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Impact of Land Use and Land Cover Change on Urban Climate: the case of  
Addis Ababa city, Ethiopia

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## **ABSTRACT**

### Impact of Land Use Land Cover Change on Land Surface

Hiwot Abraha

Addis Ababa University, 2012

For the past decades, an increase in population pressure, policy, institutional and economic development influences caused changes in LULC of city and periphery. This was mainly due to urban expansion and densification. The effects of land use and land cover changes have impacted the urban climate by altering the surface energy and water balance. Although there are few studies on land use and land cover changes in Addis Ababa, studies related to the impact of such change on urban climate are missing. As a result, this study tries to examine the influence of LULCC on urban climate in Addis Ababa city from 1986 to 2010 by analyzing Landsat TM satellite data, meteorological records, and census data by integrating remote sensing and GIS technologies. The results show that grass land, agricultural land, forest land and bare land declined by 43.32km<sup>2</sup>, 16.03km<sup>2</sup>, 9.74km<sup>2</sup>, and 9.65 km<sup>2</sup>, respectively, on the other hand, built-up areas was dramatically expanded from 100.13km<sup>2</sup> in 1986 to 180.13km<sup>2</sup> in 2010 that is almost two times from initial year. Changes in LULC were accompanied by changes in LST. The average LST in 1986 was 28.88°C and it increased to 30.88°C in 2010 with average value 2°C. The change in LST was mainly associated with changes in impervious surface and in vegetation abundance. In addition, the annual average air temperatures increase in the entire Addis Ababa city by 1.5 °C over the study period. Therefore, clear and effective policy with necessary institutional set up is important to guide the growth of city.

*Key words: Remote sensing, GIS, LST, LULC, Addis Ababa*

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## List of Acronyms

AA	Addis Ababa
AAEPA	Addis Ababa Environmental Protection Authority
AACA	Addis Ababa City Administration
Birr	Ethiopian Currency
BLHI	Boundary Layer Heat Island
CBD	Central Business District
CLHI	Canopy Layer Heat Island
CSA	Central Statistics Authority
DEM	Digital Elevation Model
DN	Digital Number
EMR	Electromagnetic Radiation
ENVI	Environment for Visualization of Images
EPA	Environmental Protection Authority
ERDAS	Earth Resource Data Analysis System
ETM+	Extended Thematic Mapper plus
FAO	Food agricultural Organization
GCP	Ground Control Points
GDP	Gross Domestic Product
GIS	Geographic Information System
GPS	Global Positioning System

ISP	Impervious Surface Percent
K	kelvin
LULC	Land use land cover
LULCC	Land use lands cover change
LST	Land Surface temperature
masl	mean above Sea Level
Mt	Mountain
NDBI	Normalized Difference Built-up Index
NDBaI	Normalized Difference Bareness Index
NDVI	Normalized Difference Vegetation Index
NGOs	Non Governmental Organization
NMSA	National Meteorological Service Agency
OPHCC	Office of the Population and Housing Census Commission
ORAAMP	Office for the Revision of the Addis Ababa Master Plan
RC	Relative Contribution
RMSE	Root Mean Square Error
TIR	Thermal Infrared
TM	Thematic Mapper
UHI	Urban Heat Island
USD	United States Dollar
UTM	Universal Traverse Mercator



# **1. Introduction**

## **1.1. Background**

Land use and land cover change is a dynamic, widespread and accelerating process, mainly driven by natural phenomena and anthropogenic activities, which in turn drive changes that would impact humans and natural ecosystem (Agarwal et al., 2002; Liu et al., 2003). Human actions rather than natural forces are the source of most present-day change in the biosphere (Turner and Meyer, 1994). Scientists estimate that about one-third to one-half of our planet's land surfaces has been transformed by human development. Thus, anthropogenic LULCC is increasingly recognized as significant driver of environmental change on all spatial and temporal scales (Turner and Meyer, 1994). There is also emerging evidence that land use and land cover change is having a significant impact on climate at regional scales (Zhao et al., 2001). LULCC influence surface climate, both through biophysical interactions that affect surface energy and water balance and through biogeochemical interactions that affect the carbon cycle (Pielke et al., 2002).

In urbanizing areas, the rapid urbanization and accelerated urban sprawl have led to the transformation of the natural landscape into a largely impervious landscape (Zhou et al., 2004). Urbanization, the conversion of other types of land to uses associated with growth of populations and economy, is a main type of land use and land cover change in human history, that has had a great impact on climate and climate change (Gao et al., 2003).

These man induced changes of the natural ecosystem have dramatically changed radiative, thermal, moisture, roughness and emission properties of the earth's surface and the atmosphere above (Kalnay and Cai, 2003). Built-up areas covered with buildings, roads, and other impervious surfaces, generally have higher absorption of solar radiation and greater thermal capacity and conductivity, thereby affecting the thermal environment (Zhou et al., 2004). These urban surface modifications resulted in increased local atmospheric and surface temperatures in urban areas (Voogt and Oke, 2003). While cities grow both in physical and population size due to urbanization, the urban-rural difference in atmospheric and surface temperature also increased, which have significant effects on urban climate, environmental change and the quality of human life. As a result, land surface temperature change in response to urban land use change has been the major concern of many urban climate studies.

In urban areas, land surface temperature is a function of several surface and subsurface properties: albedo, emissivity, thermal properties of urban construction materials, moisture, and the composition and structure of urban canopy (Goward, 1981). In particular, the composition and structure of urban canopies is a crucial factor in determining the reception and loss of radiation (Oke, 1982). Land surface temperature, which heavily influenced by urban surface structures and composition and that modulates the air temperature of the lowest layers of the atmosphere. LST is also important for environmental studies and management of the Earth's resources because its key role in the surface energy balance. LST not only helps to determine the internal climate, but also influences energy exchanges that affect the comfort of city dwellers (Voogt and Oke,

2003; Wang et al., 2004). Because of its significance, literature has witnessed a growing interest in the relationship between LST and urban materials and landscape compositions and land cover changes, especially between LST and vegetation abundance (e.g., Carlson et al., 1994; Gallo and Owen, 1998; Gillies and Carlson, 1995; Gillies et al., 1997; Lo et al., 1997; Goward et al., 2002; Weng, 2001; Weng et al., 2004), and between LST and impervious surfaces (Lu and Weng, 2006).

Research conducted in Ethiopia has shown that there were considerable land use and land cover changes in the country during the second half of the 20th century (Crummey, 1998; Kebrom and Hedlund, 2000; Rembold et al., 2000). It has been well documented that obvious land use change, especially with regard to urban expansion, loss of cultivated land, and natural vegetations has occurred in the processes of environmental changes, industrialization and urbanization in the whole country. The fundamental changes in land use and land cover patterns in urban areas were due to socio-economic, political and physical factors. Urban growth has been speeded up, and tremendous pressure to the environment has occurred. This is predominantly happening in Addis Ababa city and its peripheries where a considerable agricultural, grass land and green areas are being converted into urban/ built-ups. In the process, natural vegetation cover is largely replaced by impervious surfaces such as buildings, roads, parking lots, sidewalks and other built surfaces. This conversion of natural land into impervious areas has resulted in many environmental consequences, mainly has great impact on climate.

In the previous times very few studies mainly focussing on the impact of land use land cover changes on the environment and some related to urban expansion and squatting in different part of Addis Ababa were carried out. But, there are no specific research works inline with this topic conducted to address the above mentioned challenges. This implies there is a gap in terms of spatial representation and impacts of land use and land cover change studies in the city. Thus, the rationale of conducting this research in the aforementioned area was to fill the existing knowledge gap about the environmental challenges of the land use and land cover change and their impacts on the community, environment and particularly on climate. Therefore, this study mainly focussed on the analysis of the impact of land use and land cover changes on the surface temperatures in Addis Ababa.

## **1.2. Statement of the Problem**

Anthropogenic land use change including urbanization, deforestation, desertification and agricultural practices, which cause changes in the land cover, has a significant impact on climate and climate change, by altering land surface properties and carbon fluxes (Pielke et al., 2002). Owing to high migration, natural increase and administrative reclassification of rural areas in the periphery to urban settlements, urbanization is creating continuing outward spread of built-up areas caused by their expansion and associated problems in cities of developing countries. African cities are experiencing rapid urbanization which leads to unsustainable development of the urban areas of the continent. Ethiopia, is one of countries experiencing rapid urbanization at rates of (about 4-5%) in the world, and the

countries urban population is expected to increase from 15% in 2000 to almost 30% in 2030 (UN-HABITAT, 2004).

This is mainly due to accelerated population explosion, political, institutional and technological factors, and economic development. In the last century, Addis Ababa has emerged as the premier commercial, industrial, and transportation urban area and capital city of the nation. The rapid growth of the city, particularly within the last 20 years, has made it one of the fastest growing metropolitan areas in the region. The population of the metropolitan area increased in remarkable growth rate in the last two decades. Concomitant with this high rate of population growth has been an explosive growth in retail, industrial, commercial, and transportation services within the city. This has resulted in tremendous land cover change dynamics within the metropolitan region, wherein urbanization has consumed vast acreages of land adjacent to the city proper and has pushed the rural/urban fringe farther and farther away from the original urban core. An enormous transition of land from forest and agriculture to urban land uses has occurred in the area in the last 24 years, along with subsequent changes in the land-atmosphere energy balance relationships.

The speeding up of the urban growth has caused stress to the urban and rural environment. This is particularly true in the city and surrounding areas where substantial agricultural land and green areas converting to urban or related uses. This involves the removal of natural land cover and the introduction of urban materials in form of clearance of natural vegetation; reclamation of swampy areas; construction of buildings, roads, and

other impervious surfaces, such as metal, asphalt, and concrete. Hence, there is a continual replacement of the highly beneficial and pleasing rural green spaces and trees with bricks, concrete, and ejection of poisonous pollutants into the atmosphere. This coupled with the social and technological involvedness, lead to radical changes in the nature of the surface and atmospheric properties of cities. There are therefore, changes from precious, homogeneous countryside climate characterized by clear air and water to highly polluted, unpleasant, noisy, heterogeneous and unpredictable atmospheric conditions of urban areas as they grow. It is such deliberate and/or inadvertent modifications of the natural environment that result to the transformations of the radioactive, thermal, and aerodynamic characteristics of the city environment thereby altering the natural solar and hydrologic cascades of urban areas.

Addis Ababa City, like other large cities, often experience a distinguished climate termed the “Urban Climate”. Urban climates are characterized by differences in climatic variables (air temperature, humidity, wind speed and direction, and amount of precipitation) from those of less built-up areas. The major factors contributing to these differences are the land use and land cover transformations due to different driving forces. These land use changes often includes replacements of natural surfaces which affecting the thermal environment in cities and climate variables. Urban climate changes and effects in the city will be sure to influence the urban environment, and socio-economic development. This leads to the impairment of human health, economic and other welfare losses and damage to the urban ecosystem. In line with this, in the last few years, the dwellers of Addis Ababa are suffering from high temperature flare.

Temperature increase is felt unanimously by all dwellers and its intensity is growing rapidly in the last few years. If we keep on irresponsive on what is happening to the city, then we might end up tormenting ourselves from high temperature burn and contribute to the local and regional climate change. This, in turn, might change the city to the harshest place to live and lead to other human health problems and economy. In this regard, therefore, it is important to study the link between land use and land cover change and temperature rise, and propose a feasible solution.

The dynamic nature of land use emanating from increasing population size and distribution, technology, economic development, human institutions and other factors is of paramount stage in Ethiopia that needs primary concern. Expansion and intensification of agriculture, growth of urban areas, and extraction of timber and other natural resources will likely accelerate over the coming decades to satisfy demands of increasing population (McColl, 2007). These changes in land use and land cover have become a central component for managing natural resources and monitoring environmental changes (Bottomley, 1998).

Studying the extent and dynamics of Addis Ababa's urban land use and land cover change and its impacts is an urgent need. This is to generate information that could help in tackling some of the problems that accompanied rapid land use and land cover change and to assist for future plan in rehabilitating the area. Moreover, it helps to evaluate urban growth patterns and land use and land cover changes in Addis Ababa city and to analyze the impact of such change on surface temperature, its drivers, feedbacks to climate, and

its environmental, social, economic and human health consequences. Specifically, the study was to investigate changes in land use and land cover, as a result of urban expansion and densification over time (1986-2010) using Landsat TM imagery and how this relates to urban micro-climate by integrating remote sensing and GIS technologies, meteorological measurements and census analysis. The results presented in this paper may lead to a better understanding of the local climate of Addis Ababa city stemming from its UHI and support further investigation into the subject of LULCC induced LST.

### **1.3. Objectives of the Study**

#### **General Objectives**

- The overall objective of this study is to examine the changes in land use and land cover in Addis Ababa city, with a focus on its impacts on urban climate.

#### **Specific Objectives**

- To detect the changes in land use and land cover of Addis Ababa city;
- To identify the driving forces of land use and land cover changes;
- To assess the potential feedbacks of changes in land use and land cover to land surface temperature;
- To assess the impact of LULCC on Urban climate; and
- To examine the relationship between LULCC and LST.

## **1.4. Research Questions**

In order to address the stated problem and objectives, the study was attempted to answer the following questions:

- What were the major changes in the urban environment of the study areas or not during the study period?
- What was the spatial extent of the land cover change and where was the highest rate of changes?
- How was the pattern of urban growth?
- What are the factors responsible for land use and land cover change in the city of Addis Ababa?
- Which areas are susceptible to LST effect?
- What are the impacts of land use and land cover change on land surface temperature in particular and urban climate in the study area?
- What is the relationship between LULCC and LST?

## **1.5. Significance of the Study**

At present, one of the challenges facing Ethiopia is environmental change which results in severe degradation and/or losses of ecosystem services due to unsustainable changes in land use and land cover specially change in urban climate due to land use and land cover change experienced in many urban centers of the country. Yet the rates and extent of the problem are still debatable due to limitations of reliable data and the processes involved are not clearly understood. This study would provide information about the impact of

land use and land cover change on land surface temperature (the main contributor to urban climate). Specifically, the result of the study is expected to have the following contributions:-

- Will provide an insight towards an understanding of the dynamics of land use and land cover change processes and its impact in the city of Addis Ababa for land use planners, policy makers, other concerned government bodies to evaluate their developments programs and strategies.
- Generate information on the status and dynamics of LST of the area for environmentalists, governmental and NGOs institutions, and local dwellers that are involved in development process so as to have appropriate interventions on the issue.
- Generate first hand information on the problem of land use and land cover change in the study area for those who are interested to conduct further research on the issue.

## **1.6. Scope and Limitation of the Study**

One of the Impacts of land use and land cover change on the environment is the impact of land use and land cover change on urban climate. In this study, much emphasis was given to the factors, extent and patterns of land use and land cover changes of Addis Ababa city and its impact on land surface temperature (the main changeable element on urban climate). LULC changes were assessed by combining different spatial data sources (remotely sensed satellite images and ground based surveys).

This study faced several challenges resulting in some limitations. The challenges mainly emanate from the fact that this study is the first of its kind in Addis Ababa and Ethiopia.

The following are some of the major causes of the limitations:

- Frequent change of the structure of governmental institutions relevant to the study, resulting in interruption and poor recording of data about the demographic, socio-economic and physical changes in and around the city.
- Poor data management system; there were no well organized and reliable data in most institutions relevant to the research under the study.
- Reluctance of the respondents during the socio economic survey.
- Insufficient and improperly documented time series meteorological data such as relative humidity, wind speed and other climate elements and insufficient of data to see the impact of land use and land cover due to few number of stations.
- Limitation on getting related works for reference in line of the topic.

Despite these challenges, the researcher has exerted maximum effort to lower their effects and search sufficient and reliable data.

## **1.7. Conceptual Framework**

As it has been discussed, on the theoretical literature review land use and land cover change is the result of different factors and it has impact on environment. These different factors are integrated with one another. Therefore, the conceptual framework has been designed by the researcher to clarify the basic concepts such as proximate factors and underlying deriving forces and their effects on land use and land cover change, and the

impact of the resulted changes on urban climate in general and on land surface temperature in Particular.

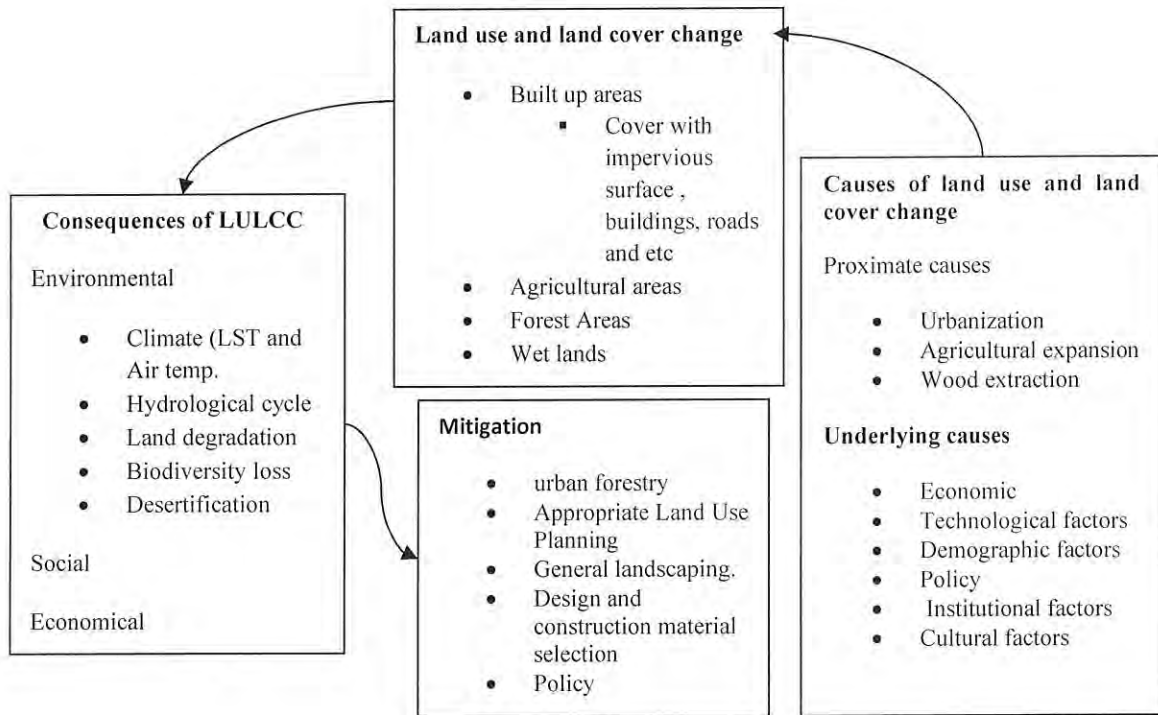


Figure 1: Conceptual Framework

Source: Designed by researcher

## 1.9. Organization of the Thesis

The thesis is organized into five chapters. The first chapter introduces the background of the study, problem statement and justification, the main objectives and sub-objectives of the study, research questions, significance, the scope and limitation of the study and the conceptual framework.

The Second chapter is describing all theoretical and related literatures for this study. The third chapter is devoted to the description of the state of the art of the study, the major methodologies followed for land use and land cover classification and land use and land cover change detection, multi-temporal data sources, land cover classes and reference data, retrieving land surface temperature. In general methodologies used to assess the problems and data analysis were stated in this chapter. The physical and socio-economical state of the study area described in words and portrayed graphically in this chapter.

Chapter Four discusses the findings and discussions of this thesis covering image, quantitative and qualitative analysis of the survey data. The chapter describes the land use and land cover change, causes of land use land cover change, effects of the land use and land cover change on urban climate and goes on to discuss the reason behind these changes. The last chapter tries to convey the major contents and concepts in the previous chapters and the basic research question posed in the introduction. To this effect, this chapter provides conclusions and recommendation of the study.

## **2. Literature Review**

### **2.1. Land Use and Land Cover Change Concepts**

Land is defined as part of the earth's surface, the characteristics of which embrace all stable, or inevitable cyclic attributes of the biosphere vertically above and below this area including those of the atmosphere, the soil and underlying geology, the hydrology, the animal and plant populations, and the results of past and present human action, to the extent that these attributes exert a significant pressure on present and future uses of the land by people (FAO, 2000).

Every tract of land on the Earth's surface is unique on the way it used and in the cover it possesses. Land use and land cover are distinct yet closely correlated characteristics of the Earth's surface. Land cover is defined as the attributes of the earth's land surface confined in the distribution of vegetation, water, desert and ice and the immediate subsurface, including soil, topography, biota, surface and groundwater, and it also includes those structures created exclusively by human activities such as mining exposures and settlement (Lambin et al., 2003; Chrysoulakis et al., 2004; Baulies and Szejwach, 1998). On the other hand, land use can be defined as the intended employment of management strategy placed on the land cover by human agents, to exploit the land cover and reflects human activities such as industrial zones, commercial zones, residential zones, agricultural fields, grazing, logging, and mining among many others (Zubair, 2006; Chrysoulakis et al., 2004).

In addition, to the above definition (FAO, 2000) defines “Land cover as the observed biophysical cover on the earth’s surface”; the same document also defines “Land use as the arrangements, activities and inputs that people undertake on a certain land cover type”. In other words, land use can be broadly defined as the level of spatial accumulation of activities such as production, transaction, administration and residence with highly dynamic relationships between them. Urban land use reflects the nature of social and economic activities in an area, as well as interactions with other areas. It results from the complicated interactions between the land system and the social economic systems (Jianquan, 2003).

The above definitions ascertain a direct link between land cover and land use. Land use differs from land cover because of the intended role of people to adapt the natural land cover to their benefit. The land use entails both the manner in which the biophysical attributes of the land are manipulated, and the intent underlying that manipulation, namely, the purpose for which the land is used.

Land use affects land cover and changes in land cover affect land use as well. The natural land cover is generally a good expression of the soil and vegetation pattern that goes with the natural environment. However, changes in the nature of land use activities often results in land cover changes. Land use change is defined to be any physical, biological or chemical change attributable to management, which may include conversion of grazing to cropping, conversion of forest, change in fertilizer use, drainage improvements, installation and use of irrigation, plantations, conversion to built-up, pollution and land degradation, vegetation removal, changed fire regime, spread of weeds

and exotic species, and conversion to agricultural and non-agricultural uses (Quentin et al., 2006).

Land use and land cover changes may be grouped into two broad categories as conversion and modification. Land cover conversion involves a change from one cover type to another. Land cover modification engrosses alterations of structure or function without a comprehensive change from one type to another; it could involve changes in Phenology, productivity, or biomass (Skole et al., 1994). Land cover changes are the results of natural processes such as climatic variations, volcanic eruptions, changes in river channels or the sea level, etc. However, nearly all of the land cover changes of the present and the recent past are due to human actions – i.e. to uses of land for production or settlement (Turner et al., 1996). "Land use (both deliberately and inadvertently) alters land cover in three ways: converting the land cover (changing it to a qualitatively different state) i.e. changes in the mix and pattern of land uses in an area; modifying it (quantitatively changing its condition without full conversion) or it may involve changes in the intensity of this use as well as alterations of its characteristic qualities/attributes – such as changes from low-income to high-income residential areas, from single story to multistory dwellings, changes of suburban forests from their natural state to recreation uses (the area of land staying unchanged); and maintaining it in its condition against natural agents of change" (Meyer and Turner, 1994).

