.55% of total area in 1989 and 1% in 2016. The second largest urban land-use class is by open area, which covers 35.49% in 1989 and 17.32% in 2016. Both are its conversion to urban area is the main factor for its decline in 2016. Others like vegetation, built-up and open area possess 8.42%, 6.08% and 0.46% of total study area in 1989 and 11.21%, 66.20% and 4.27% in 2016. Yet, many changes have observed among the urban land-use in the year between 1989 and 2016, the highest rate of changes are seen in agricultural lands which is decreased by -15.99% in every year and built-up, which is increased by 64.11% per annum. Besides vegetated and open area are also decreased in size by 8.32% and 5.15% in 2016. When compared with 1989. The increase of built up is mainly at the expense of other urban land-uses and this is recognized to population growth in the last 27 years.

Secondly, invistigate the degree of urban sprawl in the study area using Shannon's entropyAs a principal measurement of urban sprawl Shannon's entropy was used to gauge spatial dispersion or concentration of sprawling development in the study area. The factors considered for the evaluation of urban sprawl are population density and slope in the sliding order of their degree of influence. Being the entropy values in peri-urban areas population growth in the last 27 years. The entropy values in peri-urban areas are much higher than in the urban core, has indicated uneven sprawl and rapid urbanization process in the fringe areas of the town. As per the result of urban sprawl analysis, 63% of entire study area is vulnerable to urban sprawl while the remaining 37% is currently not.

Thirdly, built a Cellular Automata Markov model of urban land change based on the analysis satelliate images. Thus, modeling of urban growth were done using CA-Markov modeling tool of IDRISI Version 17 aimed to predict urban land-use change over time for better sustainable management of urban growth and development to the study area. The model helps to predict the magnitude and spatial pattern of the future urban scenario based on past trend in urban unit. Modeling of urban land use changes was performed using the probability transition matrix from the Markov chain process.

Urban land-use/land-cover change is an indirect measure of population pressure and provides evidences on the track of active human impacts on surrounding natural resources in a way that the growing population and increasing socioeconomic necessities creates a pressure on natural resources. The model predicted based on the analysis that the current physical urban expansion rates continues, urban built-up development will expand towards Northen, Southern and Western direction of the city rather than the Nort-Eastern part of Endayesus because of the area have been considered as a faulting, may be this area need further study for the future.

Finally, It was observed that the analysis of urban land-use/land-cover development using remote sensing data is accurate, rapid, cheap and release with repetitive coverage. Hence, the remotely sensed data potentially offers a rich source of information for management, planning, decision making and development on the earth's surface that change cover time. Remote sensing and GIS tools are providing powerful to analyze urban sprawl more efficiently and effectively.

6.1.2 Recommendations

From the findings of this study, it is possible to suggest the following recommendations in order to helping reforms:

The result achieved an impact on the model output; it was referred that the current trend of urban growth of the city of Mekelle will keep increasing. This is for the reason that the continuous growth of population, economic, infrastructure development, availability of healthy-developed, social and cultural assets. Being an ideal transit spot for the presence of different industries aggravates growth of factories and tourist. The study may help decision makers, environmentalist and planners to consider the impacts of disorganized urban development by identifying the current trend of urban land-use and predict urban sprawling potentiality.

The city administration and the municipality, urban planners, policy makers and natural resources managers, the decision makers can stop and give the solution in the expansion of urban sprawl in collaboration with non-governmental organizations to teach up the ground. This also needs serious attention in order to helping reforms by both the federal and regional governments. Otherwise, the expansion of urban land-use in Mekelle city is going to more impact on farmers for displaced from agriculture area because of agriculture will be converted in to the capacity of built-up area.

Urban land-use/land-cover change and sprawl are some of the main environmental concerns presently seen in the world and their environmental and social impacts is becoming obvious. In order to minimize the impacts of urban sprawl, a policy oriented urban development strategy "Smart growth" suggested. This should also be true in Mekelle city administration. Therefore, the strategy advocates the implementation of higher residential densities. Smart growth is a development strategy that serves the community, economy and the environment. In view of the on-going urban land-use/land-cover changes and sprawl in the study site, it is important to consider smart growth for the efficient and effective use of newly developed land. For effective urban developments, environmental impact assessment and public participation in decision making are also recommended. Vertical development and expansion of areas to protect natural environment. These are critical to assess the likely impacts of urban development on the surrounding ecosystems.

Urbanization and urban growth should engage different governmental and noon- government agencies. As a result, institutional collaboration among those different ministerial offices at different administrative hierarchies is required for sustainable environmental and management development. Therefore, future work will consider all these limitations and incorporate socio-economic variables like provision policy, land price assumption, owner ships style, per capital income of developers and residence system as well as the demography of the area like population growth rate. Managements, surveyor and planner use the potential of remote sensing, GIS, and modeling tool for predicating the planning of the city and urban land-use change in the future. Similarly, the best method of Cellular Automata Markov Modeling should be used the National Urban Planning Institution (NUPI) of the city of Mekelle because CA dealing with urban growth sprawl, land development and land cover, represented at finer spatial scale defined by physical morphology and dynamic in time.