## **2.2. Major Causes of Land Use and Land Cover Changes**

Land use and land cover changes may occur due to diverse factors, which may be generally divided into natural and human induced or anthropogenic causes. United States

Environmental Protection Agency (USEPA, 1999), identified the general causes of land use and land cover changes, which are: (1) natural processes, such as climate and atmospheric changes, wildfire, and pest infestation; (2) direct effects of human activity, such as deforestation, urban and agricultural expansion, and road-building; and (3) indirect effects of human activity, such as water diversion leading to lowering of the water table. Even though, natural processes may also contribute to changes in land cover, the major driving force is human induced land uses (Allen and Barnes, 1985). These anthropogenic causes of land use and land cover change, which are critical and presently growing in alarming rate, and can be grouped into two broad divisions: proximate and underlying causes. Proximate (direct) causes are immediate actions of local people in order to execute their desires from the draw on of the land (Geist and Lambin, 2002); whereas driving causes are causes which drives behind the immediate causes. These two major categories of causes work at different levels. Proximate causes operate at the local level (individual farms, householders, or communities); on the other hand, the sources of underlying causes are at regional and national levels such as districts, provinces, or countries. Underlying causes are external and beyond the control of local communities (Lambin et al., 2003).

### **2.2.1 Proximate Causes of Land Use and Land Cover Changes**

Land use and land cover is never static; it continually transforms in response to the dynamic interaction between underlying drivers and proximate causes (Lambin and Geist, 2006). In the past two centuries, the impact of human activities on land has grown enormously because of population increase, urbanization, technological and economic development and the requirements thereafter, altering entire landscapes, and ultimately

affecting the biodiversity, nutrient and hydrological cycles as well as climate. Historically, expansion of agriculture into forests, grasslands, and wetlands has been the greatest source of land cover conversion. Within the last century, however, expansion of urban areas with their associated roads, power grids, and other infrastructure, has also become a persuasive cause of land transformation.

Today close to a third of the earth's land surface is devoted to pastures or croplands, which amounts to approximately one-half of all lands suitable for agriculture. Since the dawn of plant domestication the progression of cropland was relatively slow. The past century observed over half of the worldwide increase in agricultural lands, and in the developing countries, half the land cover conversion occurred in the past 50 years (Houghton, 1994).

A documentation of global patterns of land use change from 1700 to 2000 is presented in (Goldewijk, 2001); and he reports on worldwide changes of land to crops of 136, 412 and 658 Million ha in the periods 1700-1799, 1800-1899 and 1900-1990, respectively. Conversion to grazing land was 418, 1013 and 1496 million hectares in the above pointed out three periods. All totaled, agriculture has displaced one-third of temperate and tropical forests and one-quarter of natural grasslands. Agricultural land conversion is still an important pressure on natural ecosystems in many developing nations; however, in some developed nations agricultural lands themselves are being converted to urban and industrial uses (WRI, 2000).

Urbanization is one of the most significant and long-lasting cause of land use and land cover change and its extent of increase are linked to population growth, technological and economic development. In the last decades, the world has experienced unprecedented urban expansion, especially in developing countries. By now Urban and built-up areas occupy more than 471 million ha which accounts about 4 percent of land area. Just about half of the world's population that is about 3 billion people lives in cities. Urban populations increase by another 160,000 people daily, adding pressure to expand urban boundaries (UNEP, 2002). Suburban sprawl amplifies the effect of urban population growth, particularly in North America and Europe. In the United States, the percentage of people living in urban areas increased from 65 percent of the nation's population in 1950 to 75 percent in 1990, but the area covered by cities roughly doubled in size during the same period (PRB, 1998). Future trends in land conversion are difficult to predict, but projections based on the United Nations' intermediate-range population growth model suggest that an additional one-third of the existing global land cover could be converted over the next 100 years (Walker et al., 1997).

In Ethiopia, most studies indicated that the proximate causes of land cover change particularly natural forest destruction are urban expansion and agricultural expansion, both through shifting cultivation and the spread of sedentary agriculture, the demand for increasing amounts of construction material, fuel wood, charcoal and need of areas for built-up and other uses (Belay, 2002). In case of Addis Ababa city due to notable increase in human population shown in the city demographic history and the associated demand

for residential and industrial area contributed much of the high vegetation destruction, conversion of agricultural land and other uses to urban land use (Dendena, 1995).

### **2.2.2. Underlying Driving Forces of Land Use and Land Cover Change**

Underlying (indirect or root) driving forces are fundamental socio-economic and political processes that push proximate causes into immediate action on land use land cover (Geist and Lambin, 2002). Underlying driving forces, i.e. including demographic pressure, economic status, technological, cultural, political and institutional factors, that influence land use land cover in combination rather than as single causations (Turner and Meyer, 1994).

Urban land use and land cover change is an inevitable process due economic development and rapid population growth. Aspects of the economy that can affect in urban land use and land cover change include the level of economic development, difference in household incomes, exposure to globalization, the level of foreign direct investment, the degree of employment decentralization, the level of real estate finance markets, level and effectiveness of property taxation and presence of high inflation and acute shortage of housing (Angel et al., 2005). In most cases, improved living standards, the GDP per capita and investments have increased urban growth. Higher income residents generally stipulate larger quantity of housing and the economical land to build it on is more likely on the fringe of developed urban areas (Ewing, 1994).

The understanding of institutional causes (i.e. political, legal, economic, and traditional) and their interaction with individual decision making are significant in explaining land use changes (Lambin and Geist, 2003). Institutional factors such as policies on land use and economic development, transportation, or subsidies for land-based activities, lack of adequate governance structures, land tenure and property rights issues, issues of open-access resources, squatting by landless farmers and squatter settlements (urban) are the major driving causes of land cover change. Many believe that land cover and land use change in urban areas may facilitate due to lack of strong and well defined policies and weak institutional enforcement. Cities are expanding very rapidly and are growing for non productive reasons. Some scholars believe that new policies and regulations on land acquisitions and illegal land markets might have encouraged the extensive shifts of cultivated area in to built up area (Yeh et al., 1995).

Technological changes in sectors such as transport, industry, wood and agriculture are playing significant role in changing land cover. Aspect of the technology in transport system and others that affect urban expansion and urban land use and land cover changes may include the introduction of new transport technologies and most notably the private automobile, transportation costs vis-à-vis household incomes, the level of government investment in roads, the existence of city centers that were already developed before the advent of the automobile, and the existence of a viable public transport system. Consumer preferences that may affect the form of urban expansion include: preferences for proximity to open space, for single-family dwellings, or for home ownership;

preferences for urbanism as a way of life, for proximity to other people and to urban amenities, or for proximity to one's place of work.

Cultural factors include attitudes and perceptions such as less concern for forests due to low morale and frontier mentalities, lack of stewardship values, and disregard for "nature", profit-orientation of actors, traditional or inherited modes of cultivation or land-exploitation, and a commonly expressed sentiment that it is necessary to clear the land to establish an exclusive claim.

Demographic factors such as natural increase or migration are other driving factor. Most of its explanatory power tends to be derived from inter linkages with other underlying forces, especially in the full interplay of all five major drivers. Studies conducted at longer time scales show that land cover change had and still has tremendously been influenced by both the increase and decrease of a given population (Lambin et al., 2003). In most developing countries population growth has been a dominant cause of land use and land cover change than other forces (Sege, 1994). There is a significant statistical correlation between population growth and land cover conversion (forest change) in most of African, Asian, and Latin American countries (Turner and Meyer, 1994).

In urban land use and land cover change natural population growth is a major element for all countries, but rural urban migration contributes more in many developing countries (Gugler, 1996). Migration contributes fast growth of urban population due to the relative economic development that attracts people to urban nuclei for commerce, employment,

and education. In general, scholars believe that there are economic and non-economic factors that are encouraging the expansion of urban to non urban areas.

### **2.3. Impact of Land Use and Land Cover Change on Climate**

Land use and land cover change is increasingly acknowledged as an important driver of environmental change on all spatial and temporal scales (Turner and Meyer, 1994). It contributes significantly to earth atmosphere interaction, forest fragmentation, and biodiversity loss. Changes in land cover do not necessarily imply a degradation of the land. However, many shifting land use patterns, driven by a variety of social causes, result in land cover changes that affect biodiversity, water and radiation budgets, trace gas emissions and other processes that, cumulatively, affect global climate and biosphere (Turner and Meyer, 1994).

Climate is the interaction of all of the components of the Earth's system and it includes the solar and infrared radiation and sensible and latent heat fluxes that are all impacted by changes in the Earth's surface. Human induced land use change, that causes changes in the land cover, includes urbanization, deforestation, and agricultural expansion, all of which have been shown to have an important effect on climate and climate change (Pielke et al., 2002). Many observational studies have shown the impact of land cover change on regional climate. For instance, an analysis of observations has revealed that urbanization and the related heat island contribute regionally to the warming trend of the last 50 years over the United States (Gallo et al., 1999), and that the contributions of agricultural expansion and urbanization combined account for as much as half of that

trend (Kalnay and Cai, 2003). In addition, satellite observations explain an increase in the seasonality of clouds and convection over the Amazon basin associated with deforestation (Durieux et al., 2003). Other observational studies confirm that the conversion of land in southwestern Australia has been linked with increased formation of cumulus clouds in that region (Ray et al., 2001). Due to land use and land cover change climate records in Australia are also showing an increase in climate extremes with considerable regional variations (Alexander and Arblaster, 2008; Gallant et al., 2007). Since, the middle age the deforestation of southern Spain is associated with a regional desertification and change in the regional hydrological regime (Millan et al, 2005).

Land use and land cover changes influences surface climate, both through biophysical interactions that affect surface energy and water balance and through biogeochemical interactions that affect the carbon cycle (Pielke et al., 2002). Biogeochemical influences are linked with changes in the net carbon uptake by plants and soils and tend to have positive feedbacks on climate (Lucht et al., 2002). The Earth system is composed of a number of biogeochemical cycles, all powered by the sun's energy. These global cycles include the circulation of certain elements, or nutrients, upon which life and the earth's climate depend. Biophysical influences are typically caused by changes in the radiative properties of the land surface (e.g., albedo) and the properties directly affecting the surface water budget and turbulent exchanges (e.g., root and stomata properties, roughness length). Changes of vegetation type and surface cover can modify the characteristics of the regional atmospheric circulation and the large-scale external moisture fluxes. Changes in surface energy budgets resulting from land surface change

can have a profound influence on the Earth's climate (WMO, 2005). For instance, the presence of urban areas causes local heating (e.g., Brazel et al., 2007) and can even alter the path of individual thunderstorms (e.g., Changnon, 2001).

Urbanization has been a major force of LUCC throughout human history that has had a great impact on climate and climate change (Gao et al., 2003). It affects surface climate by altering the carbon, water, and energy budgets through several physical mechanisms: 1) the reduction in the fraction of vegetated area, which reduces photosynthesis and consequently reduces transpiration and interception loss, 2) the modification of surface roughness and albedo, and 3) the change in surface hydrology. These physical mechanisms are tightly coupled land–atmosphere processes and their alteration may have important impacts on local and regional climate. For instance, in cities existing vegetation covered removed and replaced by non- evaporating and non- transpiring surfaces such as asphalt, concrete and metal etc. These impermeable materials would affect the climate through disrupting evaporation, evapo-transpiration and infiltration. Most importantly; the amount of heat flux trapped by surface material would increase significantly at the expense of latent heat flux, and this would increase the surface temperature (Oke, 1982; Owen et al., 1998). As a result, urban areas often experience high temperature rise compared to rural areas of the same elevation. The heat island is one of the examples of inadvertent climate modification when urbanization changes the characteristics of earth surface and atmosphere (Voogt and Oke, 2003). UHI effects are exacerbated by the anthropogenic heat generated by traffic, industry and domestic buildings, impacting the local climate through the city's compact mass of buildings that affect exchange of energy

and levels of conductivity. The impacts of urban heat island ranges from local to global scale and highlight the effects of urbanization to environmental change. Some of its effect on the local community includes increasing summer time energy, air conditioning cost, air pollution, green house gas emission, and modification of precipitation patterns.

Heat islands can be characterized for different layers of the urban atmosphere and for various surfaces and divided into three categories: canopy layer heat island (CLHI), boundary layer heat island (BLHI), and surface urban heat island (SUHI). The urban canopy layer extends upwards from the surface to approximately mean building height, whereas the urban boundary layer is located above the canopy layer (Voogt and Oke, 2003). The CLHI and the BLHI are atmospheric heat islands since they denote a warming of the urban atmosphere, whereas the SUHI refers to the relative warmth of urban surfaces compared to surrounding rural areas. It is known that atmospheric UHIs are larger at night while surface UHIs are larger during the day (Roth et al., 1989). While atmospheric heat islands are normally measured by in situ sensors of air temperature via weather station networks, the surface UHI is typically characterized as land surface temperature (LST) measured through the use of airborne or satellite thermal infrared remote sensing.

## **2.4. Importance of LST to Study Urban Climate**

Land use and land cover change can importantly influence climatological elements such as maximum, minimum and diurnal temperature (Gallo et al., 1999; Hale et al., 2006). LST is generally defined as the skin temperature of the surface which refers to land

temperature for bare soil, canopy surface temperature for densely vegetated ground and combination of two in case of sparsely vegetated ground (Qin and Karnieli, 1999). Land surface temperature (LST), controlled by the surface energy balance, atmospheric state, thermal properties of the surface, and subsurface mediums, is significant factor controlling mainly physical, biological, and chemical processes of the Earth (Becker and Li, 1990). Land surface temperature is important for environmental studies and management of the Earth's resources because it determines the effective radiating temperature of the Earth's surface. This controls the surface air temperature as well as the clear sky outgoing long wave radiation, which is important in the energy balance of the Earth. It is also a major factor in determining the partition of the available energy into sensible and latent heat fluxes. For example, the rate of change of LST is sensitive to the characteristics of the land surface such as soil moisture, impervious surface, land use and vegetation (Gillies et al., 1997; Verstracken et al., 2006).

The surface temperature is of prime importance to the study of urban climate, not only in obtaining boundary conditions of the atmosphere, but also in understanding the environmental conditions necessary to sustain human beings. Urbanization, including residential, commercial and industrial developments, creates one of the most dramatic human-induced changes on a natural ecosystem, causing the local air and surface temperature to rise several degrees higher than the temperatures of the surrounding rural areas. The interactions of urban surfaces with the atmosphere are governed by surface heat fluxes, the distribution of which is drastically modified by urbanization. The major contributing factors are alteration in the physical characteristics of the surface (albedo,

thermal capacity, heat conductivity), owing to the replacement of vegetation by asphalt, non-porous material and concrete; the reduce of surface moisture available for evapotranspiration; changes in the radiative fluxes and in the near surface flow, due to the complicated geometry of streets and tall buildings, and anthropogenic heat (Dousset and Gourmelon, 2003). According to Streutker (2003), the most significant among these is the difference in the thermal properties of surface areas resulting from the changing character of the urban landscape.

As a result, a large number of studies have sought to analyze the relationship between surface temperature and land use and land cover. Unger et al., (2001) applied regression analysis to examine the influences of urban and meteorological factors on the surface air temperature in Szeged, Hungary. Dousset and Gourmelon (2003) investigated the effects of downtown surface physical properties, especially in industrial and business districts that display heat island effects larger than 7°C. Weng (2001) examined LST pattern and its relationship with land cover in the Zhujiang Delta, China. Work by Nichol (2005) also indicated that different land uses present different thermal behaviors between day and night. Voogt and Oke (1998) found strong directional variations in apparent surface temperature over each of three urban land use areas (light industrial, residential, and downtown). These researches have contributed to our understanding of the thermal patterns created by individual land use land cover within a city such as parks, water, industrial complexes, vegetation cover, and so on.

## **2.5. Change detection and Its Approach**

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times. Fundamentally, it involves the ability to quantify temporal effects using multitemporal data sets (Singh, 1989). Change detection is an important process in monitoring and managing natural resources and urban growth because it gives quantitative analysis of the spatial distribution (Tardie and Congalton, 2004). Change detection is also helpful in such diverse applications as land use change analysis, monitoring shifting cultivation, assessment of deforestation, and study of changes in vegetation conditions, seasonal changes in pasture production, damage assessment, crop stress detection, urban and environmental changes (Bottomley, 1998).

A number of approaches have emerged and applied in various studies to determine the spatial extent of land cover changes. Various researchers have attempted to group change detection methods into different broad categories based on the data transformation procedures and the analysis of techniques applied. For example, Singh (1989) classified change detection methods into two types, namely, classification comparison and direct comparison. Deer (1995) proposed a classification of three categories, including pixel-based, feature-based and object-based change detection. Lu et al., (2004) generalized the change detection methods into seven types, namely, arithmetic operation, transformation, classification comparison, advanced models, GIS integration, visual analysis and some other methods.

No single approach is optimal and applicable to all cases each of them has its own merit and demerit. The selection of an appropriate technique depends on knowledge of the algorithms and characteristic features of the study area (Elnazir et al., 2004), and accurate registration of the satellite input data. Among a number of change detection approaches post classification comparison, which is available in various software platforms, is used in this research for its simplicity and suitability to detect land use land cover change.

### **2.5.1. Post Classification Comparison Approach**

Post classification comparison is among the most widely applied techniques for change detection purpose. Numerous studies have been carried out using post classification approach. In post classification change detection approach two images from different dates are classified and labeled (Jensen, 2005). The area of change is then extracted through the direct comparison of the classification results (Lunetta and Elvidge, 1999). It has its own advantage and disadvantages. The main advantages of post classification includes

- Detailed “from-to” information (Chen, 2000) can be obtained.
- It bypasses the difficulties associated with the analysis of images acquired at different times of year or sensor (Chen, 2000).
- It does not require data normalization between two dates (e.g. Singh, 1989) as the two dates of imagery are separately classified; and
- It provides information about the nature of change (including trajectories of change) (Song et al., 2001; Coppin et al., 2004).

The main disadvantage of the post classification approach is

- The dependency of the land cover change results on the individual classification accuracies (Chen, 2000).

This approach can produce a large number of erroneous change indications since an error on either data gives a false indication of change (Singh, 1989). Therefore, it is imperative that the individual classification be as accurate as possible (Chen, 2000).

## **2.6. Related Works on LULCC and Its Impact on LST**

Studies have shown that there remain only few landscapes on the Earth those are still in their natural state. Due to anthropogenic activities, the Earth surface is being significantly altered in some manner and man's presence on the Earth and his use of land has had a profound effect upon the natural environment thus resulting into an observable pattern in the land use and land cover over time. Studies of the detailed history of LULC change in an area can help explain the spatial extent and the degree of the change itself, and help to assess the directions and degree of other human-related environmental changes. The integration of remote sensing and geographic information systems (GIS) has been widely applied and been recognized as a powerful and effective tool in detecting of both urban and rural land use and land cover change (Ehlers et al., 1990; Treitz and Hobbs 1992; Harris and Ventura,1995). Satellite remote sensing collects multispectral, multi-resolution and multi-temporal data, and turns them into information valuable for understanding and monitoring urban land processes and for building urban land cover datasets.

A number of related studies were conducted using GIS and Remote Sensing. For example, Xiao and Weng (2007) used Landsat TM imagery to examine LULC changes and to assess the impact of these changes on the local ecosystem in terms of the change in land surface temperature focuses on the Chinese Karst area. The study has examined LULC changes in four counties of Karst area in Guizhou Province, of China, from 1991 to 2001. The results indicate that urban/built-up areas expanded dramatically, while agricultural land declined. Naturally vegetated areas decreased from 1991 to 1994, but increased from 1994 to 2001. Barren land increased, mainly in the boundary areas between forest and dry agricultural fields, especially in steeply sloping areas. The observed changes in LULC were largely attributed to population pressure on the land, a rapidly growing economy, poor land use planning, and the inconsistency in the governmental policies. Changes in LULC were accompanied by changes in LST. From 1991 to 1994, the urban or built-up surface temperature climbed at all four counties, and continued to increase in Guiyang and Anshun between 1994 and 2001. Moreover, temperature differences between the urban/ built-up and the surrounding rural areas significantly widened, especially in Guiyang and Qingzheng. This could lead to an intensified urban heat island effect in the urban areas.

Yonghong et al., (2003) integrated Landsat MSS/TM/ETM+ and MODIS satellite imagery, meteorological records, and census data, Topo-sheets to examine the influence of land use change on UHI in greater Guangzhou from 1980–2007 and an integrated and modified single-channel method was used to retrieve land surface temperature (LST). Decadal changes in land use fraction and UHI pattern show that cropland decreased in parallel to

the increase in built-up area and the correlation coefficient reached 0.97. The UHI effect expanded from urban areas to surrounding suburban areas and countryside with an increase in land surface temperature (mean LST increased by 2.48 from 1990 to 2007) and a decrease in the green vegetation fraction (GVF) (mean GVF decreased by 0.16 from 1990 to 2007). The spatial heterogeneity of UHI expansion can be explained by spatial patterns of economic development, population increase, and abundance of vegetation cover. Suthinee Dontree (2010) combines the techniques of remote sensing and geographic information system (GIS) to detect the spatial variation of LST and determine its quantitative relationship with LULC and elevation in Chiang Mai-Lamphun basin. Zamba et al., (2010) apply remote sensing and geographic information systems (GIS) for detection urban growth and assessing its impact on surface temperature in Jimeta city, Nigeria. Remote sensing techniques were utilized to carry out land use and land cover change detection by using multi-temporal Landsat Thematic Mapper data. Urban growth patterns were analyzed by using a GIS-based modeling approach. The integration of remote sensing and GIS was further applied to examine the impact of urban growth on surface temperatures. The results revealed a notable and uneven urban growth in the study area. This urban development had raised surface radiant temperature by 9<sup>0</sup>C from 1986 to 2008 in the urbanized area. The integration of remote sensing and GIS was found to be effective in monitoring and analyzing urban growth patterns, and in evaluating urbanization impact on surface temperature. There are many examples of related works to mention. However, it is important to understand that there is no any standard technique that can be used to analyze impact of land use and land cover change on land surface temperature.

### **3. Background of the Study Area: Addis Ababa**

#### **3.1. Historical Background of Addis Ababa**

Addis Ababa - the capital of Ethiopia - is a relatively new city compared to older religious, administrative and commercial centers like Axum, Yeha and Gondar. It is located at 09<sup>0</sup> 02' 00' 'N Latitude and 38<sup>0</sup> 44' 00" E Longitude. The city overlies at the western margin of the Main Ethiopian Rift and is a part of the western highland of Ethiopia.

It is not exactly agreed as to when Addis Ababa was established as a city, but it became emperor Menelik's residence between 1886 and 1891 (Horvath, 1966; Solomon 1985). As documented in many literatures, it was around 1886, when Menelik, the king of Shoa, permeate with the desire to build the great Ethiopian empire by conquering the southern part of the country and settled at Entoto, strategic area for his governance. In November 1886, while Menelik was off in a distant corner of the empire, his wife Taytu moved the encampment from the hills down onto the current site of Addis Ababa. She reportedly left the Entotto mountain camp because of the unpleasantly cool temperatures at that high elevation and was drawn to the site of Addis by the Fel Weha hot springs (Zewde, 1991). More important than the comfort of the Addis Ababa site, was its potential for expansion. The Entotto site was suspended on a ridge and offered little room for development of the grand city Menelik envisioned. The hills were also limited in proximity to water and

business routes (Pankhurst, 1962). Upon his return, Menelik apparently became fond of the new location and in 1892 named the settlement, Addis Ababa, proclaiming it the new and permanent capital of the Ethiopian Empire (Pankhurst, 1962).

The first land use and land cover patterns of Addis Ababa thus evolved by expelling the neighboring farming community to the periphery as a serf (Tesfaye, 1987). Subsequently, Addis Ababa became the political, religious and administrative centre of the country extending horizontally to the periphery covering large areas. Plan for the city's development has begun after coronation of Menlik II as a king of Ethiopia that formed the base for the present structure of Addis Ababa. The foundation and early expansion of the city was started at the Menelik's Gebbi (palace) at the highest point around the hot spring which served as a political centre and extended to areas of St. George Cathedral that served as a religious centre, adjacent to the church the main local market centre opened in the Arada district (Pankhurst, 1962). Today's Addis Ababa is the result of sprawl to all direction around these centers.

With the introduction of modern public services and technological advancement, establishment of institutions and different small and large scale manufacturing firms, Addis Ababa increased in physical size and population. Currently, Addis Ababa also serves as diplomatic capital of Africa, housing numerous embassies and International Organizations including the United Nation Economic Commission for Africa (UN-ECA) and the African Union (AU) and many other development organizations. By and large, after becoming the capital of Ethiopia, Addis Ababa has been growing by leaping and bounding in physical, social, economic and environmental changes.

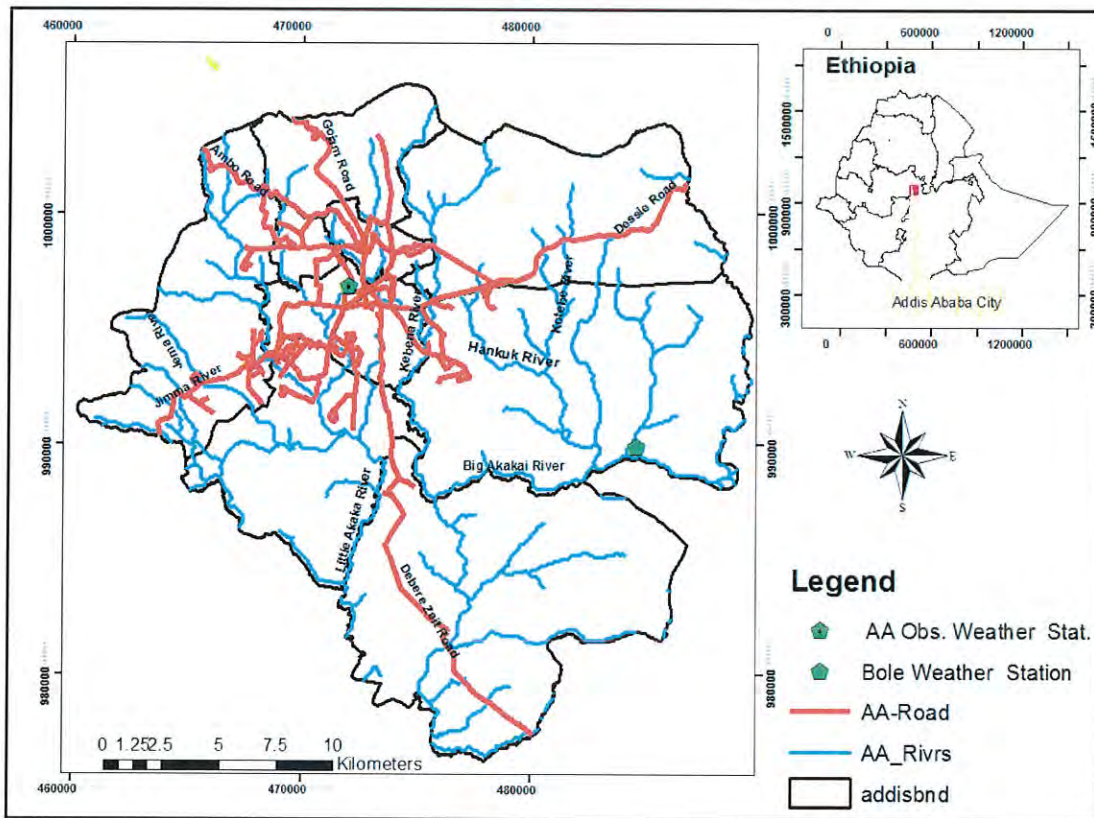


Figure 2: Location Map of Addis Ababa

### 3.2. Physical Expansion and Trend Profile of Addis Ababa

The rapid increase of population associated with economy has lay great pressure on the demand for urban space in the city. In response to this demand, efforts are being made by the city government to incorporate the neighboring areas of the city, which is resulting in speeding up the sprawl of the built-up area of the city. Consequently, Addis Ababa has experienced rapid physical expansion and densification. Table 1 shows the physical growth of the total municipal areas of Addis Ababa since 1984.

Table 1: Area Covered by City Administration of AA

Years	Area in hectares	Growth in hectares
1984	22,200	-
1994	53,014	30,814
2000	53,014	-
2005	54,000	986

Sources: Computed from data found from OPHCC (1987); ORAAMP (1999)

On the other hand, the Office for the Revision of the Addis Ababa Master Plan (ORAAMP) has assessed the expansion trends of Addis Ababa in different periods. The assessment indicates built-up areas of the city in different physical expansion period (Table 2).

The early development of the city was from 1886 to 1936 and is known for its haphazard and extended settlements of the land lords and military camps' occupation of large compound as 'sefer'. The built up area of the early period of development covered 1863.13 hectares that is 12.7 of the present. Following Italian occupation in 1937, the process of physical development of Addis Ababa was characterized by infill development and consolidation of the former fragmented settlements (ORAAMP, 1999). The physical expansion of the built-up area of the city during the period 1937 to 1975 was characterized by a compact type of development except some fringe developments. Fragmented developments occurred along major outlets and around the industries established as satellite development. From 1976 to 1985, the built-up area increased by 4788 hectares, thus increasing the cumulative total to 10,838 hectares. During this period,

the expansion took places in all directions except the north. The general character of the expansion is consolidation of Akaki and Kality with the core city, infill the former fragmented development, elongation along Deberzeit Road, and addition of well structured fabrics in other parts of city.

The next period of physical expansion of the city was between 1986 and 1995, when the built-up area expanded by 2925.3 hectares, increasing the cumulative total to 13,763.3 hectares. Simultaneously, horizontal expansion took place in all peripheral areas of the city, where both legal and squatter settlements were established. Out of the total 94,135 housing units built in the city between 1984 and 1994, 15.7% (14,794 housing units) were built by squatters (ORAAMP, 2001). This period was the period where Dergi regime became feeble and the change of government took place. Due to such reasons, squatar settlement increased and these contributed to the physical expansion of the city in this transition period.

During the most recent period of physical expansion, between 1996 and 2000, the physical built-up area of Addis Ababa increased by 909.4 hectares, reaching a cumulative total of 14,672.7 hectares. Expansion of the city was characterized by the development of scattered and fragmented settlements in the peripheral areas of the city, with both legal residents and squatters. In 2000, Addis Ababa had an estimated total of 60,000 housing units with squatter settlements. This figure accounted for 20% of the total housing stock of the city and the total area occupied by squatter settlements was estimated at 13.6% of the total built-up area (Minwuyelet, 2005).

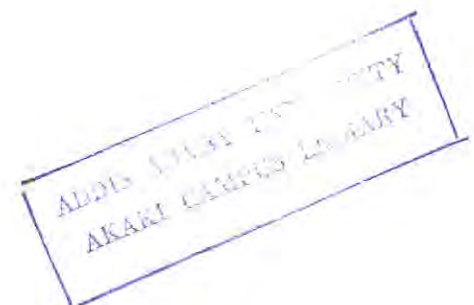


Table 2: Physical Growth of Addis Ababa (1986-2005)

Period	Area covered	Total built-up area (ha)	Rate of increment
1886-1936	1869.13	1869.13	-
1937-1975	4186.87	6050.00	3.1
1976-1985	4788.00	10838.00	6.0
1986-1995	2925.30	13763.30	2.4
1996-2000	909.40	14672.70	1.6

Source: Based on data obtained from ORAAMP (2001).

### 3.3. Land Use and Land Cover of the City

The land use of Addis Ababa has been changed rapidly due to extensive urbanization as a result of socio-economic, political, and physical factors. The extensive urbanization results in replacement of vegetated land, cultivated land, grass land and wet land by built up. Urban land stretched out on the undulating topography with some flat land areas. Forest lands, grassland, wet lands and cultivated land are found on the fringes and some patches of other than built-up found on the city center. The greatest part of forest land covered by Eucalyptus, and other endemic and endanger species such as Juniperious procera (Yehabesh Tid), Hypericum revolution, Olinia rochetiona, Myrsine africana and Erics arbrea(Asta). Even though, the environment is not suitable for wild life habitat due to encroachment of forest land and change of land cover, but some wild animals like spotted hyena, common jackal, white tailed mongoose, velvet monkey, baboon and antelopes and many others exist in forest area. During, the field survey, forest land and cultivated land have been observed changing to built up, single story building to multistory buildings and from extensive use to intensive use. The increase in the demand

of, land for urban, fuel and construction materials has highly affected the land cover in recent years.

The above mentioned land use land cover types were identified from observation of the study area during field visit and from AAEP. The classification was modified based on Anderson level 1 classification.

### **3.4. Demographic Background of Addis Ababa**

Based on the 2007 census results, Addis Ababa has a total population of 2,738,248, consisting of 1,304,518 men and 1,433,730 women. The city is fully urban, with no rural dwellers within the city's administrative boundaries. For the capital city 662,728 households were counted living in 628,984 housing units, which results in an average of 4.2 persons to a household. Addis Ababa contains 22.9% of all urban dwellers in Ethiopia and for about 3.7% of the total population of the country. The City is divided into 10 Sub cities; again the sub cities are divided in to 99 Kebles. There is a disparity in Sub city population distribution which shows uneven distribution. The majority of the city population lives in Kolfe Keranyo (15.6%), Yeka (12.6%), Nefas Silk Lafto (11.5%), Bole (11.2%), Gullele (9.76%), Addis Ketema(9.3%), Kirikos(8%), Lideta(7.4%), Arada(7.7%) and Akaki Kality Sub City (6.7%) Arada and Akaki Kality have the smallest share from the City's total population.

Addis Ababa, the capital city of Ethiopia, is among the fast growing cities of Africa in terms of both population and physical size. In 1910 the population of the city was only

65,000 and in 1935 the population of the city grew to 100,000 (Solomon, 1985). The primary census result of the city held in 1961 indicates that the city had a population of 443,728 (OPHCC, 1987). The following Table 3 illustrates the population growth patterns of Addis Ababa since its establishment.

As shown in Table 3. Addis Ababa's population growth pattern has been irregular during the greater part of its history, largely due to changes in the country's social, economic and political conditions. Natural increase and substantial migration are main factors contributing to the fast growing population of the city. The data revealed that there was exceptionally high average annual rate of growth between the years 1935 and 1956. This was perhaps due to established road network and work opportunity created by Italian Administration in its short rule of the country that attracted people to urban settlement.

During the period 1956-1961 the average annual growth rate of the population decreased. From 1961-1967 and 1967-1978 the population grew at an average rate of about 7.9 and 9 percent per annum, which has dropped by about 3 percent per annum between 1978 and 1984. This decline seems due to the political unrest in the country since February 1974 revolution.

The data also indicates an upward trend in between 1984 and 1994. This was perhaps partly due to instability and civil war in the country so that people fled to the city because of war displacement. From the 1994 census onwards the city is experiencing one of its slowest-ever growth rates, just slightly below three percent per annum. Even with

this low growth rate, the capital continues to attract 90,000 to 120,000 new residents every year (ORAAMP, 1999).

Table 3: Patterns of Change in Population Size and Growth Rate of Addis Ababa

Years	Population size	Absolute Change	Average Annual Growth Rate
1900	50,000	-	-
1910	65,000	15,000	3.00
1935	100,000	35,000	2.15
1941	143,000	43,000	7.17
1956	318,000	175,000	8.16
1961	443,728	125,728	7.91
1967	683,530	239,802	9.01
1978	1,167,315	483,785	6.43
1984	1,423,111	255,796	3.0
1994	2,112,737	689,626	3.3
2007	2,738,248	625,511	2.1
2010	2,958,839	151,910	2.1

Sources: Compiled from data found in Solomon (1985); OPHCC (1987); CSA (1995); CSA (2010)

Migration has direct effect on the geographic distribution of the population and change of land use land cover. Moreover, migration in interaction with other demographic forces as well as other aspects of social and economic changes. Addis Ababa, the capital city of the country, attracts a number of migrants from all regions in the nation due to different reasons. According to the country's 2007 population and housing census, out of the total population of the city, 1,302,966 (47.6%) were migrants from rural and other urban areas in Ethiopia (CSA, 2010). Drought and famine demobilize army of the Derg government, the Ethio- Eritrea conflict during 1998-2000, and displacements of people due to conflicts have increased the level of migration in Addis Ababa city in all these years. For instance,

113, 418 migrants flooded Addis Ababa during Ethio- Eritrea conflict and at the end of 1997 there were 53, 000 migrants in the city (AACCA, 1997). Migrants driven out of their regular location due to adverse socio-economic and culture grounds and became the burden to the city and the dwellers and are the causes of urban expansion.

Generally, the overall picture of Addis Ababa city's population growth pattern reveals accelerated urban growth and subsequently high conversion of land from other uses to urban. Thus high population growth and haphazard nature, which has unleash tremendous agglomeration of unplanned and shanty settlements in the periphery with high population density in some parts of the center typifies the City.

### **3.5. Climate Characteristics**

#### **3.5.1. Rainfall**

The mean annual rainfall in the Addis Ababa ranges between 1132mm and 1179mm. There are marked inter and intra-annual variations in rainfall. There were notable periods of above average rain in 1989, 1993, 1996, 2005-07, and 2010 and periods of below average rainfall in 1994, 1997, 1999-2000, and 2002. The period 1994 to 2000 is one of rainfall deficit, as indicated by the cumulative departure from the mean (Figure3).

The rainfall regime in the study area is bi-modal, and has strong seasonal variations due to the passage of the ITCZ (Inter Tropical Convergence Zone). The mean monthly rainfall in Addis Ababa is above 162.11 mm between April and September inclusive, with the highest mean monthly rainfall recorded in August at 265.99 mm and the months

with the lowest rainfall are November, December and January with 6.35, 7.73 and 13.65 mm mean monthly rainfall, respectively.

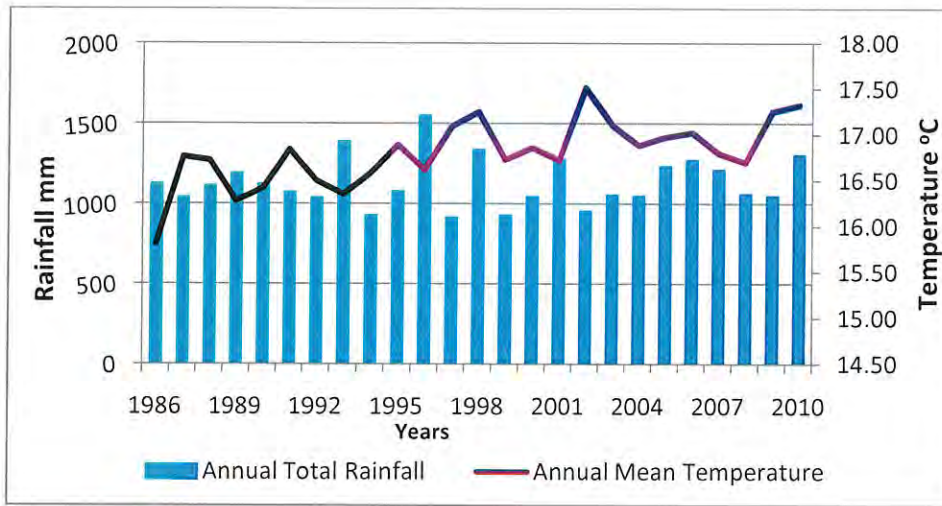


Figure 3: Annual Mean Rainfall and Mean Annual Temperature of Addis Ababa

Source: National Meteorological Services Agency, 2012).

### 3.5.2. Temperature

Latitude, altitude, winds and humidity, with varying magnitude have significant impacts on temperature conditions in Ethiopia. The overall temperature in Ethiopian highlands is lower than those in tropical lowlands. The average fall in temperature is  $0.6^{\circ}\text{C}$  for every 100m rise in elevation. The average temperatures are typically tropical and fluctuate by  $5^{\circ}\text{C}$  between the coldest and warmest months. The annual variation is from 2 to  $6^{\circ}\text{C}$  in the Ethiopian highlands (Akundabweni, 1984). Highest temperature was observed for the months of March, April, May and June. While the months of October, November and December had the lowest temperatures in the years under study.

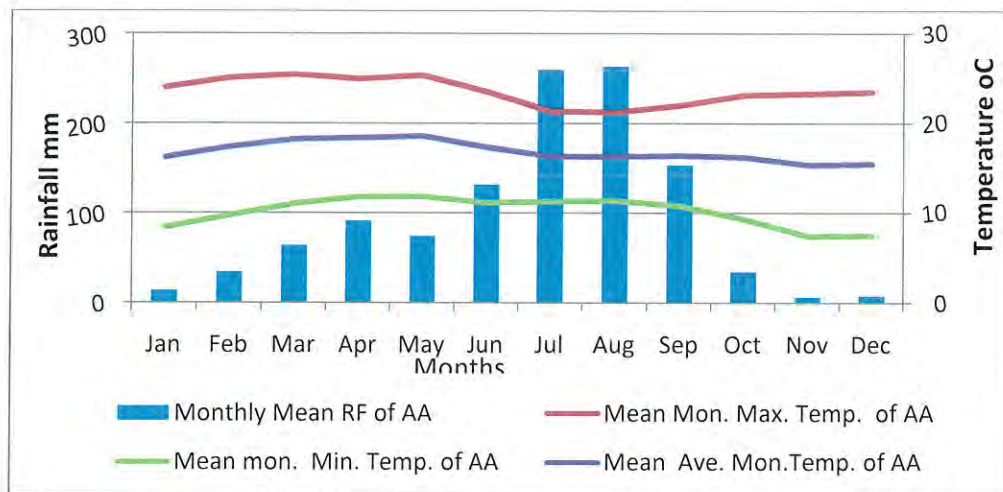


Figure4: Monthly Mean Rainfall and Mean, Maximum and Minimum Monthly Temperature of AA

(Source: National Meteorological Services Agency, 2012)

The city experiences a temperature of moderate type of climate with an average maximum of 23.5°C to an average minimum of 9.6°C. The mean annual temperature in Addis Ababa lies between 15.85°C -17.51°C at the study periods. The average monthly temperature of the hottest month (May) and the coldest month (November) is 18.6 °C and 15.6 °C, respectively with an annual range of a mere 3 °C (Figure 4).

### 3.6. Physiography of Addis Ababa

Ethiopia can be divided into four major physiographic regions widely known as the Western plateau, Southern plateau, the Main Ethiopian Rift and Afar Depression (Mengesha et al., 1996).

Addis Ababa is situated on a plateau with an elevation ranging from 2131 to 3193m a.s.l. on the summit of the western Main Ethiopian Rift escarpment. The morphology of Addis

Ababa is a direct reflection of the different volcanic stratigraphic successions, tectonic activities and the action of erosion between successive lava flows (Tamiru et al., 2006). The city is bounded by high rising mountain systems in all directions and the center of the city lies on an undulating topography with some flat land areas. The built-up area of the city is deeply dissected by numerous valley formed by the river systems crossing the city from north to east.

Entoto mountain ridge forms the northern boundary of the city following the East-West trending Ambo-Kassam major fault system. The elevation of this ridge ranges from 2600 to 3200masl. The volcanic mountains; Mt. Furi in the south-west, Mt. Yerer in the southeast and Mt. Wechecha in the west are the high massive volcanic centers rising to elevations of 2839m, 3100m and 3385masl respectively

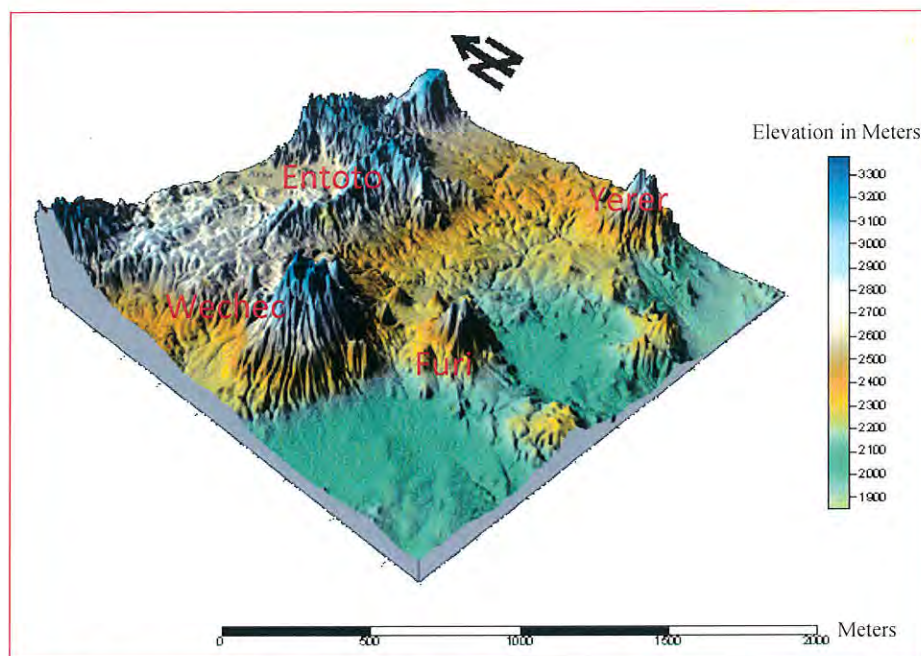


Figure 5: Physiographic Model of Addis Ababa

Undulating to flat topography is dominant within the city boundary. The occurrence of domes and stream valleys create this undulating topography. Further south wards, the topography becomes very gentle and a very wide area falls under a smaller elevation range of 1960masl and 2160masl (Figure 5).

Addis Ababa lies within the Awash River Basin. The water divide between Awash Basin and Blue Nile Basin lies on the top of Entoto Ridge. The catchment area of Akaki River basin that totally includes Addis Ababa area is divided into two sub basins - the Big Akaki River (Eastern) sub basin and the Little Akaki River (Western) sub basin.

The streams of Addis Ababa drain towards south from Entoto ridge, south east from Mt. Weheca and Mt. Furi and towards south west from Mt. Yerer and other elevated areas of the eastern outskirts of the city. The potential streams in the city are Little Akaki, Bantiyketu, Kurtume, Kebena, Ginifile, and Big Akaki. Other streams are intermittent in nature. Streams are dense with deep valleys on top of mountains such as Entoto ridge forming radial and dendritic drainage patterns (Figure 2). In the southern part of the city the density of the streams is reduced and the main rivers show meandering type of flow. This is due to the decrease in the gradient of the valley floor.

### **3.7. Geology**

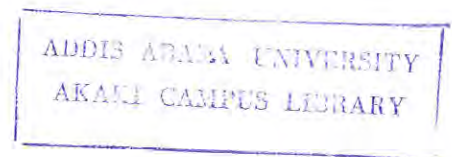
The situated hill chain (Entoto and Yeka) in the northern part of Addis Ababa is composed of Termaber basalts. It is called Entoto Cilcic and it is covered with volcanic topsoil materials of about one to two meters thick. The urban area is composed of

younger basalts called Addis Ababa basalts which are also covered with volcanic topsoil materials. The western part of Addis Ababa belongs to the younger age stratum; the northern part is mainly composed of Trachey basalts. In the Bole area, a kind of basalt, called ignimbrites, is partly found. The topsoil materials in the western part are thick and soft compared to those of the northern and eastern parts.

### **3.8. Socioeconomic Characteristics**

The economic activities in Addis Ababa are diverse. According to official statistics from the federal government, some 119,197 people in the city are engaged in trade and commerce; 113,977 in manufacturing and industry; 80,391 homemakers of different variety; 71,186 in civil administration; 50,538 in transport and communication; 42,514 in education, health and social services; 32,685 in hotel and catering services; and 16,602 in agriculture. In addition to the residents of rural parts of Addis Ababa, the city dwellers also participate in animal husbandry and cultivation of gardens. 677 hectares (1,670 acres) of land is irrigated annually, on which 129,880 quintals of vegetables are cultivated. A construction boom with tall buildings rising in many places. Various luxury services have also become available and the construction of shopping malls has recently increased. According to Finance and Economic Development Bureau GDP study document contribution of sectors in Addis Ababa to the national economy is 77% Service, 22 % Industry and the rest 1% is Agriculture.