Finally, one point raised because to helping in the reforms point of view, during the ground truth data collection, some displaced farmers said that about non-reasonable and acceptable the amount of compensation to be paid the regional governments. From my belief the federal and the regional governments should review the laws which were adopted in relation to expropriation and improve the packages for the displaced farmers in turn with the best experiences of other countries. Besides, the issue of compensation should address strongly with different questions; for example, what to compensate for? How much to compensate for displaced farmers? How to compensate the active displaced farmers? And when to compensate? The higher manager and the city planning decision makers control the payment of each displaced farmer till teach on the ground.

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Appendices

Appendix 1. Ground truth data

Table 4.5: Ground truth collected by Global Positioning System points (GPS).

No.	Northing	Easting	ULULC		Northing	Easting	ULULC
1	13^0 31' 07.18" N	39^0 28' 08.49"E	Built-up	27	13^0 28' 45.00" N	39^0 32' 47.07"E	Vegetation
2	13^0 31' 10.97"N	39^0 28' 01.85" E	Built-up	28	13^0 28' 52.59" N	39^0 32' 49.37"E	Vegetation
3	13^0 31' 24.17" N	39^0 28' 00.08" E	Built-up	29	13^0 30' 35.88" N	39^0 27' 02.92"E	Vegetation
4	13^0 30' 50.02" N	39^0 27' 56.73" E	Built-up	30	13^0 29' 03.48" N	39^0 27' 28.57"E	Vegetation
5	13^0 30' 43.84" N	39^0 28' 04.65" E	Built-up	31	13^0 29' 36.68" N	39^0 29' 03.67"E	Vegetation
6	13^0 30' 42.63" N	39^0 28' 14.47" E	Built-up	32	13^0 31' 27.13" N	39^0 30' 00.06"E	Water bodies
7	13^0 30' 38.66" N	39^0 28' 24.86" E	Built-up	33	13^0 31' 28.09" N	39^0 30' 13.00"E	Water bodies
8	13^0 30' 10.40" N	39^0 28' 17.66" E	Built-up	34	13^0 31' 30.19" N	39^0 30' 19.20"E	Water bodies
9	13^0 29' 53.38" N	39^0 27' 34.44" E	Built-up	35	13^0 31' 30.57" N	39^0 30' 21.19"E	Water bodies
10	13^0 31' 16.56" N	39^0 27' 48.76"E	Agriculture	36	13^0 28' 39.15" N	39^0 28' 45.36"E	Open area
11	13^0 28' 45.17" N	39^0 29' 04.70"E	Agriculture	37	13^0 28' 00.77" N	39^0 28' 58.66"E	Open area
12	13^0 28' 27.79" N	39^0 29' 04.70"E	Agriculture	38	13^0 28' 31.35" N	39^0 32' 43.00"E	Open area
13	13^0 28' 06.02" N	39^0 29' 19.08"E	Agriculture	39	13^0 28' 25.16" N	39^0 32' 38.48"E	Open area
14	13^0 28' 58.91" N	39^0 32' 53.11"E	Agriculture	40	13^0 28' 43.02" N	39^0 32' 43.41"E	Open area
15	13^0 31' 17.14' N	39^0 27' 53.84"E	Vegetation	41	13^0 29' 11.87" N	39^0 33' 00.70"E	Open area
16	13^0 31' 00.80" N	39^0 27' 52.65"E	Vegetation	42	13^0 27' 45.17" N	39^0 33' 40.26"E	Agriculture
17	13^{0}28' 07.12" N	39^0 28' 29.37"E	Built-up	43	13^0 31' 16.56" N	39^0 27' 48.76"E	Agriculture
18	13^{0}27' 40.28" N	39^0 29' 32.28"E	Built-up	44	13^0 28' 27.79" N	39^0 29' 04.70"E	Agriculture
19	13^{0}27' 39.08" N	39^0 29' 38.06"E	Built-up	45	13^0 28' 06.02" N	39^0 29' 19.08"E	Agriculture
20	13^{0}27' 37.97" N	39^0 29' 33.66"E	Built-up	46	13^0 29' 02.52" N	39^0 32' 29.28"E	Agriculture
21	13^{0}27' 37.54" N	39^0 29' 37.93"E	Built-up	47	13^0 31' 29.69" N	39^0 30' 30.35"E	Agriculture
22	13^{0}28' 47.89" N	38^0 29' 05.87"E	Built-up	48	13^0 31' 17.14" N	39^0 27' 53.84"E	Vegetation
23	13^{0}29' 53.38" N	39^0 27' 34.44"E	Built-up	49	13^0 31' 00.80" N	39^0 27' 52.65"E	Vegetation
24	13^{0}30' 09.74" N	39^0 27' 40.95"E	Built-up	50	13^0 30' 11.02" N	39^0 27' 43.40"E	Vegetation
25	13^{0}29' 51.76" N	39^0 27' 56.35"E	Built-up	51	13^0 28' 45.00" N	39^0 32' 47.07"E	Vegetation
26	13^{0}30' 10.40" N	39^0 28' 17.66"E	Built-up	52	13^0 28' 52.59" N	39^0 32' 49.37"E	Vegetation

Appendix 2. Sample sites profiles using GARMIN GPS.