According to the 2007 national census, 98.64% of the housing units of Addis Ababa had access to safe drinking water, while 14.9% had flush toilets, 70.7% pit toilets (both ventilated and unventilated), and 14.3% had no toilet facilities. Values for other reported common indicators of the standard of living for Addis Ababa as of 2005 include the following: 0.1% of the inhabitants fall into the lowest wealth quintile; adult literacy for men is 93.6% and for women 79.95%, the highest in the nation for both sexes; and the civic infant mortality rate is 45 infant deaths per 1,000 live births, which is less than the nationwide average of 77; at least half of these deaths occurred in the infants' first month.



## **4. Research Methodology and Design**

This section explains the research methodology that was used in the study. It gives detail explanation of methods of data collection and its data source. Subsequently, it outlines the sampling procedures and techniques that were employed in the study. Finally, it presents the method of analysis and interpretation. General methods and techniques of data collection and data analysis used in this study were illustrated in Figure 6 (Methodological flow chart).

### **4.1. Materials and Data Collection**

#### **4.1.1. Materials**

To meet the objectives of the research satellite images (Multi temporal Landsat TM, Spot-5 and Google Earth images), topographic maps, GPs for ground verification and digital camera were used. In addition, software's such as ArcGIS 10 (analysis and image processing), ERDAS IMAGINE 2011(image processing), ENVI 4.7(change detection and classification), Ms Excel (charts and graphs), Ms Word for word processing and others were used.

#### **4.1.2. Data Collection**

Both quantitative and qualitative types of data from both primary and secondary sources were collected in this study. Two cloud-free Landsat TM scenes, acquired on December 23, 1986, and December 10, 2010 with Row/Path: 54/168, were obtained to quantitatively measure land surface temperature and to observe the trends and patterns of land use and

land cover of the study area. The two images were taken at a similar time of year to minimize phenological effects. All images bands 1–5 and 7 have a spatial resolution of 30 m, and the thermal infrared band has a spatial resolution of 120 m. The image was acquired through the USGS Earth Resource Observation and Science (EROS) through <http://glovis.usgs.gov/> free of charge, which had been geo-referenced by supplier to the Universal Transverse Mercator (UTM) map projection (Zone 37), WGS 84 datum and ellipsoid. In order to see the clear change in land use and land cover both satellite images of 1986 and 2010 were clipped by the same current boundary shape file. Due to this reason may be hinterlands in 1986 were added to city boundary.

A city boundary file, 1:50,000 scale topographic maps, Spot -5 image acquired 2005, Google Earth image, Digital elevation model (DEM) with 30\*30 ground resolution, Road map of AA, historical LULC maps and documents related to study were also collected from different data sources for the study.

In order to make a closer investigation of the effects of land use and land cover change, driving forces of LULCC, patterns and trends of LULCC, and its impacts on local community and environment, data were collected from the study area by means of structured and unstructured interviews and participatory discussions. Accordingly, the required data were obtained from both primary and secondary sources. The primary data were collected through participatory approach, which included focus group discussions and key informants interviews. The secondary sources of information were collected and used from published, unpublished, and other related works. Data on rainfall, temperature and humidity and other climate elements over a period of 24 years from 1986 to 2010

were collected from National Metrology Agency. Demographic data were collected from Central Statistics Agency. Guidelines covering a wide range of topics relevant to the central issue of interest were developed to conduct interview and group discussion (Appendix 1 and 2).

#### **4.1.2.1 Socioeconomic Data Collection**

Broader issues on economic, social, environmental and political effects of land use and land cover change and deriving forces for these changes were raised and discussed with the key informants from the community, kebele administration and relevant sectoral offices of the City Administration including Addis Ababa, urban planning and information Agency, Land Development Agency, EPA and other stakeholders. Purposive and area sampling methods were employed to pick individuals in the process of conducting interview and discussion in the study area. First the city was geographically divided in to three area clusters based on their location and setting: city center (Addis Ketema, Arada, Kirkos, and Lideta), upper catchment (Gullele, Kolfefe Keranyo and Yeka) and lower catchment (Nifasilk Lafeto, Bole and Akaki Kality).

Second, samples were purposely selected one from each cluster that are Kirkos, Yeka , Nifas Silk-Lafto sub-cities based on their proportion and representativeness. And then, the interview was conducted with three key informants one from kebele administration two from community in each kebele from the selected sub cities. Furthermore, three key informants from each sector of relevant departments have been interviewed.

Group discussion with different stakeholders and social groups were conducted to elicit pertinent data. To this end, two focus group discussions one from community (Elders, community based organization leaders, Women, Youth) and one from stakeholders with minimum of eight and maximum of ten in each selected sub city overall six group discussions were conducted.

## **4.2. Data Analysis**

### **4.2.1. Analysis of Socioeconomic and Meteorological Data**

Qualitative data gathered through participatory assessment involving key informant interviews, focus group discussions, and observation and assessment of the researcher were processed and analyzed qualitatively in line with the objective of the study. The meteorological data were analyzed using several quantitative techniques such as mean, annual, and time series averages (five year and ten years moving averages).

### **4.2.2. Analysis of Satellite Images for Land Use and Land Cover Change**

#### **4.2.2.1. Image Pre-processing**

Preprocessing of satellite images has been done to create more faithful representation of the original scene. Different preprocessing methods were implemented before the classification and the change detection and LST retrieval. These include layer stacking, geometric, radiometric, atmospheric, and topographic correction. Some of the preprocessing steps to be followed in this research are briefly described below.

### ***Layer Stacking***

All five bands of TM, excluding the thermal band, were considered for layers stacking. The nature of these different bands had to be considered to make a decision as to which three band combination would be most helpful for classification and visual interpretation. The Band 4 reflective infrared wavelength (0.76-0.90 $\mu\text{m}$ ) is absorbed by water (appearing dark) and reflected by vegetation (appearing bright), while mid-infrared bands 5 (1.55-1.75 $\mu\text{m}$ ) and band 7 (2.08-2.35 $\mu\text{m}$ ) contrast well, revealing differences in types and conditions of vegetation and soil (McHugh, 2006). By taking all these facts into consideration, band 4 in the green, band 5 in the red and band 7 in the blue wavelengths were used to create a false color composite from TM images). After layer stacking, all the scenes were registered to topographic maps of the UTM coordinate system.

### ***Geometric Correction***

Raw digital image cannot be used as map without correcting geometrically as well as radiometrically. The geometrical distortion of raw digital image is caused by two ways. The first one is systematic (predictable) and the second one is random (unpredictable) distortion. The former is caused by the Earth as it rotates from West to East direction during the satellite imagine from North to South direction. As a result of this, the full scene image has declined the South part to west and the North part decline to East. For this study, In order to reach an acceptable geometric accuracy and eliminate the discrepancy between the imageries and other underlying layers, Satellite imageries were georeferenced to their actual latitude and longitude using approximately 60 GCPs, primarily road intersections which are evenly distributed across the entire image, taken

from topographic map and georeferenced road map of the city. These images were re-projected to the local level projection system datum of Adindan, reference spheroid of Clark1880 and projection type of UTM Zone 37 North and masked by the study area boundary shape file. To subset both images of 1986 and 2010 the current boundary shape file was used and to perform this ERDAS Imagine 2011 software was utilized. Due to rugged topography of the city, ortho-correction was seemed to be important and therefore the nearest neighbor resampling method was used to avoid altering the original pixel values of the image data. The images were re-sampled using the nearest neighbor algorithm with a pixel size of 30 m by 30 m for all bands, including the thermal band. The RMSE of rectification was less than 0.5 in this study.

#### ***Radiometric, Atmospheric and Topographic Correction and Haze Reduction***

Radiometric corrections serve to remove the effects that alter the spectral characteristics of land features, except for actual changes in ground target. Radiometric correction methods of satellite images can be grouped in two major categories: absolute and relative (Du et al., 2002). Absolute radiometric correction converts the digital counts ( $Q$ ), in which satellite image data are distributed, to at sensor radiance ( $Q_{cal}$ ) and then, through atmospheric correction, to reflectance at the surface of the Earth. Relative radiometric correction normalizes multiple satellite scenes to each other. Most forms of absolute radiometric correction rely on any combination of sensor calibration coefficients, atmospheric correction algorithms, and illumination and observation geometry coefficients. These data are used in a radiative transfer model to correct the imagery to reflectance values. So for this study absolute radiometric correction method was used. Radiometric calibration of the 1986 and 2010 TM sensor involves rescaling the raw

digital numbers (Q) transmitted from the satellite to calibrated digital numbers (Qcal), which have the same radiometric scaling for all scenes processed on the ground for a specific period. Radiometric calibration was done using ATCOR for ERDAS imagine 2011.

Atmospheric correction is an important preprocessing step in remote sensing digital image analysis, especially when multi-temporal data are applied to extract such information as biomass; land use and land cover features and their changes. Atmospheric correction methods employed to remove atmospheric attenuation are grouped under radiometric corrections. The methods to be used for atmospheric correction are the function of nature of problem, the type of remote sensing data, the amount of in situ historical atmospheric information available, how accurate the biophysical information to be extracted from the remote sensing data (Jenth,1996). To Process multi spectral image data sets, statistical based relative atmosphere correction methods and physics based absolute correction models are available.

Statistical based relative atmosphere correction methods used reflectance as the basis of change detection over time such as FFC (Flat Line Correction), Internal Average Relative Reflectance (IARR) and Empirical calibration technique (ii) by using reflectance in physics based on absolute models used such as(ATCOR) Atmospheric CORrection Now (Vermote et al., 1997), Fast Line-of sight Atmospheric analysis of spectral Hypercube (FLAASH), (MODTRAN) Moderate Resolution Atmospheric Radiance Transmittance Model (Berk et al., 1999), Atmospheric REMoval Program (ATRIM), High accuracy Atmospheric Correction for Hyperspectral data, (6S Code) Second

Simulation of the Satellite Signal in the Solar Spectrum (Vermote et al., 1997), and COST (Chavez, 1996) etc.

As mentioned above several atmospheric correction models have been developed to eliminate atmospheric effects to retrieve correct physical parameters of the earth. Despite the variety of available techniques, for this study to eliminate the effects of atmospheric scattering and absorption in the image and to increase the accuracy of land use and land cover classification, the original DN values was converted to surface reflectance by atmospheric and topographic correction model ATCOR 3 for ERDAS Imagine 2011.

Topographic correction is equally important processing step as atmospheric correction to enhance the data quality, help the interpreter, and improve the performance of subsequent processing. Mainly, two different approaches have been used to correct for varying illumination and reflection geometry caused by the topography. The first employs band ratio (Holben and Justice, 1980) and statistical transformation such as Principal Component or regression techniques (Civco, 1989) to get a band specific and scene dependent correction. The second approach employs a radiative transfer code to get a deterministic description of the topographic effect (Conese, 1993). While, ATCOR 3 is a method using for radiometric correction of satellite imagery over rugged and mountainous terrain and removes atmospheric and topographic effects and haze reduction. Addis Ababa is by its nature rugged and mountainous city it needs topographic correction. So, due to such reason atmospheric and topographic correction as well as haze reduction were performed by ATCOR 3 model for ERDAS Imagine 2011 that for this study. The haze reduction was done before atmospheric and topographic correction.

#### **4.2.2.2. Reference Data**

To acquire a land use and land cover map precisely, reference data were developed for each of the years and then randomly divided for classifier training and accuracy assessment. Due to the retrospective nature of study, it was necessary to employ a variety of methods to develop reference data sets for training and accuracy assessment. Training areas/sample objects which are typical representatives of the classes were collected using high resolution images; existing land cover maps, analyst's personal experiences and knowledge of the physiographical nature of the area.

Large scale (1:50,000) topographic map acquired in 1984 were used as reference data for the 1986 classification. Stratified random sampling was used for selecting samples. More specifically, the Addis Ababa was divided into 19 columns and 18 rows resulting in 342 cells, and a 600\*600 m site was randomly sampled from each cell. The topo map corresponding with the sample sites were then interpreted and 20 polygons of cover types were delineated. These polygons included approximately 1.66 % of the total pixels; 63% were used for training and the remainder for accuracy assessment.

The reference data for the 2010 classification were acquired from different sources. The primary data was a field verified set of reference sites collected in the February of 2011. This data set was created by collecting cover type information for a stratified random sample of 350 points with 70 points per level 1 class (excluding bare lands). At each sample point ArcGIS and GPS was used to digitize a polygon of the area of the 2010 cover type identified, along with other cover types in the vicinity of the randomly

area of the impervious surface polygons by the total area of the AOI. Originally 150 random samples were generated for the entire image. Samples outside of the study area were subsequently excluded, leaving 141 valid samples representing varying percentages and kinds of impervious surfaces.

#### **4.2.4. Computation of Normalized Difference Vegetation Index (NDVI)**

Normalized difference vegetation index (NDVI) may be used as an indicator of abundance of biomass and greenness (Chen and Brutsaert, 1998). When standardized, it may also be used as a method for comparing vegetation greenness between satellite images (Gillies et al., 1997). The index value is sensitive to the presence of vegetation on the Earth's land surface, and is also highly correlated with climatic variables, such as precipitation (Schmidt and Karnieli, 2000). Many studies have revealed temperature to be the leading climatic factor in controlling the vegetation greenness in the northern hemisphere (Zhou et al., 2001; Lucht et al., 2002; Ichii et al., 2002). Others have related NDVI to ecological quantities such as terrestrial net primary productivity (Kaufmann et al., 2004), and soil organic carbon at the local, regional, and global scales (Fung et al., 1987). In this research, NDVI was calculated to infer general vegetation conditions and describes the greenness of areas. In addition, to examine the relationship between LST and greenness and to see how vegetation abundance has effect on urban climate. NDVI was calculated as the ratio between measured reflectance in the red (R) and near infrared (NIR) spectral bands of the images using the following formula:

$$NDVI = \frac{Near\ IR\ Band - Red\ Band}{Near\ IR\ Band + Red\ Band} \quad (5)$$

## 4.2.5. Retrieval of Land Surface Temperature

The conceptual framework used in this study for LST retrieval from Landsat TM 5 data follows that proposed by Qin et al., (2001). It requires radiometric calibration (spectral radiance conversion to at-sensor brightness temperature), correction for atmospheric absorption and re-emission, and emissivity estimation prior to LST estimation.

### 4.2.5.1. Radiometric Calibration for the Thermal Band

The actual measurements acquired by a TIR sensor will be in units of spectral radiance that reaches the sensor for a certain wavelength. However for reasons of storage, the radiance values are usually scaled and stored as DN values. So to retrieve effective at-sensor brightness temperature from the thermal band data (Band 6 on TM) a two step process is needed. The first step is to convert the DNs to radiance values that is radiometric correction and the second step converts the radiance data to degrees Kelvin Atmospheric correction.

Radiometric calibration was performed by converting the Digital Number (DN) values to radiance based on sensor calibration parameters. The conversion from  $Q_{cal}$  to at-sensor spectral radiance ( $L_{sen}$ ) is performed using sensor calibration parameters published by Chander et al., (2009) and in image header file by following gain and bias method Eq 3.

$$L_{sen} = \mathbf{G}_{rescale} \times \mathbf{Q}_{cal} + \mathbf{B}_{rescale} \quad (6)$$

Where  $L_{sen}$  = Spectral radiance at the sensor's aperture [ $W / (m^2 sr \mu m)$ ]

$Q_{cal}$  = Quantized calibrated pixel value [DN]

#### 4.2.5.4. Land Surface Temperature Computation

In this study, the LST was retrieved using a LST software tool developed by Zhang et al., (2006), which includes three major steps: (i) NDVI Calculation, (ii) Emissivity preparation and the (iii) LST calculation. In the LST software two method of calculating the surface temperature has been programmed namely the Qin et al's Mono window Algorithm and Jimenez Munoz and Sobrino's algorithm. In this study, the Qin et al's mono window algorithm has been used to retrieve LST because it uses the atmospheric water vapor and the near-surface air temperature for retrieving the LST and validity. The model used for obtaining LST by Qin et al., (2001) mono-window algorithm was expressed as follows:

$$T_s = \frac{a_6(1-c_6+D_6)+[b_6(1+c_6-D_6)+c_6+D_6]T_{sensor}-D_6T_a}{c_6} \quad (10)$$

where  $T_s$  is the land surface temperature in K,  $T_{sensor}$  is the brightness temperature in K computed from Landsat TM/ETM+ band6,  $T_a$  is the effective mean atmospheric temperature (K),  $a_6$  and  $b_6$  are constants with values of -67.355351 for  $a_6$  and 0.458606 for  $b_6$  when the LST is between 273.5 and 343.5 K.  $C_6$  and  $D_6$  can be calculated by the following equations:

$$c_6 = \varepsilon T_6$$
$$D_6 = (1 - T_6)[1 + (1 - \varepsilon)T_6] \quad (11)$$

Where  $\varepsilon$  is the ground surface emissivity and  $T_6$  is the atmospheric transmittance.  $T_a$ ,  $\varepsilon$ , and  $T_6$  are the three parameters needed to convert the brightness temperature to LST. According to the work of Qin et al., (2001),  $T_6$  could be estimated by

western part of the study area which is higher in altitude (Figure 7). Generally, in the 1986's result as indicated in Table 6 the area was mostly covered with agriculture, grass land, urban and forest where as bare land and wet lands covered smallest part of the area.

In 2010 agriculture, was the largest LULC category in the study area. It accounted for 36.72% of the total land. Urban land was the second largest category, covering 33.97%. Grass land was widely distributed, accounting for 14.87% of the land, while forest land and bare land covered 9.63% and 3.57%, respectively (Table 6).

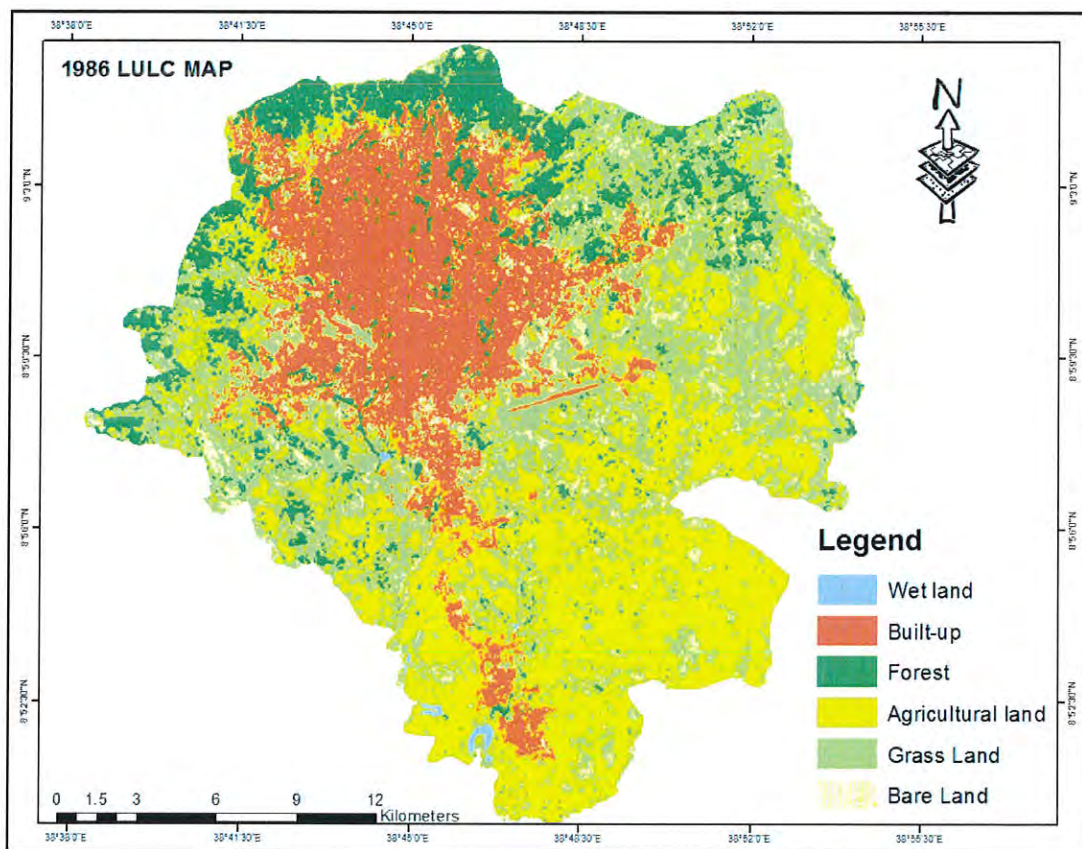


Figure 7: Land Use and Land Cover Map of 1986

Forest was almost exclusively located at the top of Entoto ridge and distributed unevenly in the study. A high proportion of agricultural land was located in the south, south east, south west and east part of the study area, on the flat floor of the city. There also existed many narrow strips and small patches of cultivation areas distributed in the study area. Bare land often have a scattered pattern and was discovered mainly along the boundary line between forest, built up areas and agricultural fields, especially in steeply sloping areas and outskirts of the city ( Figure 8). Urban/ built-up land was mainly found in the floors of Entoto hill stretched to all direction. Figure 7 and 8 show patterns and classes of land use and land cover over the study period.

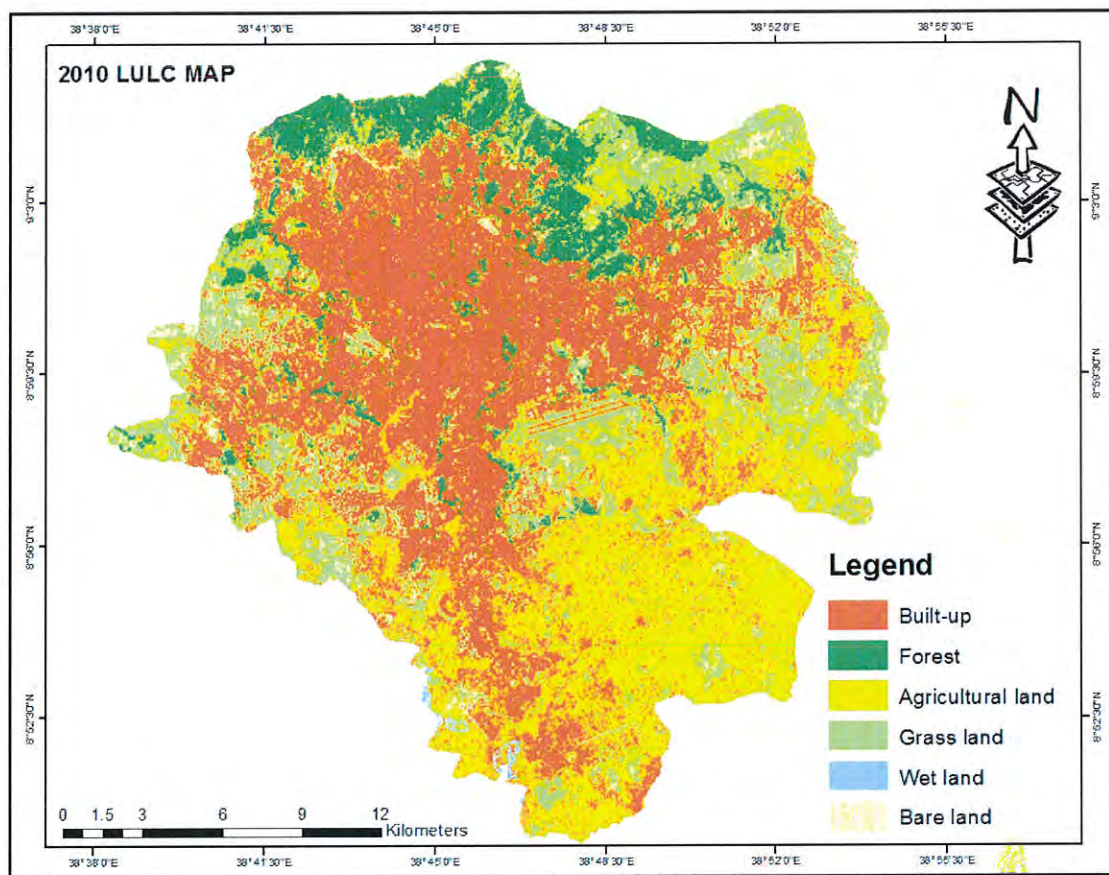


Figure 8: Land Use and Land Cover Map of 2010

## **5.2. Land Use and Land Cover Changes**

Analyzing the change at different times, help in determining the causal factors, the level of the change, impact of change and the respective management techniques. The rate of change (difference in area from the final to the initial state of each land use and land cover category over the specified time period or number of years in each period) across the study period has also been analyzed based on the statistical data derived from the images (Table 7).

In order to put a clear picture and understanding of the land use and land cover dynamics, change matrix has been generated on the basis of the classified image data (Table 8). These tables show the areal distribution of each land category that has undergone conversion and transformation from one category to the other.

### **5.2.1 Trend and Rate of Land Use and Land Cover Change**

The data revealed that the land cover in two different times showed significant changes. Urban coverage was drastically changed from 18.88% in 1986 to 33.97% in 2010 that is almost two times from initial year (Table 6). Urban/ built-up expanded to all directions particularly to the south, east and North West side.

Overall, the built-up land had the highest change rate among the land use classes, with 3.3 Km<sup>2</sup> (0.63%) per year of other land use classes changing into built-up land (Table 7 and Figure 10). It was suggested that the expansion of the urban area to the surrounding

environment had an impact on the decrement of agricultural, forest, grassland and bare fields. Thus, agricultural land, which constituted 39.76 % of the total area in 1986, reduced to 36.72% in 2010 (Table 6). It was continuously encroached, with an average annual loss of 0.13% per year.

Table 7 : Change in Extents and Rate of LULCC

LULC Category	Change 1986-2010		Annual rate of Change 1986-2010	
	Area (Km <sup>2</sup> )	Area (%)	Area (Km <sup>2</sup> )	Area (%)
Built-up	80	15.09	3.3	0.63
Forest	-9.74	-1.83	-0.40	-0.08
Agriculture	-16.09	-3.04	-0.67	-0.13
Grass Land	-43.32	-8.17	-1.81	-0.34
Wet Land	-1.19	-0.23	-0.05	-0.01
Bare Land	-9.65	-1.82	-0.41	-0.08

Bare land and forest land showed significant changes; the first one decreased in 9.65 km<sup>2</sup> with 0.4 km<sup>2</sup>/yr (0.08%) rate of change, the later one also lessened with 9.74km<sup>2</sup> by 0.4km<sup>2</sup>/yr. Grass lands showed major changes in that has declined with 43.32 km<sup>2</sup> (0.34% per year negative rate of change). Wet land in showed very small contraction (1.19km<sup>2</sup>) and the rate of reduction over the period has been estimated as 0.05km<sup>2</sup>/yr (0.01%per year) which is relatively the lowest rate of change Table 7 and Figure 10).

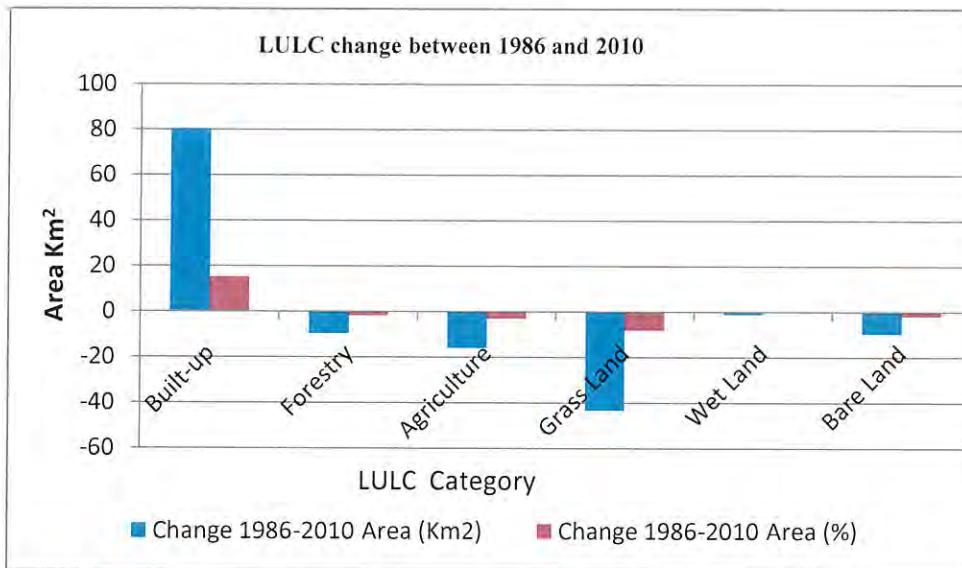


Figure 9: Land Use and Land Cover Change over the study period

Generally the trend and rate of land use and land cover between the 1986 to 2010 shows that a reduction in agriculture, grass land, forest, bare lands and wet lands, whereas urban/ built-up highly increased from 1986 to 2010. Thus, at the expense of other land use and land cover such as agricultural land, forest, bare land, grassland and wet land, the built up areas including continuous and discontinuous urban fabrics, industrial, commercial and residential units with other associated urban facilities dynamically increased in the period under discussion. This might be due to high acceleration of population increment with high demand for land and urban provisions, land allocation policy of the government and unplanned (slum) urban sprawl at the periphery of the conurbation. Figure 9 and 10 show the area extent of change and rate of land use land cover change.

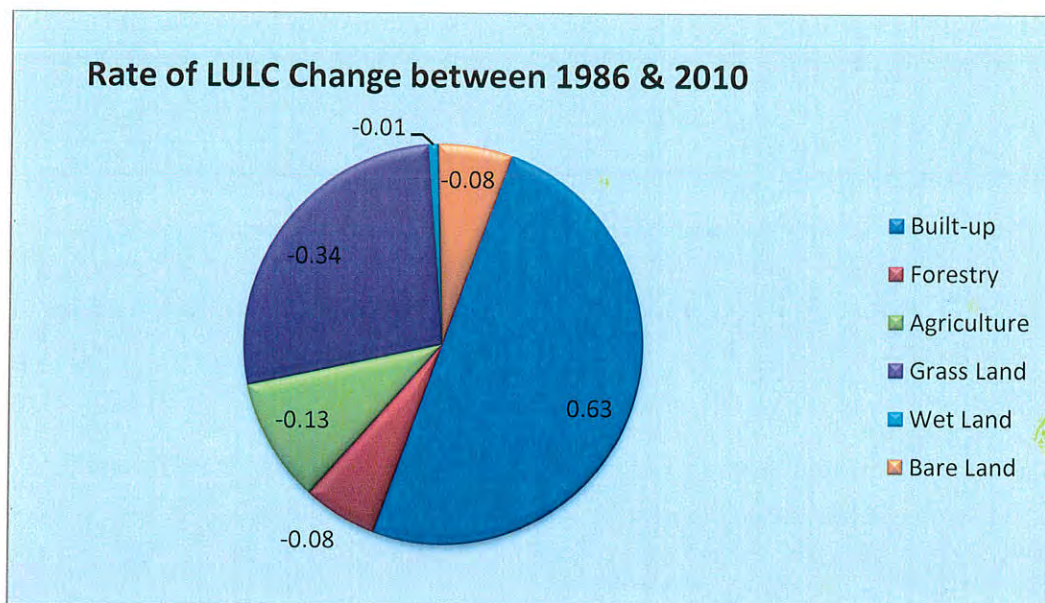


Figure 10: Rate of Land Use and Land cover Change

Note: Rate of change in percent is calculated as change in between the two study years per total change of these years divided by the time interval times 100.

### 5.2.2. Land Use and Land Cover Dynamics

The matrix of change detection result shows results from one class change to another. This method is useful to understand how classified land covers have changed over time. Table 8 shows the land use land cover dynamics between 1986 and 2010. In the table the diagonal cells indicate the stable land classes' which were not changed to other classes between 1986 and 2010. But the off diagonal areas of each class indicate the changes of one class to the other by losing or gaining from the initial state. The column total of the table indicates the total area of that particular land use and land cover class of the initial state (1986); whereas the row total indicates the area of that particular land use land cover class of the final state (2010).

Table 8: Land Use Land Cover Change Transition Matrix

LULC Change Detection Statistics		Initial State Image (1986)						
		Urban	Forestry	Agriculture	Grass Land	Wet Land	Bare Land	Class Total
Final State Image (2010)	Urban	<b>81.77</b>	7.70	47.74	35.15	1.13	6.64	<b>180.13</b>
	Forestry	5.33	<b>28.23</b>	8.49	6.75	1.02	1.22	<b>51.04</b>
	Agriculture	8.92	14.54	<b>127.02</b>	37.11	0.98	6.16	<b>194.74</b>
	Grass L.	2.86	7.18	23.11	<b>35.43</b>	1.18	9.07	<b>78.83</b>
	Wet Land	0.38	1.18	0.88	1.08	<b>1.48</b>	1.07	<b>6.07</b>
	Bare	0.87	1.95	3.59	6.63	1.47	<b>4.94</b>	<b>19.45</b>
	Class Total	<b>100.13</b>	<b>60.78</b>	<b>210.83</b>	<b>122.15</b>	<b>7.26</b>	<b>29.10</b>	<b>530.26</b>
	Class Change	18.36	32.55	83.81	86.72	5.78	24.16	

Based on the land use land cover transition statistics between 1986 and 2010, 47.74 km<sup>2</sup> of agricultural land, 7.7 km<sup>2</sup> of forest, 35.15 km<sup>2</sup> of grass land, 6.64 km<sup>2</sup> bare lands and 1.13 km<sup>2</sup> of wetlands were converted to built-up area. From 1986 to 2010, about 8.49 km<sup>2</sup> of agricultural land was converted to forest, 23.11km<sup>2</sup> to grass land, 47.74 km<sup>2</sup> to urban development 3.59km<sup>2</sup> to bare land and 0.88 km<sup>2</sup> to wet land. Almost the majority part of the urban expansion resulted from the conversion of agricultural land. On the other hand agriculture gain from, urban 8.92km<sup>2</sup>, forest 14.54 km<sup>2</sup>, grass land 37.11 km<sup>2</sup>, wet land 0.98 km<sup>2</sup>, and bare lands 6.16 km<sup>2</sup> and 127.02 km<sup>2</sup> of the area of agriculture remains stable. The conversion of built-up area to other land cover classes is unlikely to happen. These changes may seem to be classification errors due to the heterogeneous nature of urban area and the existence of mixed pixels on different objects which become spectrally similar one another (e.g. built areas and bare land), mapping inconsistencies and smoothing and generalization applied. The conversion of built-up to other LULC also may be due to the redevelopment and densification program in the inner city built-up areas were demolished and these areas may be observed as bare land and grass land.

Grass land losses 86.72 km<sup>2</sup> from 1986 and changed to 6.63 km<sup>2</sup> bare land, 37.11 km<sup>2</sup> agriculture, 6.75 km<sup>2</sup> forests, 35.15 km<sup>2</sup> built-up and 1.08 km<sup>2</sup> wet lands. In contrast it gains 43.4 km<sup>2</sup> in 2010 from 1986 land use land cover classes: 2.86 km<sup>2</sup> urban, 7.18 km<sup>2</sup> forests, 23.11 km<sup>2</sup> agriculture and 9.07 km<sup>2</sup> bare lands and the rest 1.18 km<sup>2</sup> from wet lands. Within the study time frame, wet lands are converted to other land use land cover. For instance wet lands with 1.13 km<sup>2</sup> were converted to urban land, 1.02 km<sup>2</sup> to forest, 0.98 km<sup>2</sup> to agriculture and the rest to grass land and bare lands. Most of the grass land change occurred in the peripheries of urban in all direction.

Between 1986 and 2010, about 7.7 km<sup>2</sup>, 14.54 km<sup>2</sup>, 7.18 km<sup>2</sup>, 1.18 km<sup>2</sup> and 1.95 km<sup>2</sup> of the forested area was converted into urban, agriculture, grass land, wet land and bare land, respectively. In contrast, other land use land covers were converted to forest in the period under study. So that forest gain 5.33 km<sup>2</sup> from urban, 8.49 km<sup>2</sup> from agriculture, 6.75 km<sup>2</sup> from grass land 1.02 km<sup>2</sup> from wet land and 1.22 km<sup>2</sup> from bare land. All of these encroachment occurred at the edges of forested land and in areas around Lebu, west and east out skirts, and at city center. Likewise, bare land in city decreased from 1986 to 2010, from an initial 29 km<sup>2</sup> to the final stage 19.45 km<sup>2</sup>. Bare lands was converted to 6.63 km<sup>2</sup> urban, 1.22 km<sup>2</sup> forest, 6.16 km<sup>2</sup> agriculture, 9.07 km<sup>2</sup> grass land and 1.07 km<sup>2</sup> wet land. Most of the changes in bare land were detected at the edges of forested and agricultural lands on the slopes of the mountains and in areas placed in the southwest and southeast of the study area. The majority of the conversions between agricultural land, grass land and bare land or forest were in the mountains, and periphery especially along boundaries between these three LULC types.

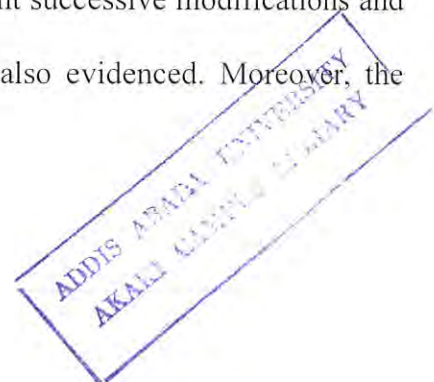
Among these changes, the most prominent was the conversion between agriculture and grassland, and the next dominant change was between agriculture and forest. Conversion of other land use land covers to urban land use took huge share within the years of study. This increment of the built-up area is predominantly at the expense of grass land, agricultural area, and forest cover in the surroundings. The major and significant scales of land conversion to urban functions have mainly been observed along the highway connecting Debrezeit (Gelan and Dukem areas) to the south, Jimma (Sebeta and Alemgena area) to the west, Dessie (Sendafa area) to the east, and Ambo (Asko area) to the north west, where a great many manufacturing plants and associated housing units were concentrated.

Dandena (1995) pointed out that the demographic, social and policy issues are major cause for land cover change of the area. In addition, due to the improvements in infrastructures, high value of land at the center of the city, housing policy and program, development of new industrial and recreational zones and population explosion, the rate of urban growth has expanded into the rural-urban fringe.

### **5.3. Causal Factors of Land Use and Land Cover Changes**

#### **5.3.1. Proximate Causes**

The discussions earlier in this document indicate that Addis Ababa city is experiencing fast LULC changes especially in this decade. Enormous extent of grass land and agricultural land has been converted to built-up. Significant successive modifications and conversions among the land uses and land cover were also evidenced. Moreover, the



encroachment and establishment of built-up in forest areas, bare lands and wet lands is also major LULC change in the city. However, urban expansion and densification has been the most important proximate cause of land use land cover change in the study area between 1986 and 2010.

#### **5.3.1.1. Urban expansion of Addis Ababa**

Addis Ababa city has experienced a series of drastic changes in its administrative boundaries. The current city jurisdiction came into effect in 1980s at the Derge regime, as a result of the increasing demand for residential use forced the Derge administration to adopt self-help housing cooperative system. Accordingly, the city outskirts occupied by farmers were allotted to new settlement for houseless urban dwellers. It was in this system that more than 25 Peasant Associations (PAs) of rural farming community administered under adjacent Woredas were included under the Addis Ababa Administration. In addition, the Master Plan of Addis Ababa prepared in 1986 has influenced the current city boundary and urban expansion.

It was discovered that Addis Ababa started growing faster as an urban centre, since the late 1960s, Addis Ababa being the seat for the administration of the country, head office of Organization of African Unity (OAU), branch offices of the United Nations, and head office of the United Nation Economic Commission for Africa (UNECA), and diplomatic machines and residence. The city expanded from 101.13 km<sup>2</sup> in 1986 to 180.13 km<sup>2</sup> in 2010 (Table 8). Most of the new developments during this study period, took place in the suburbs as organized clusters for accommodating especially residential expansions,

industrial, commercial, condominium, emerging settlements, warehouses, or external transportation facilities, in addition to rapid developments on the outskirts of the old city core. Growth of small urban centers along the outlet roads like Kotebe, Akaki, Kaliti, Repi led to massive construction of new residential buildings in these areas. By this time, new developments were mostly directed to the suburbs in order to contain the growth of the inner city.

In late 1980 and early 1990, the inner city became densely populated with no improvement in house provision to meet the increasing demand, latter squatter settlement and illegal land transaction intensified in the peripheries. Along with, housing construction with low bank interest set by the system that was induced many dwellers to construct houses, due to such reason the expansion of the city took places on all peripheries of the city, the major areas of expansion were to the east to Kotebe area along Dessie Road (for residence both informal and formal and some industries); to the south Kalitti and Makkanisa area (dominantly planed for both residence and industry), to the West along the road to Jimma Road and Keraniyo (mainly housing both formal and informal), and along the road to Ambo (mainly formal housing).. In this time, Derge regime became feeble and the change of government took place for this reason squatter settlement increased more and contributed to the physical expansion of the city.

Dramatic urban development was also observed in the early 2000s. The reconstruction, expansion and upgrading of Bole airport to international status; buildings of different factory in industrial area; establishment of private College of Education, Office buildings,

hotels, and recreational facilities played greater role in shaping and added attribute to a modern Addis Ababa city. Ring road was constructed to provide the foundation for future expansion.

In the late 2000, Addis Ababa witnessed yet another significant expansion in terms of both land area and population. This is evident in areas like Ayat, Lebu, Summit, Asko, Jemo, and other areas where various stages of land development like condominiums, single and multistory residential and other types of constructions have been taking place. Furthermore, a number of renewals, upgrading or slum improvement strategies undertaken such as redevelopment Lideta area, Arat Killo area, Merkato area, and etc. Moreover, the land use and land cover maps derived from the Landsat images show that the urban and built-up area increased by 80 km<sup>2</sup>, or by 15.09% in the 24-year period (1986-2010) (Table 6 and Figure 7&8). Generally, the city has shown rapid Vertical and horizontal expansion both planned and unplanned. The overall expansion of city shows long fringes along four outlets of the city excluding Gojam road mainly due to its topography (Fig11). These areas can be characterized as “Zone of Discard”, which hinders further urban development as oppose to “Zone of Assimilation”. This indicates that other land cover types were massively converted to urban land use at an annual rate of 3.3km<sup>2</sup>.

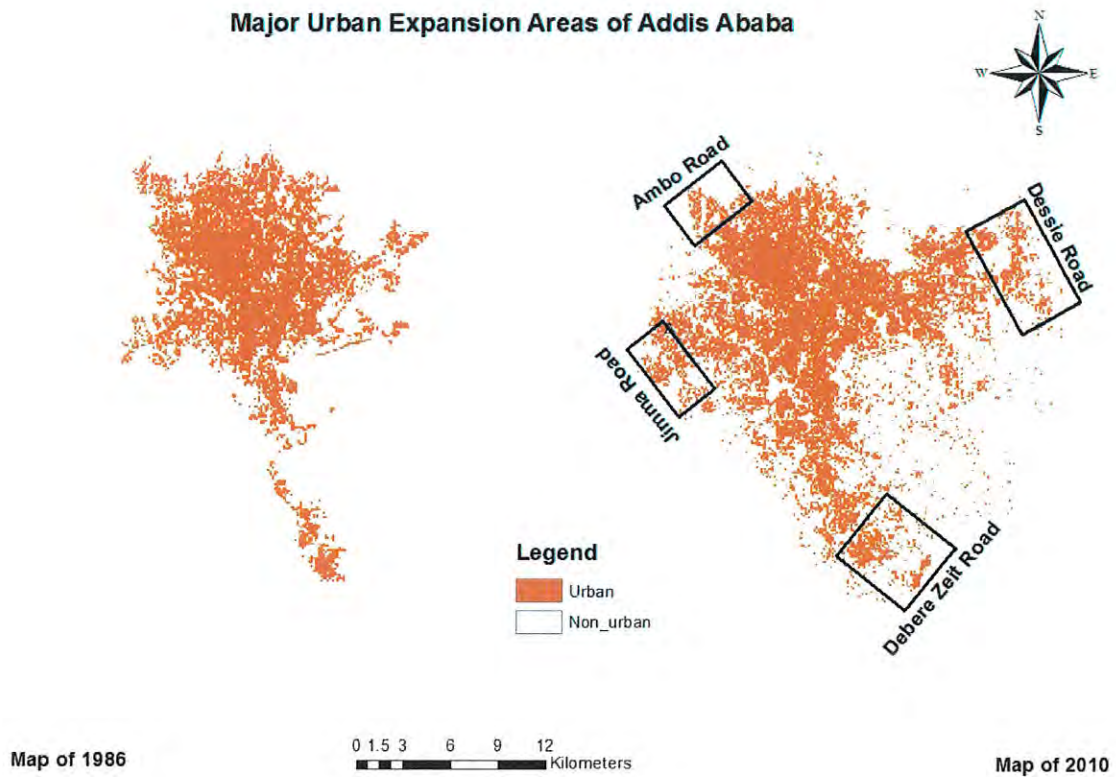


Figure 11: Major Expansion Areas

### 5.3.1.2. Urban Densification in Addis Ababa

Analysis of the population density reveals that the density of population in Addis Ababa increased substantially between 1986 and 2010 (Table 9). The density of population was 3062 in 1986 which increased to 5499 persons per sq. km. in 2010. It is evident from the map and table that there was a densification gradient diminished from the Central Business District (CBD) outward into the countryside over the study periods. From the analysis some high density zones, can be easily identified, for instance, a notable increase in population and physical density occurred in the central part of the CBD. Regarding, physical density sub cities in the center Addis Ketema, Arada, Kirkos and Lideta about

75-89% of their land occupied by built-up (Table 9). From this it can be concluded that city center not only experiencing population density but also physical density. The main reason behind the physical density may be due to 1986 master plan of the city because the interventions proposed in the master plan were redevelopment, infill and densification of the centre to do so the city becomes denser.