Plate 1: Mekelle Municipality Administration Office

Plate 2: Built-up area (Down town Mekelle)

Plate 3: Open area (South East direction)


Plate 4: Agriculture (South direction)   Plate 5: Ellala water bodies (North direction)


Plate 6: Vegetation (North East direction)   Plate 7: Leap frog urban sprawl pattern (Semen)

Plate 8: Cluster urban sprawl pattern (Adihaki)   Plate 9: Linear urban sprawl pattern (Ayder)

Plate 10: GPS data collection in the study area

Appendix 3. Time series analysis land-use/land-cover change formula

The formula of dynamic change rate of sprawl adapted from Feng Li (2012) is given as;

$$DU = \frac{DBr2 - DBr1 \; x\,1 \div T2 - T1}{DBr1} \; x\,100$$

Where;

DU = the dynamic change rate of urban sprawl

T1, T2 = Specific years

DBr1 = Total area of Built-up in T1

DBr2 = Total area of Built-up in T2

For this particular analysis, instead of Li's dynamic change rate of urban sprawl, the rate of urban built-up area between two given periods is used for computing the rate. Hence, the above formula can be rewritten and used as follows:

$$BU = \frac{BUr2 - BUr1 \; \text{x}\,1 \div T2 - T1}{BUr1} \; x100$$

Where;

BU = Built-up change Rate

T1, T2 = Specific years or periods

BBr1 = Total area of Built-up in T1 (first period)

BBr2 = Total area of Built-up in T2 (the latter period)

I. Built-up change rate the period 1989 − 2005

$$BU = \frac{Built-up\,1989 - Built-up\,2005 \; x\,1 \div 2005 - 1989}{Area\ of\ Built-up\,1989} \; x\,100$$

$$= \frac{4580.95 - 561.56 \, x\,1 \div 2005 - 1989}{} \; x\,100$$

$$561.56$$

$$= \frac{4019.39\ x 1 \div 16}{561.56}\ x\ 100$$

BU = 44.74 %

II. Built-up change rate the period 200 −2016

$$BU = \frac{\text{Built-up 2016} - \text{Built-up 2005}\ \text{x}\ 1 \div 2016\ -\ 2005}{Area\ of\ Built - up\ 2005}\ x\ 100$$

$$= \frac{17858.68 - 4580.95\ x\ 1 \div 11}{4580.95}\ x\ 100$$

$$= \frac{13287.73\ x 1 \div\ 11}{4580.95}\ x\ 100$$

BU = 26.4 %

III. Built-up change rate the period 1989 − 2016

$$BU = \frac{Built\text{-up 2016} - \text{Built-up 1989}\ \ x\ 1\ \div\ 2016 - 1989}{Area\ of\ Built\text{-up 1989}}\ x\ 100$$

$$= \frac{17858.68 - 561.56\ x\ 1\ \div\ 27}{561.56}\ \text{x 100}$$

$$= \frac{17247.12\ x\ 1 \div\ 27}{561.56}\ x\ 100$$

BU = 113.8 %

DECLARATION

This is to declare that entitled "Cellular Automata Model Based Urban Sprawl Mapping: A case of Mekelle City, Ethiopia" has been carried out by me under the supervision of Dr. Binyam Tesfaw, School of Earth Sciences, College of Natural and Computational Sciences, Addis Ababa University, Addis Ababa during the year 2016–2017 as a part of Master of Science program in Remote Sensing and GIS. I additional declare that this work has not been submitted to any other University for the award of any degree or diploma.

Berhanu Kidane

Signature: _______________

Addis Ababa University

Addis Ababa

Date: June, 2017

CERTIFICATE

This is certified that the thesis entitled "Cellular Automata Model Based Urban Sprawl Mapping: A case of Mekelle City, Ethiopia" is a bona fide work carried out by Berhanu Kidane for the partial fulfillment of the award of the Degree of Master of Science in Remote Sensing and GIS from Addis Ababa University. Addis Ababa, Ethiopia.

Dr. Binyam Tesfaw

Signature: _______________

School of Earth Sciences

Addis Ababa University

Addis Ababa

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Chapter Five	100	0
Chapter Six	100	0
References	100	0
Appendices	100	0
Total	1063/11= 96.64	37/11= 3.36

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Date: June, 2017