Table9: Population Distribution and Population Density at Sub city Level

Sub City	Total Area Km <sup>2</sup>	1986				2010				
		Built-up area km <sup>2</sup>	Pop.	PD of A	PD of B	Built-up area km <sup>2</sup>	Pop.	PD of A	PD of B	% Built-up
Addis Ketema	9.44	6.99	221226	23435	31649	7.40	271937	28807	36748	78.4
Arada	11.54	8.38	137721	11934	16434	9.21	225221	19517	24454	79.8
Lideta	11.92	8.64	173579	14562	20090	9.25	214798	18020	23221	77.6
Kirkos	15.59	13.08	156481	10037	11963	13.99	235585	15111	16840	89.7
Gullele	32.18	11.06	171534	5330	15509	11.42	284984	8856	24955	35.5
Kolfe Keranio	64.85	11.33	176771	2726	15602	24.12	456716	7043	18935	37.2
Nifas Silk Lafto	60.12	11.6	207753	3456	17910	26.06	336799	5602	12924	43.3
Yeka	83.18	11.67	169788	2041	14549	21.25	369151	4438	17372	25.5
Bole	119.5	9.9	126845	1061	12813	32.73	329039	2753	10053	27.4
Akaki Kality	121.98	7.48	81848	671	10942	24.68	193029	1582	7821	20.2
Total	530.26	100.13	1623545	3062	16214	180.13	291587	5499	16188	34.0

Source: compiled and computed based on population data of CSA 2007

Note: Pd of A=Population/Total area and Pd of B= Population/ Built-up Area  
 % of built-up= Area occupied by built-up/Total Area \*100

The density decrease was equally evident in all direction towards north, west, south, and east side of the city center. Kebeles of peripheral sub cities are sparsely occupied less than 7500 persons per km<sup>2</sup> and kebeles of the city center are highly populated specially kebele 14/21, 13/15, 01/02/03 and 04/05 of Addis Ketema and 09/10 and 04,06 of Lideta sub city (Figure 12). Akaki Kality, Yeka and Bole, Yeka sub cities are the less density occupied below 2050 persons per km<sup>2</sup> in 1986, and Akaki Kality and Bole in 2010 with

value lower than 2750 persons per km<sup>2</sup>. Gulele, Kolfefe Keranio and Nifas Silk Lafito are medium populated sub cities with value ranging from 2050- 5550 person per km<sup>2</sup> in 1986. In 2010, Yeka subcity as well added to the medium populated sub cities with value ranged 2750 to 8850 person per km<sup>2</sup>. As usual in all cities, central areas have higher densities and are sometimes very densely occupied districts. In 1986 and 2010, Arada, Kirkos and Lideta are high populated sub cities ranged 5550 to 15000 and 8850 to 19000 persons per km<sup>2</sup>, respectively. Addis Ketema is the most densely populated sub city 23435 and 28807 persons per km<sup>2</sup> in 1986 and 2010, respectively. The analysis reveals that sub cities such as Nifas Lafito, Aakaki Kality, Bole, Kolfefe Keranio and Yeka their built-up coverage as well as population density increases from 1986 to 2010 (Table 9). This is evident that agricultural land and other land use converted to built-up in peripheral sub cities. In addition, open areas and bare lands in center city (1986) were converted to built-up in 2010. In general, the high population density activates the demand for urban service and intensifies demand of land for residence and economy. To accommodate this, the city has practiced physical density by converting single story houses to high skyscraper buildings and condominiums and by converting open fields and bare lands to build-up in the city center which all have impact surface temperature.

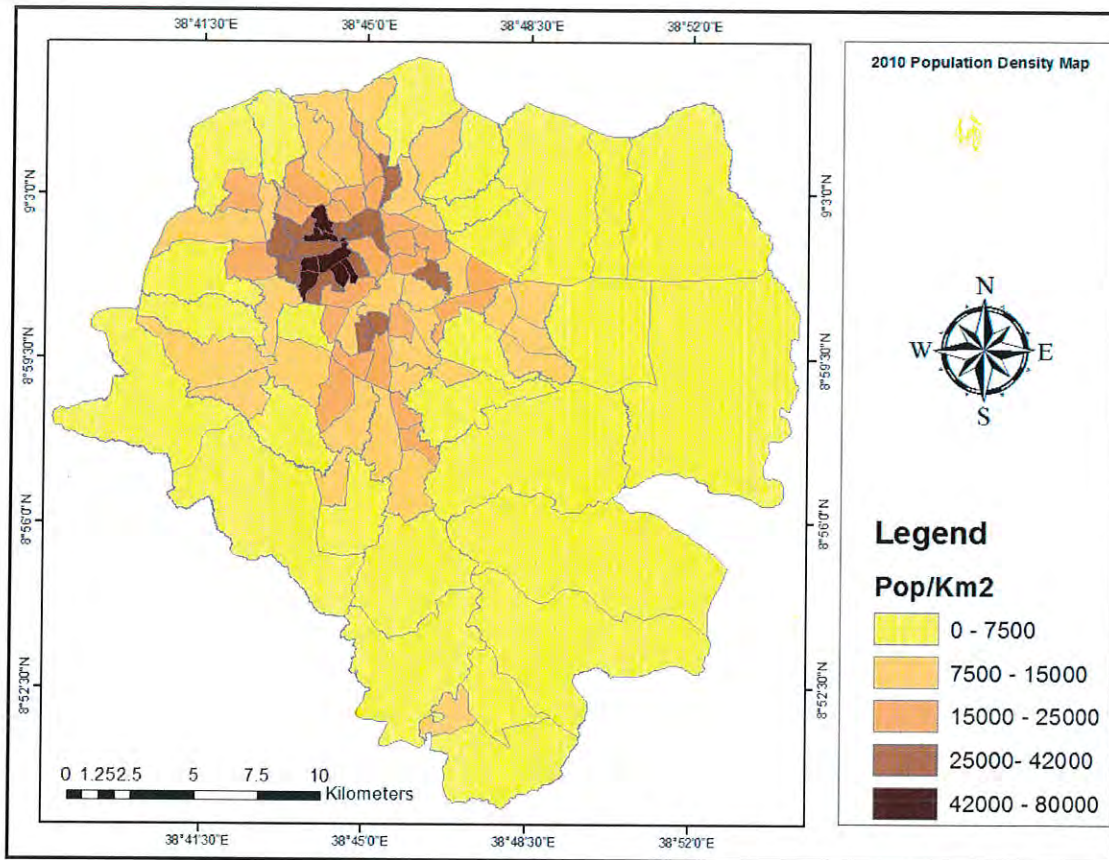


Figure 12: Population Density Map

### 5.3.2. Underlying Driving Forces

Land means a combination of nature-human factors. LULCC is constrained by both the natural driving force and the social, economic, technical and historical factors. It is both comprehensive and geographical (Turner et al., 1996; Lambin et al., 2001; Togtohyn and Denssi, 2002). In areas with complicated natural conditions, such as plateau and mountainous areas, various natural driving forces have a great impact on the change of land use. Whereas in areas with little natural constraints, such as developed areas, the land use changes are mainly controlled by the human driving force such as economic development, population growth and policies (Gobin et al., 2002; Yu and Yang, 2002).

What has been the driving forces underlying the urban expansion that caused the land use changes documented above?

A case in point is what an age 73 years elderly key informant said (Nefas Silk Lafeto Sub city):

"...I was born and grown up here. This area was covered by forests and coarse grasses during my early days. Giant trees and woody plants were plentiful in the area. I am a living witness for the fact that the forest coverage has been diminishing gradually all over my age. Woodlands are severely deforested and converted into cultivated and built-up areas. Most vegetation areas and cultivated are plummeted into almost built-up these days. Particularly, due to the urban expansion and redevelopment of the city other land uses and land covers have been converted to urban that exerted heavy pressure on the environment and climate..."

At this juncture, one may raise a question regarding the driving forces of LULC changes in Addis Ababa. As point out above, LULC changes are the result of a number of interacting variables and processes. Correspondingly, the series of key informant interviews and group discussions conducted with the community, with reference to the suggestions from experts, literature reviews and data available. The major driving forces of the rapid urban expansion and densification of the study area are categorized as population growth, informal settlements, economic development, and unplanned development and absence of clear policy of the city.

### 5.3.2.1. Population Growth

Population growth has long been considered as a major factor leading to land use and land cover change. Natural increase and substantial migration are main factors contributing to the fast growing population. The population of Addis Ababa has shown a dramatic increase over the years since its foundation in 1886. According to (Techeste, 1987), “it is reported that the city had a population of 65,000 inhabitants in 1910 which grew to 100,000 in 1935. After some years, it had increased to 1,167,315”. From the time of its establishment it has taken about seven decades to reach half a million, while it took it to reach a million city populations in less than two decades between 1961 and 1978 (Techeste, 1987). The population of Addis Ababa at initial stage of the study period was around 1,423,111 has grown to about 2,112,737 in 1994 with 4.85 % per year annual growth rate. The growth of the city continued to grown-up to 2,738,248 in 2007, with annual growth 2.28% per year, which was a lower than that of the previous periods. And also it continues to grow to around 3 million in 2010. Hence, population growth of Addis Ababa in about three decades was doubling its self (CSA, 2006).

Moreover, Addis Ababa with the highest concentration of basic service facilities per population than other centers in Ethiopia enjoys a ‘privileged position’ (Tegenge, 2000). In addition to natural increase, the privileged position of Addis Ababa has played an important role in attracting migrants from different areas. The high population concentration triggers the ever-growing demand for urban service: demand of land for residence, economic and industrial activities and other public services and it also intensify the problem of housing demand. Demand for housing increased at higher rate

than its supply encouraging both unplanned settlement and planned urban expansion in the periphery. To accommodate this, Addis Ababa city has experienced rapid physical expansion in all directions. This horizontal expansion might be both legal and squatter. Generally, the overall picture of Addis Ababa city's population growth pattern reveals accelerated urban growth and subsequently high conversion of land from other uses to urban. This rapid expansion of urban is at the expense of forest, agriculture land, grass land and other types of uses

#### **5.3.2.2. Informal Settlements and Unplanned Development**

According to key informants and focus group discussions, one of the main causes the rapid physical expansions of Addis Ababa city to the periphery is informal settlement. Squatting is one of the factors that accelerate urban expansion. For instance, in Egypt more than 10% of the nation's most productive land has been lost to city expansion; much of it through squatter settlements (Hardoy et al., 2001). The expansion of informal settlement in the study area is generally taking place on agricultural land and forest area occupied by peasant association and green areas. Squatter settlements are mainly located in the peripheral areas of the city, where they are numerous, and irregular in shape. In most cases they are characterized by large plot sizes and have greatly contributed to the unplanned and rapid horizontal expansion of the built-up area of the city.

According to the city administration, Out of the total 94,135 housing units built in the city between 1984 and 1994, 15.7% (14,794 housing units) were built by informal (ORAAMP, 2001). In 2000, Addis Ababa had an estimated total of 60,000 housing units

with squatter settlements. This figure accounted for 20% of the total housing stock of the city and the total area occupied by squatter settlements was estimated at 13.6% of the total built-up area. This was much contributed by the emergence and development of squatter settlements that caused rapid urban settlement expansion of the city to the periphery.

### **5.3.2.3. Economic Development and Investment**

Economic development obviously spurred land use land cover change. It should be noted that since Ethiopia adopted free market economy and open-door for large investment and commerce in the country, economic development has increased greatly. The city GDP has reached Birr 20,367.75 million and per capital income Birr 6,857.8 in the year 2009/10. Its economy is growing annually by 9.2%. According to the World Bank 2007 Report Standard set for medium income person is 13,500 birr (997USD). Table 10 shows Trend of GDP and Per capita Income of Addis Ababa (2000-2010).

Due to the remarkable increase of GDP and per capital income the potential income of municipality to provide services to the residents increase. This factor also triggered the preference of people for single family dwellings and urbanism way of life that increase demand of land. This is evident that highly standard single family dwellings in areas like Ayat, Diaspora sefer, Woyera sefer, Lebu, Summit, Asko, Jemo and other areas, constructed in the last decades in the expense of other land use land covers.

temperature spots scattered in all direction in the city. Numerous strip-shaped high temperature spots were also detectable in the south east, close to quarry site and in areas where there has been a rapid growth in settlements. There were also many tiny hot spot along the busy highways like Deberezeit road, Churchill, Ring road and others. The non-existence of extensive land surface temperature in the extreme west and northern parts of the city could be attributed to the cooling effect of forests.

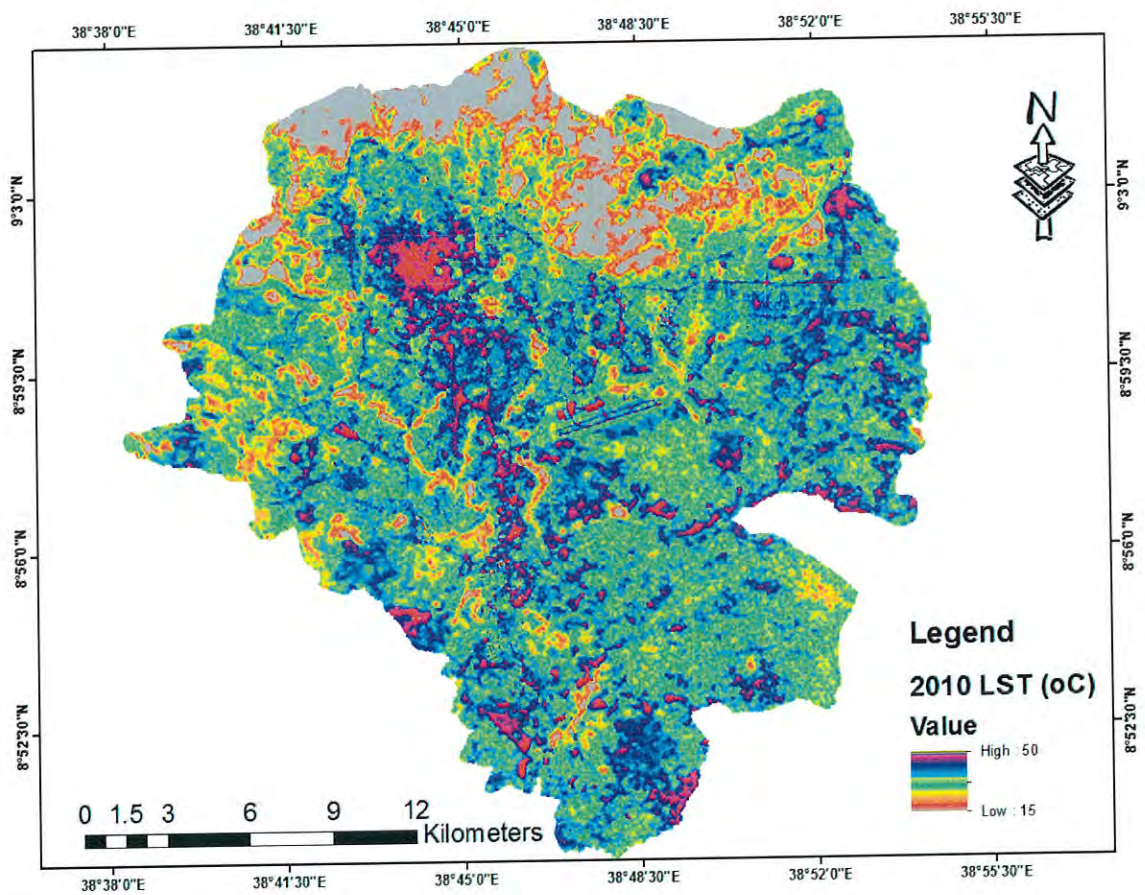


Figure 14: Land Surface Temperature of 2010

The distinctive land surface temperature patterns are associated with the thermal characteristics of land cover classes. To better understand the impact of urban development on land surface temperatures, the thermal signature of each land cover type

was obtained by overlaying a land surface temperature image with a land use and land cover map of the same year. The average value of land surface temperature by land cover types is summarized in Table 11. Of all the LULC categories, urban and built-up had the highest LST for both years. This implied that urban development, due to the replacing of natural vegetation with non-evaporating, non-transpiring surfaces, such as stone, metal, and concrete, did have an effect on raising LST. The lowest LST in 1986 was observed in forest, followed by wet land, grass land, agriculture, and bare land. The pattern in 2010 has slight difference, the lowest LST was found in forest, followed by wet land, agriculture, grass land, and bare land probably due to spectral reflectance similarity and soil moisture content between grass land and agriculture in the two study years. These results in line with the results of research entitle Evaluation of The Impact of Urban Expansion on Surface Temperature Variations Using Remote Sensing-GIS approach conducted in Jimeta by Zemba et al., (2002).

Table11: Derived LST for each LULC type

Land Use & land cover	LST 1986 (0C)	LST 2010 (0C)	$dT$ (°C)
Urban/ built-up	30.4±2.88	31.42±3.01	1.02
Forest	23.51±3.3	22±2.99	-1.51
Agriculture	29.93±2.69	29.98±2.92	0.05
Grass Land	29.79±2.28	30.81±2.46	1.02
Wet Land	28.53±1.45	29.48±1.68	0.95
Bare Land	30.3±2.27	31.25±2.64	0.95

$dT$  is the Mean temperature difference between 1986 and 2010

The average LSTs for urban and built-up land 30.4°C in 1986, this number changed to 31.42°C in 2010, meaning an increase by 1.02°C. For forest land LSTs had a decreasing change trend, changes from 23.51°C in 1986 to 22°C 2010 by 1.51°C. In the study area,

Table 13: Monthly Minimum, Maximum, Mean Temperature at Both Stations

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly Temperature at AA Observatory in °C												
Mean Min.	8.97	10.25	11.45	12.16	12.34	11.45	11.36	11.46	11.27	10.26	8.59	8.44
Mean Max.	24.02	25.07	25.30	24.70	25.20	23.35	21.15	21.21	21.94	23.01	23.30	23.42
Mean of Mean	16.50	17.66	18.38	18.43	18.77	17.40	16.25	16.33	16.60	16.63	15.95	15.93
Monthly Temperature at Bole in °C												
Mean Min.	7.72	9.10	10.53	11.38	11.24	10.81	11.16	11.20	10.35	8.34	6.25	6.53
Mean Max.	23.82	24.93	25.45	25.02	25.36	23.53	21.39	21.11	21.88	23.12	23.16	23.39
Mean of Mean	15.77	17.02	17.99	18.20	18.30	17.17	16.27	16.16	16.12	15.73	14.70	14.96
Monthly Temperature at Addis Ababa City in °C												
Mean Min.	8.35	9.68	10.99	11.77	11.79	11.13	11.26	11.33	10.81	9.30	7.42	7.49
Mean Max.	23.92	25.00	25.38	24.86	25.28	23.44	21.27	21.16	21.91	23.06	23.23	23.41
Mean of Mean	16.13	17.34	18.18	18.32	18.54	17.29	16.26	16.25	16.36	16.18	15.32	15.45

Source: National Meteorological Agency, (2011)

The analysis of average monthly temperature distribution of the weather stations of Addis Ababa city (1986 and 2010) reveals that the temperatures are more or less uniform throughout the year with a very little distinction between the hottest and coldest months at both the stations (Table 13). The average monthly temperature of the hottest month (May) and the coldest month (November) at Bole are 18.3 °C and 14.7 °C, respectively with an annual range of a mere 3.6 °C. Similarly, the monthly average temperature during the hottest month (May) at Addis Ababa Observatory is 18.77°C and the average for the coldest month (December) is 15.95 °C with the annual range of only 2.82 °C. It also revealed that the annual average temperatures are higher near Addis Ababa obs. station (17.4 °C) than at Bole station (16.5 °C), which means that the city centre records 0.9 °C higher temperature than the surrounding areas.



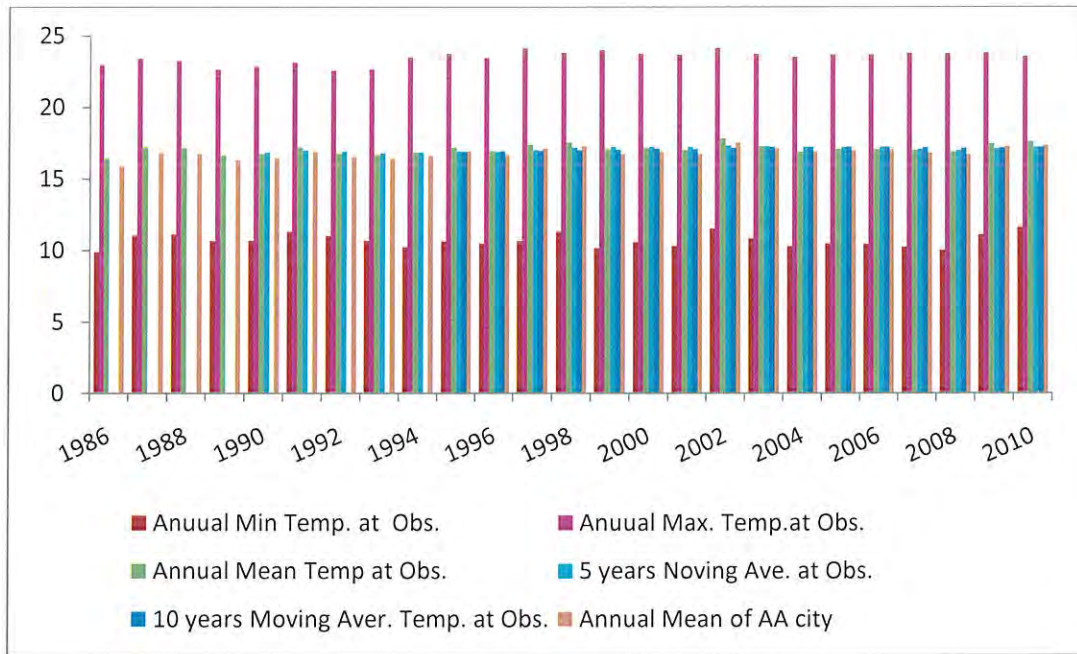
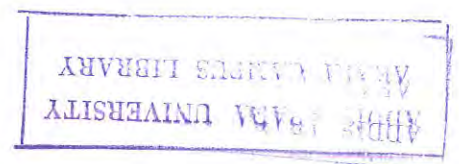


Figure 16: Annual Temperatures at AA Observatory Station

Source: National Meteorological Service Agency, 2011

The seasonal distribution of temperatures indicates that the city centre records maximum temperature during Belg with 18.31 °C followed by Kiremt (16.65 °C) and Bega (16.25 °C). Similarly, of all the three seasons Belg season records maximum temperature in the Bole area with 17.88 °C followed by Kiremt (16.43 °C) and Bega (15.29 °C). The analysis indicated that within the city, the city centre (Addis Ababa Observatory) records more temperatures in all the three seasons than at the Bole station in the peripheral area (Table 13).

Even if, there were fluctuations in some years intermittently, the annual average temperature of the Addis Ababa city as a whole has an increasing trend during the study period and reached its peak in the year 2002 (Fig 17 and 18). The same figures reveal that the trend in average annual temperature as well as 5 and 10 years moving average graphs



at Bole and Addis Ababa indicated a clear increasing trend in temperature between 1986 and 2010, but the difference is Addis Ababa observatory records higher temperatures than Bole.

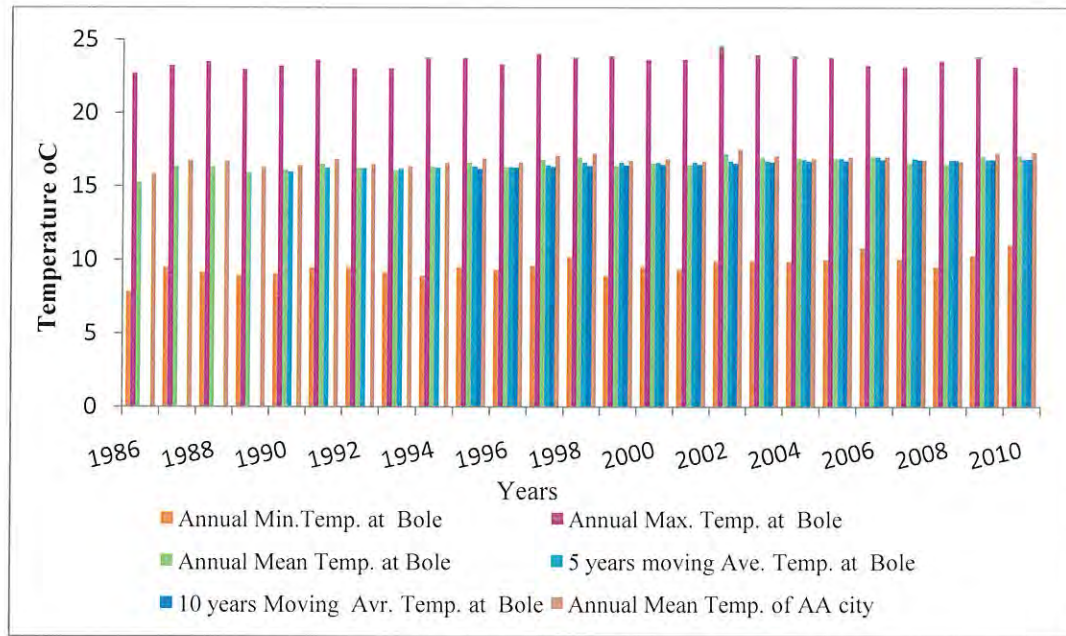


Figure 17: Annual Temperatures at Bole Station

Source: National Meteorological Service Agency, 2011

From Figure 17 and 18 therefore, the annual average temperatures indicate an increase in the entire Addis Ababa city by 1.5 °C in the study period. The increase in the average temperature was 1.2°C and 1.8 °C in the city periphery (Bole) as well as in the city center Addis Ababa Observatory, respectively. On the other hand, maximum temperature increase in daytime is more at the city centre (0.8°C) than in the peripheral areas (0.4°C). In contrast, minimum temperatures increase is more at the city periphery (3.2°C) than the city centre (1.7°C). Since the air temperature is the result of the process of atmosphere heat from the sun radiation and from the earth surface, the high LST resulted from change

in land use and land cover may contribute in high increase of the air temperature in the city center than the surrounding. For example, average air temperature difference of the two stations was 1.2°C in 1986, but this difference jumped to 1.4°C in 2010, which indicates the warming effect of land use and land cover change. The LST differences between the two stations urban center (AA. Obs.) and periphery (Bole station) (Figure 18) shows a maximum of 8°C difference in temperature in 1986. The same figure shows the land surface temperature in the urban center (AA Obs.) was of 15 °C warmer than that in surrounding rural areas (Bole station) in 2010. Both the results of land surface temperature and air temperature shows that UHIs existed significantly in the city of Addis Ababa. This meteorological data analysis reflects the same result as of the LST results.

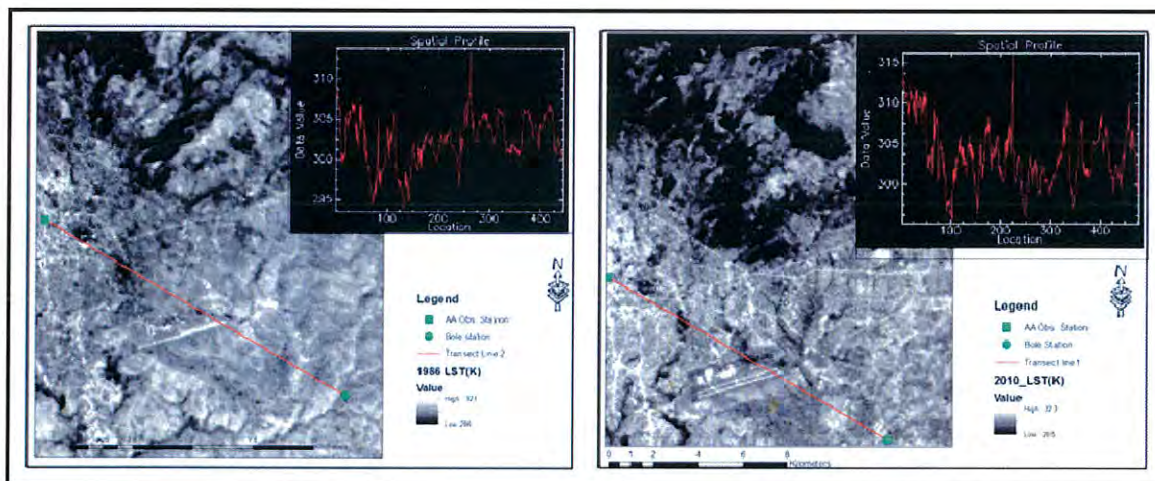


Figure 18: Difference in LST between around AA Obs. and Bole Stations of 1986 and 2010

Land use and land cover change due to urbanization can also alter regional precipitation. The climate of Addis Ababa as well as getting warmer, it is also getting wetter. The rising motions over urban centers draw cool, moist low-level air into the city from surrounding

rural areas. This combined with increased amounts of aerosols in the polluted urban air that act as cloud condensation nuclei, can lead to increased rainfall and increased frequency of severe weather. For example, the daily precipitation records of two stations at 2010 reveals that storms resulting in over 20 mm of rain were more frequent over urban center areas than suburban. Figure 19 and 20 shows an approximate 20% and 9.6% increase in annual precipitation over the past 24 years at the city center and periphery, respectively. And also, the annual precipitation shows an increasing trend in both stations, but city center records greater amount of rainfall in every year than periphery. The same figures also shows how the precipitation record has been distributed over the three seasons: Bega (October- January), Belg (February-May) and Kiremt (June-September). It is interesting to note that at Bega, and Kermt seasons of the two stations from 1986 to 2010, are showing a trend of increased precipitation; however, the trend is most pronounced in Kiremt records in both stations. But the Belg season reveal decreasing trend in the years of study.

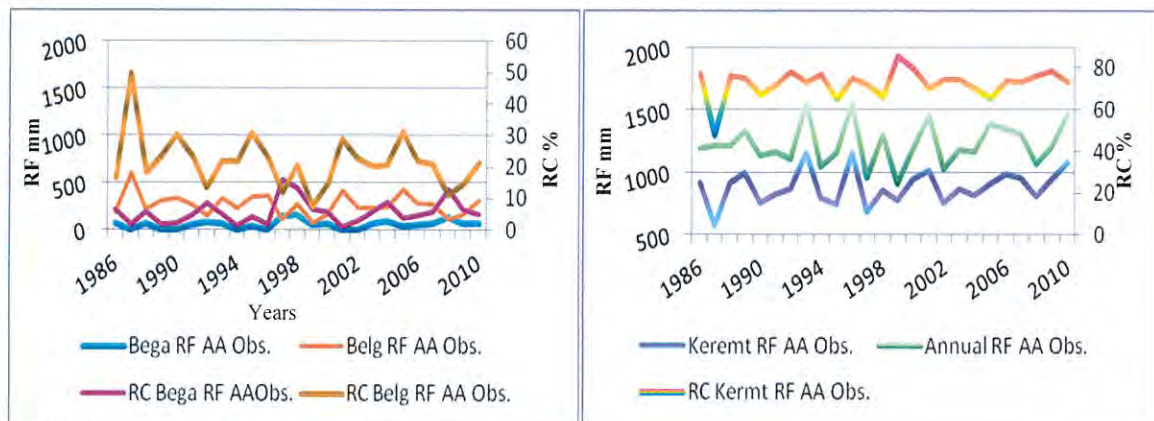


Figure 19: Annual, Seasonal Precipitation and Relative Contribution of each season at AA Observatory Station

Source: National Meteorological Service Agency, 2011

The relative contribution of precipitation to the annual total from each season is reflected in Figure 19 and 20. These show how the relative contribution of the seasons to annual precipitation is changing. Even though, there is some fluctuation in the proportion of the relative contribution to the annual total. The overall trend RC has an increasing trend in Bega and Kiremt at the expense of the Belg at both stations. But, the relative contribution of Kirmet at city center is greater than the suburbs and RC of Bega at Bole is greater than city center. For instance, city center and Bole average relative contribution of Kiremt are 73% and 70% respectively, on the other hand, Bole and city center average RC of Bega 24% and 20% respectively. The decreasing trend of Belg rain fall and shift of rainy season is a clear indicator of urban climate change. In addition, the increasing trend of precipitation of city center greater than periphery is may be due to LULCC.

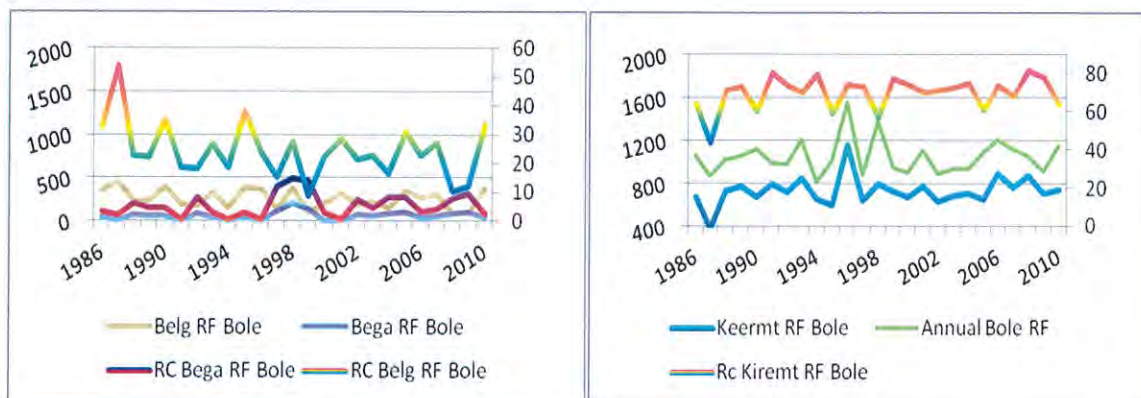


Figure 20: Annual, Seasonal Precipitation and Relative contribution of each season at Bole Station

Source: National Meteorological Service Agency, 2011

Atmospheric humidity also had a strong relationship with land use land cover change. RH at both stations measured three times a day and it shows a decreasing trend when we see the long term data of RH (1986-2005). Even though, the trend of Relative humidity at both stations shows a decreasing trend, the rural site was more humid than the urban

station in the central business district (62% versus 52%). On average, the humidity in the city is about 10% less than in the surrounding areas on a yearly basis. This difference was strongest from 12:00pm to 6:00 with a difference of 10-15% (Figure 21).

A special characteristic of the city is the change in wind patterns with regards to both the direction and the velocity of wind. The larger surface area and irregularity of a built area causes increased friction that reduces wind velocity – up to 30% less on average per year. Particularly, the frequency of zero-wind conditions is increased by up to 20%, which leads to a reduction in air circulation and thus hinders the dispersal of pollutants

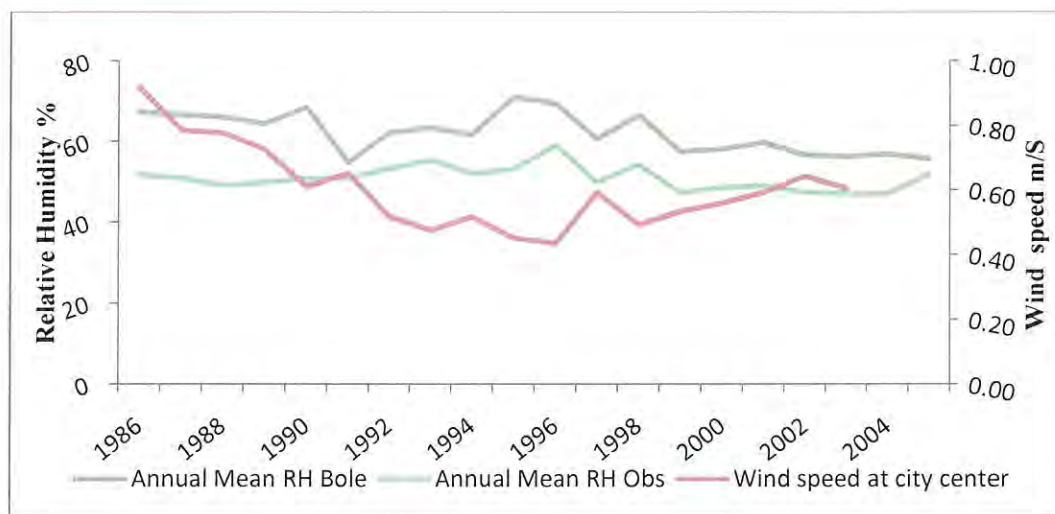


Figure 21: Annual Mean Relative Humidity and Wind Speed at Both Stations

Source: National Meteorological Service Agency, 2011)

Figure 19 depicts the wind profiles of the inner city. The differences in the wind profiles of the inner city and the city’s priphery could not be depicted because, the data of Bole

station is not available at NMSA. However, the inner city wind profile shows decreasing trend in the years.

Based on the data analysis the evaporation of the two stations shows a decreasing trend with some year's fluctuation. Since pan evaporation is greater than evaporation from outside, pan coefficient of 0.8 is used to correct the various effects during evaporation from the pan. As a result the mean annual evaporation of city center and the periphery is 1152.3mm and 1415.61mm, respectively (Figure 22). In this regard, evaporation at the city center is less by 233.3mm than the evaporation at periphery, because the city center has less water and greater runoff due to the pavement are largely nonporous and impermeable (except by the pot holes).

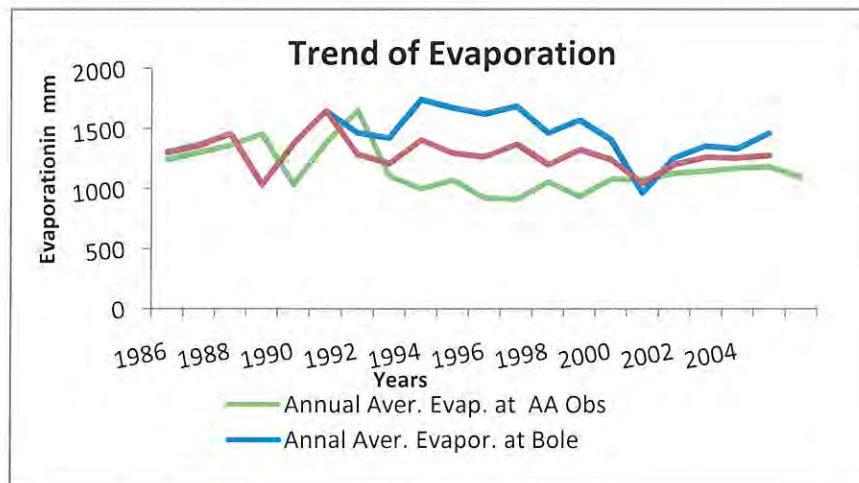


Figure 22 : Annual Average Evaporation Trends

Source: National Meteorological Service Agency, 2011)

## 5.6. Relationship between LULC and Biophysical Parameters

To understand the relationship between land use and land cover and thus vegetation abundance indicators (NDVI), emissivity and impervious surface area the thermal signature of each LULC type must be investigated. The statistics of NDVI, emissivity and impervious surface area by LULC type were obtained by superimposing LULC image with the three images (Figure 23, 24, and 25). The result of the GIS overlays is shown in Table 14.

Table 14: Descriptive Statistics of Biophysical Parameters of each LULC

Land Use land cover	NDVI 1986	NDVI 2010	Emissivity 1986	Emissivity 2010	Impervious Surface % 1986	Impervious Surface % 2010
Urban/ built-up	0.134±0.095	0.082±0.083	0.981±0.009	0.977±0.011	6.41±4.56	10.48±5.19
Forest	0.294±0.122	0.359±0.098	0.988±0.003	0.988±0.007	1.04±1.49	1.28 ±1.86
Agriculture	0.151±0.083	0.142±0.11	0.984±0.005	0.980±0.008	5.44±3.46	5.79±3.82
Grass Land	0.170±0.084	0.121±0.076	0.985±0.005	0.981±0.009	3.75±4.1	5.32±4.54
Wet Land	0.249±0.101	0.330±0.124	0.9851±0.044	0.985±0.006	2.10±2.09	2.81±4.21
Bare Land	0.171±0.086	0.118±0.72	0.9841±0.005	0.981±0.008	3.36±4.94	4.87±5.91

The NDVI values estimated are in the range of -0.241 to 0.676 having a mean value of 0.220 with standard deviation of 0.102 in 1986. Similarly, the NDVI values in 2010 ranged from -0.228 to 0.698 (mean of 0.14 and standard deviation of 0.121). The average NDVI value decreased from 0.170 in 1986 to 0.139 in 2010 in the city. Forest had the highest average NDVI value 0.294 and 0.359 in 1986 and 2010, respectively. The NDVI value of forest increased significantly by 0.065 from 1986 to 2010. These higher NDVI

values are observed around mount Entoto (forest), north-west and North-east part of the two images (Figure 23). The increase in average NDVI value in forest land may be the reflection of ecosystem restoration measure taken by government. The re-greening campaign (afforestation and reforestation) for the mountainous and hilly slopes of Entoto was observed in the study. So this greening campaign led to a slight increase in NDVI in the forest land. Wet lands exhibited the second highest average value of NDVI over the years of study. The lowest NDVI value shows in built-up areas with mean value of 0.134 (ranging from -0.2 to 0.664 with standard deviation of 0.0698) in 1986 and with significance declination to mean NDVI value is 0.082 (ranging from -0.228 to 0.574 with standard deviation of 0.083) in 2010. This observed lower NDVI value corresponds to built-up areas placed on the city center and in areas have high impervious surface all around the city. According to interviews with officials and group discussion with stakeholders, even though, there were some attempts by the city government to urban green and there is accredited direction to use the land 80% for construction and 20% greening, the greening was impractical by individuals owners due to their greediness of land of using for building . So the NDVI of the city that is the abundance of vegetation on built-up areas declined. Medium NDVI values are observed over agricultural, grass lands and bare lands with mean value 0.151, 0.170 and 0.171 in 1986, it decreased to 0.142, 0.121 and 0.118, respectively in 2010. NDVI values shows an increment in wet land and forest land covers and a decline trend in other land use land covers probably because of the decreases in vegetation in all LULC. This decline in NDVI in agriculture and grass land may be due to lack of land ownership security in agricultural land and grass lands and clear direction in the right to cut and sell trees of private and communal property.

Individuals do not have courage to plant trees around agricultural and grass land. As result, the trees around these LULC were frequently cut down to build houses, for fire wood as well as market purposes, due to of this type deforestation activity NDVI decrease in these land use types. The result of NDVI values over different LULC of this research is in line with other works of Xiao and Weng, (2007) and Weng et al., (2004).

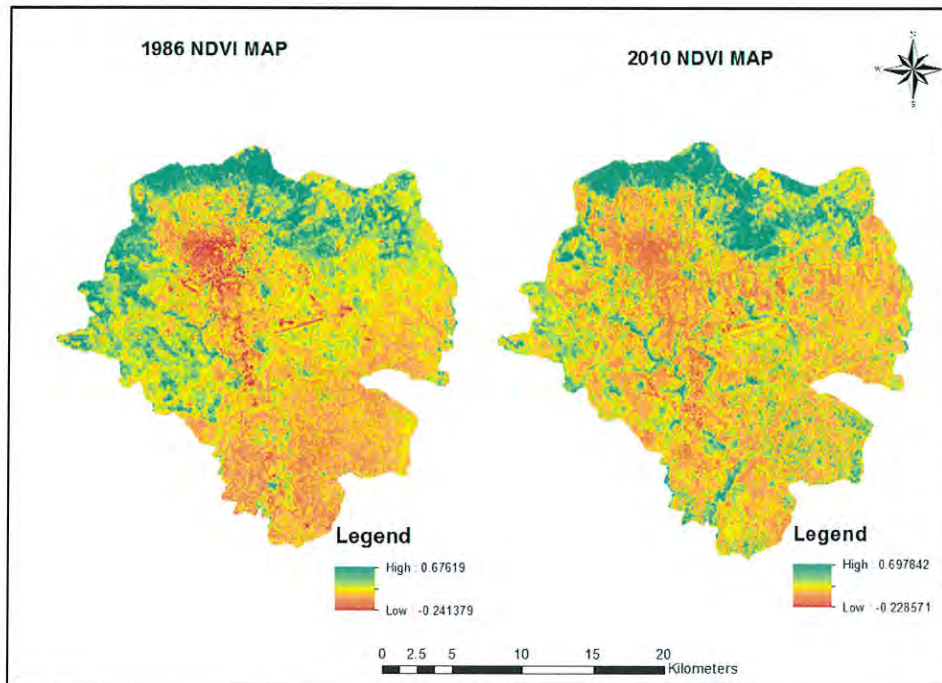


Figure 23: Spatial and Temporal Patterns Map of NDVI

From the derived emissivity values, the maximum values are observed over forest and range from 0.964 to 0.994 (mean of 0.9877 and standard deviation of 0.0037) in 1986. Similarly, forest in 2010 depicted emissivity values in the range 0.968 to 0.995 (mean of 0.9884 and standard deviation of 0.0066). The emissivity values over agricultural land, grass land and bare land are found to be in the range of 0.962 to 0.990, 0.963 to 0.991 and 0.963 to 0.992 (mean of 0.984 0.985 and 0.9851 and standard deviation of 0.0047, 0048 and 0.0044), respectively in 1986. The values over agricultural land, grass land and bare

land decreased in 2010 to 0.980, 0.981 and 0.9817, respectively. The derived emissivity values over different features have been compared with those in the literature (Salisbury and D’Aria, 1992; Rubio et al., 1997; Van de Griend and Owe, 1993) and found to be in agreement. Table 14 shows the derived emissivity value in respective LULC categories, with their mean emissivity value over urban varies from 0.9550 to 0.99 (mean 0.9811 and standard deviation of 0.009) in 1986 and shows declination to average value of 0.977 and standard deviation 0.011 in 2010. This declination of emissivity in urban areas and other land use land cover may be due to increment of impervious surface as the result of urban expansion and densification. Figure 24 shows the spatial and temporal pattern and distribution of emissivity and it shows suburbs around mount Entoto which is mainly covered by forest have high emissivity.

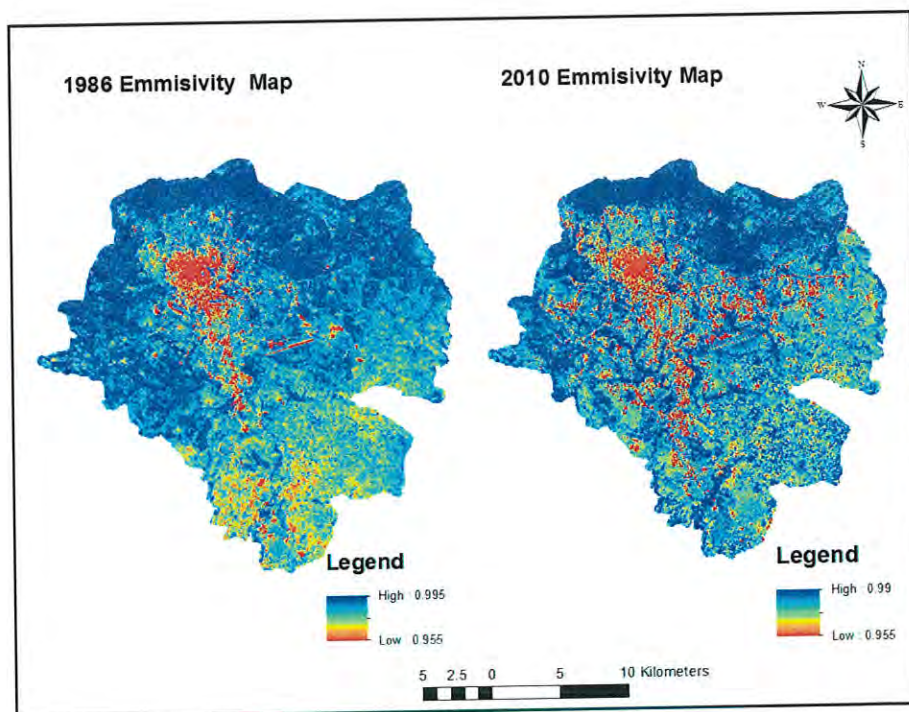


Figure 24: Spatial and Temporal Patterns of Emissivity

The percentage of land covered by impervious surfaces varies significantly with LULC categories and sub-categories (Soil Conservation Service, 1975). A LULC type with a higher NDVI and Emissivity appeared to have a lower impervious fraction. The highest impervious coverage was discovered in urban/ built up ranging from 0.0 to 89.93 with a mean value of 10.48 and standard deviation 5.19 in 2010. Likewise, urban areas exhibit highest impervious surface with mean value of 6.41 and 4.56 standard deviation in the year 1986 (Table 14). The mean impervious surface was increased substantially from 1986 to 2010. The spatial and temporal impervious surface percentage map shows the city center accommodate high impervious surface rather than the suburbs (Figure 25). The reason of the increment of impervious surface in urban areas, according to group discussion and interview from officials is due to lack of clear direction and rules of using construction materials and impermeable materials to build houses and infrastructure such parking lots, multi and single story residences, roads etc

Agricultural land and Grass land came in second and third, with a value of 5.44 and 3.75 and standard deviation 3.46 and 4.1 in 1986, respectively. In 2010, agricultural and grass land also took the second and third place with mean value 5.79 and 5.32 and standard deviation 3.82 and 4.54, respectively. Bare land perceived medium value of impervious with mean value of 3.36 and 4.87 with standard deviation 4.94 and 5.91 in 1986 and 2010, respectively. In 1986 and 2010, a lower value of impervious surface of an average value of 2.10 and 2.81 with a standard deviation of 2.04 and 4.21 respectively were observed on wetland. Forestland received a minimal impervious value 1.04(1986) and 1.28(2010). The highest standard deviation value in bare land and urban / built up may

due to various amount of emerged vegetation and urban green. In general, impervious surface percentage increase in all land use land covers over the study period. The end result of the percentage impervious surface values over different land use land cover have been similar with those in the literature Li et al., (2011) and Rong-bo et al., (2007).

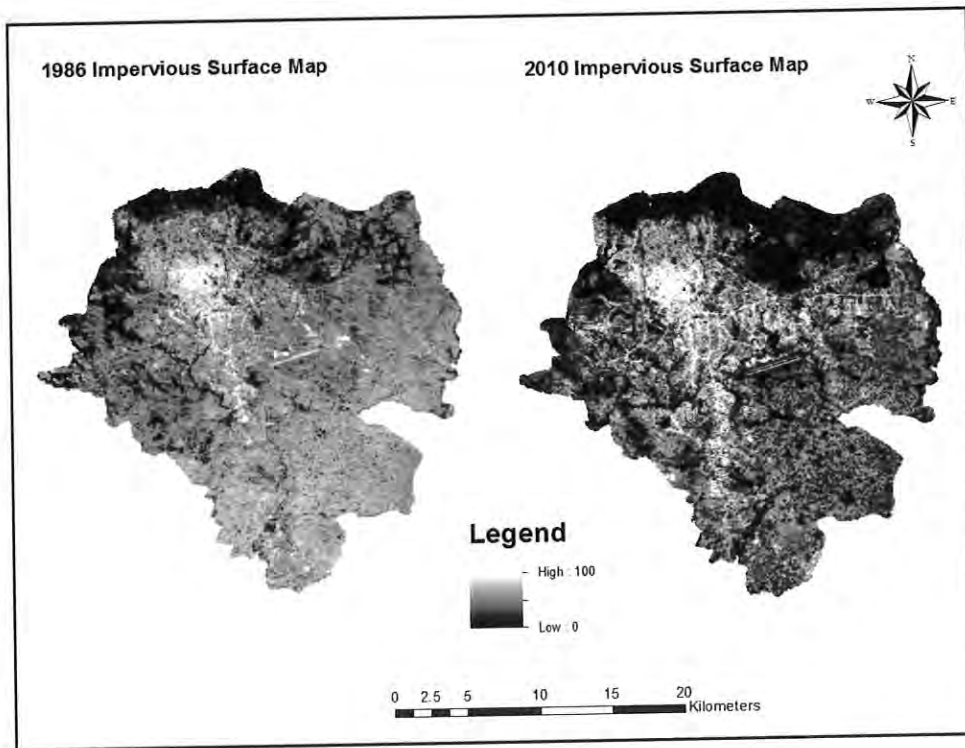


Figure 25: Spatial and Temporal Pattern Map of Impervious Surface

### 5.7. Relationship between LST and Biophysical Parameters

Research over the past two decades has shown that the surface radiant temperature response is determined by both surface soil water content and vegetation cover (Carlson et al., 1994; Gillies and Carlson, 1995; Goward et al., 1985; Nemani and Running, 1989; Owen et al., 1998; Price, 1990; Weng et al., 2004). In the urbanized area of the study site where bare soil is limited, the resultant temperatures variation depend on the relative

proportions of surfaces that are vegetated and non-vegetated surfaces, mainly impervious surfaces. In addition, previous studies have demonstrated that LULC changes, especially urban development, can alter LST patterns (Lo et al. 1997; Weng 2001). Since changes in LULC would lead to changes in the composition of image fractions, the magnitude and spatial distribution of each fraction image should be related to LST patterns. Therefore, to better understand how LST dynamics were associated with LUCC, Pearson's correlation analysis was conducted to explore the relationships between LST, and biophysical descriptors (i.e., vegetation abundance and impervious surface).

The correlation analysis was conducted between the LST maps with NDVI and impervious surface images using all pixels in the images as observation units. The significance of each correlation coefficient was determined using a one-tail Student's t-test. It is apparent from Table 15 that LST was positively correlated with impervious surface percentage (coefficient=0.51) in 1986 and coefficient = 0.57 in 2010 respectively but negatively correlate with NDVI (coefficient= -0.97 and -0.92) in 1986 and 2010, respectively, both significant at 0.05 level. LST generally increased with percent ISA, opposite to the pattern between vegetation abundance and LST because ISA and vegetation fraction are mutually exclusive. The main reason for this correlation is that vegetation or water covering and an increased rate of evapotranspiration in the non-impervious surfaces, which could contribute to decreasing surface temperature. On the other hand, impervious surface (non- evaporating, non-transpiring surface) such as stone, metal, and concrete enhance land surface temperature by absorbing the sun's rays (heat), decline evaporation and boost runoff.

Table 15: Correlation Coefficient between LST and Biophysical Parameters

LST	NDVI	ISA
1986	-0.92	0.51
2010	-0.97	0.57

The correlation between LST and the NDVI and ISA promises a potential success for using linear regression models and a scatter plot to predict the LST. The modelling results and scatter plots of LST versus NDVI are displayed in figure 26. NDVI showed a negative relation with LST where NDVI value was above zero, denoting that densely vegetated areas were associated with a lower LST. For NDVI values below zero, there were some scattered points deviated from the trend line, largely due to the presence of water which has a lower LST than that of any other land use types. LST displayed a uniformly positive relationship with impervious surface percentage, suggesting that densely distributed built-up areas and highly impervious surfaces experienced a higher LST (Figure 26).

Areas with high vegetation cover were generally cooler, while most of the high LST areas were located over paved roads and building blocks. The pattern of LST was largely determined by increasing evaporation and roughness, decreasing albedo, and changes in the land surface heat flux that were affected by vegetation cover (Oke, 1982; Stabler et al., 2005; Small, 2006). The rapid urbanization in Addis Ababa from 1986 to 2010 led to a decline in the urban vegetation cover and expansion of the urban thermal environment. Generally, 0.08 decreases in NDVI (vegetation cover) was correspondent to 1 K increase in LST over the area (Table 14 and 16). The spatial pattern of NDVI (Figure 23) demonstrated that a large fraction of green vegetation including cropland and grass land

was converted to urban land surface in the period, which extended UHIs rapidly to suburban and rural areas.

To better understand the relationship between LST and urban surface biophysical descriptors, the statistics of LST, impervious surface percentage, and NDVI by LULC type were obtained by superimposing LULC image with the images of LST, impervious, and NDVI. A pixel-by-pixel correlation analysis was conducted by computing Pearson's correlation coefficients between LST and NDVI, and between LST and impervious surface percentage. Results are displayed in Table 16.

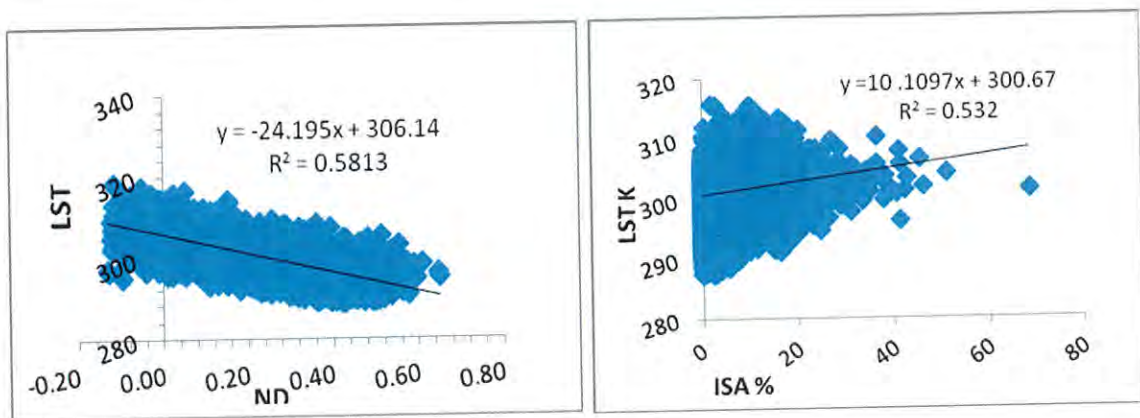


Figure 26: Scatter Plots of LST Vs NDVI and LST Vs ISA

For all LULC types, LST values were negatively correlated with NDVI values, but were positively correlated with impervious percentage values. The strongest negative correlation existed between LST and NDVI values in forest (-0.481 and -0.518), and agricultural land (0.47 and -0.561). Urban/ built-up areas followed with values of (-0.293 and -0.281). The correlation coefficient values dropped slightly for bare land (-0.253 and -0.283), with a considerable decrease for grass land (-0.176 and -0.121) and wet land (-

0.196 and -0.127) in both years under study, respectively. The result suggests that urban green space such as shade trees would have an effect on lowering LST.

On the other hand, the highest positive correlation between LST and impervious percentage was found in urban/ built-up (0.456 and 0.691) and bare land (0.451 and 0.441), followed by agricultural land (0.158 and 0.216) forest land (0.189 and 0.266). The lowest correlations were observed in grass land (0.0153 and 0.056 and wet land (0.017 and 0.059) in 1986 and 2010, respectively. The pattern of changing correlation coefficient values is observed in all of the LULC categories in relation to change in vegetation abundance and surface imperviousness (Table 16). Yuan and Bauer (2007) and Li et al. (2011) reported a linear relationship between LST and percent ISA based on regional mean values. In this analysis also found a similar linear relationship between LST and percent ISA.

Table 16: Correlation of Biophysical Parameters by LULC type with LST

Land Use land cover	LST Vs NDVI 1986	LST Vs NDVI 2010	LST Vs ISP 1986	LST Vs ISP 2010
Urban/ built-up	-0.293	-0.281	0.456	0.0691
Forest	-0.481	-0.518	0.189	0.266
Agriculture	-0.47	-0.561	0.158	0.216
Grass Land	-0.176	-0.121	0.0153	0.056
Wet Land	-0.196	-0.127	0.017	0.059
Bare Land	-0.253	-0.283	0.481.	0.441

The vegetation indicator show, negative correlation with land surface temperatures, and impermeable surface indicator shows positive correlation with land surface temperature. So, it can be concluded that the higher biomass/vegetation abundance a land cover has,

the lower the land surface temperature. On the other hand, land cover which has high impervious exhibit high temperature. Therefore, this shows that land use lands cover changes that are conversion of natural vegetation, forests and other uses to other land uses land cover have impact on land surface temperature through biophysical interactions that affect surface energy balance.

## **6. Conclusion and Recommendation**

### **6.1. Conclusions**

In this paper, qualitative and quantitative analyses techniques have been applied to study the impact of land use and land cover change on land surface temperature. Several conclusions were made pertaining to the research questions posed in the objectives of the study. Based on the analysis of the input data the study area is composed of six major land use and land cover types; urban/ built-up, forest, agriculture, grasslands, wetlands and bare lands. The results of years over study indicate that agriculture was primarily practiced throughout the study area followed by urban/ built-up. Grass land and bare land also widely distributed over study area to built-up. Forest covers considerable area around northern and north western part of the study area which is higher in altitude, where as wet lands covered smallest part of the area.

Over the last three decades Addis Ababa city has experienced huge change in its land use and land cover. In the period from 1986 to 2010 the land use and land cover that are subjected to gigantic changes are built-up and agricultural land. The urban/built-up areas expanded dramatically, while agricultural land declined. Urban coverage was drastically changed almost two times from initial year. It was suggested that the expansion of the urban area to the surrounding environment had an impact on the decrement of agricultural, forest, grassland, wet land and bare fields. The general trend observed was a decreased in grass cover and forest cover at considerable rate per year. A corresponding decrease was also observed in bare land and wet land. Besides, agricultural was also

continuously encroached, at significance rate. In general, there has been a dramatic increase of the built up areas including continuous and discontinuous urban fabrics, industrial, commercial and residential units with other associated urban facilities at the expense of agricultural land and vegetated areas including natural and manmade forest, and sparse forest during the study period. The city of Addis Ababa as expanded out ward it also densified both in population and in physical. The densification gradient diminished from the Central Business District (CBD) outward into the countryside over the study periods.

Thus, the observed changes in LULC were largely attributed as a consequence of human activities such as urban expansion and densification. Although urban expansion and densification are generally seen as two of the most important factors of land use and land cover change in the study area. It is a combination factors such as population pressure, improvements in infrastructures, informal settlements, a rapidly growing economy and investment, poor land use planning and the inconsistency in the governmental policies that actually drive the change, at the back of the phenomenon of urban expansion and densification. These underlying factors have triggered urban expansion and densification, which in turn appears to be the main proximate cause of land use land cover change.

Examination of the relationship between LUCC and the modification in LST showed that the change of land use and land cover types caused a spatial redistribution of LST. Changes in LULC were accompanied by changes in LST. From 1986 to 2010 surface temperature was climbed with considerable value in the entire city. Built-up and bare lands are the highest contributors to the rise in LST in the city during the study period.

LST shows an increasing trend for areas where forests, agricultural lands, grass lands and bare lands converted into built-up areas. LST dropped when built-up, agriculture land, grass land and bare land returned back to forest, but rose when forest turned into agriculture land, grass land, wet land, and bare land. A small fraction of the built-up land changed to forest, grass land and agricultural land accompanied by a decreased LST. This demonstrated that the decrease of biomass and increase of built-up primarily triggered the impacts of land use and land cover change on LST.

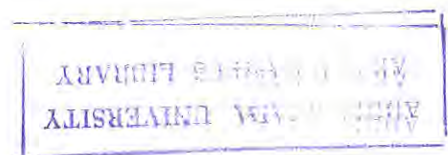
Furthermore, the changes in LULC have also considerably widened the air temperature difference between the urban and the surrounding areas. The average air temperature difference between Addis Ababa city center and outskirts (rural) increased significantly in the years under study, which indicates that, the warming effect of LULCC. Since, air temperature is the result of the process of atmosphere heat from the sun radiation and the earth, the high LST contribute in raising air temperature. The results of land surface temperature and air temperature shows that UHIs existed significantly in the city of Addis Ababa. If this difference in temperature between the built-up and the surrounding rural areas extend it could lead to intensify urban heat island effect in the urban center. The time-series analysis of temperatures in Addis Ababa city indicated that the increase in temperature is higher in the densely populated city centre rather than the low populated fringe areas.

Change in land use and land cover not only has an effect on temperature but also on urban climate in general. The climate of Addis Ababa as well as getting warmer, it is also getting wetter. The annual precipitation shows an increasing trend in both stations, but

city center records greater amount of rainfall in every year than periphery. The relative contribution of the seasons to annual precipitation is changing. Even though, there is some fluctuation in the proportion of the contribution to the annual total, but in general has an increasing trend in Bega and Kiremt season at the expense of the Belg at both stations. The decreasing trend of Belg rain fall and shift of rainy season is a clear indicator of urban climate change. The trend of relative humidity at both stations shows a decreasing trend, the rural site was more humid than the urban station at the central business district. The evaporation of the two stations shows a decreasing trend, but evaporation at the city center is less than the evaporation at periphery.

The change in LST was mainly associated with changes in urban surface properties such as impervious surface and vegetation abundance. Spatial patterns of IS and NDVI exhibited changing gradients across different land use and land covers , with LST values showing an increasing trend as land use land covers converted to built-up and decreasing trend land cover converts to forest. The positive linear relationship model between the LST and %ISA suggests that impervious surface area accounts for most of the variation in land surface temperature dynamics. The strongest negative correlation existed between LST and NDVI values shows that the decrement of surface temperature in LULU is due to vegetation abundance and higher biomass.

In general, land use and land cover changes that are conversion of natural vegetation, forests and other uses to other land use and land cover, specially to urban/ built-up have impact on urban climate particularly for land surface temperature through biophysical



interactions that affect surface energy balance. The increase of surface radiant temperature was related to the decrease of biomass. The spatial pattern of radiant temperature increase was correlated with the pattern of urban expansion and densification. With Addis Ababa city Development Plan, Addis Ababa is having a great opportunity to develop. The findings and lessons learned from the study, in the most developed areas in the country may be applicable to other areas in order to preserve the land and to minimize the loss of agricultural land and green areas to urban development.

## **6.2. Recommendations**

Based on the outcome of these research findings, the researcher would like to forward the following suggestions to mitigate the impact of land use and land cover change on land surface temperature and urban climate in general.

- Addis Ababa is expanding at an alarming rate changing large productive farmlands and green areas. Consequently, brought social, economic and environmental problems. To alleviate these problems, there should be a clear and effective policy with the necessary institutional set up to guide the growth of the city and monitor the proper implementation of the master plan.
- Different plans such as environmental plan, infrastructures plan, and service provision plan and others should be integrated with land use plan to build effective land use management system.
- The city Administration should have clear and consistent policy and directives to regulate of development patterns and unplanned development.

- Addis Ababa city the foci of investors and the majority of the investors need to invest in the city due concentration of basic service facilities. Thus, in order to minimize pressure on the primate city, strengthening of the regional capitals and other small urban centers should be enhanced.
- One of the causes of the land use and land cover change is the high rate of rural–urban migration; therefore, the government needs different development interventions to improve the livelihoods of the rural population to minimize out migration.
- Awareness should be created among the society concerning optimum use of natural resources, conservation systems, urban greening, driving forces including population pressure and their respective benefits is vital for sustainable land resource management
- Fast growing trees, shrubs and grasses should be planted to increase the forest coverage of upper catchment mountain so that flooding problem and environmental degradation on the lower catchment areas will get minimized and could provide a buffer zone between the urban and rural areas to absorb excess heat generated by automobiles and factories.
- Grasses and permeable structures should be used on gardens, vacant areas, river and road sides to increase infiltration, reduce flooding hazards and to enhance evaporation.
- Wet lands should be developed and urban agriculture should be encouraged in and around the city to minimize the warming effect.

- The buffer zones of rivers set by the AAEPAs should be implemented for the sustainable urban drainage management of rivers thereby then avoid the ever existing pollution problem and reduce temperature (due to its cooling effect).
- Construction of buildings, parking lots and roads should be accompanied with eco friendly methods such as water retention pavements and the heat shield pavements, cool roof, cool pavements, and etc.
- Finally there should be participatory urban land use management which involves all actors to minimize the negative consequences of rapid and uncontrolled urban growth and densification which affects the socio-economic and environmental sustainability of the city.

## References

- AACA, 1997. The First Five Years (1997-2001) Development Plan. Addis Ababa: Addis Ababa City Administration.
- AACA, 2000. The Second Five Years (2000-2004) Development Plan. Addis Ababa: Addis Ababa City Administration.
- Agarwal, C., Green, G. M., Grove, J. M., Evans, T. P., and Schweik, C. M., 2002. A Review and Assessment of Land-Use Change Models: Dynamics of Space, Time, and Human Choice. General Technical Report NE-297. Newtown Square, Pennsylvania: U.S. Department of Agriculture, Forest Service, Northeastern Research Station.
- Akundabweni, L., 1984. Forage Potential of some Annual Native Trifolium Species in the Ethiopian highlands, PhD Thesis, South Dakota State University, Brookings (USA), 208.
- Alberti, M., and Waddell, P., 2000. An Integrated Urban Development and Ecological Simulation Model. *Integrated Assessment*, 1 (3): 215–27.
- Alexander, L.V., Arblaster, J. M., 2008. Assessing Trends in Observed and Modelled Climate Extremes over Australia in Relation to Future Projections. *International Journal of Climatology*, doi:10.1002/joc.1730.
- Allen, J.C., and Barnes, D.F., 1985. The Causes of Deforestation in Developing Countries. *Annals of the Association of American Geographers*, 75(2):163-184.
- Anderson, J., Hardy, E., Roach, J., and Witner, R., 1976. A Land Use and Land cover Classification System for Use with Remote Sensor Data, Geological Survey Professional paper 964, United States Government Printing Office.
- Angel, S., Sheppard, S., Civco, D., 2005. The Dynamics of Global Urban Expansion. Transport and Urban Development Department, World Bank, Washington DC.
- Baulies, X., and Szejwach, G., 1998. LUCC Data Requirements Workshop Survey of Needs, Gaps and Priorities on Data for Land Use and Land Cover Change Research Organized by IGBP/IHDP- LUCC AND IGBP-DIS, Barcelona, Spain, 11-14 November 1997 LUCC report series no. 3.
- Becker, F., and Li, Z., 1990. Temperature Independent Spectral Indices in Thermal

- Infrared Bands: *Rem. Sens. Environ.*, 32: 17–33.
- Belay Tegene ., 2002. Land cover and Land Use Change in the Derekolli Catchment, South Wolo Zone of Amhara Region, Ethiopia. *Eastern Africa Social Science Research Review XVIII*,1: 1–20.
- Berk, A., Anderson, G. P., Bernstein, L. S., Acharya, P. K., Dothe, H., Matthew, M. W., Adler- Golden, S. M., Chetwynd, J. H., Richtsmeier, S. C., Pukall, B., Allred, C. L., Jeong, L.S., and Hoke, M. L., 1999. MODTRAN4 Radiative Transfer Modeling for Atmospheric Correction, in: *Proceedings of SPIE Optical Spectroscopic Techniques and Instrumentation for Atmospheric and Space Research III*, Denver, Co, USA.
- Betts, R.A., 2001. Biogeophysical Impacts of Land Use on Present-day Climate: Near Surface Temperature Change and Radiative Forcing. *Atmospheric Science Letters*, 2(1-4): 39-51.
- Bottomley, B. R., 1998. Mapping Rural Land Use and Land Cover Change in Carroll County, Arkansas utilizing multi-temporal Landsat Thematic Mapper satellite imagery. Dissertation, University of Arkansas. [http://www.cast.uark.edu/local/brandon\\_thesis/](http://www.cast.uark.edu/local/brandon_thesis/).
- Brazel, A., Gober, P., Lee, S.J., Grossman-Clarke, S., Zehnder, J., Hedquist, B., Comparri, E., 2007. Determinants of Changes in the Regional Urban Heat Island in Metropolitan Phoenix, Arizona, USA, between 1990 and 2004. *Clim Res* 33:171–182. doi:10.3354/ cr033171.
- Carlson, T. N., Gillies, R. R., Perry, E. M., 1994. A Method to Make Use of Thermal Infrared Temperature and NDVI Measurements to Infer Surface Soil Water Content and Fractional vegetation cover. *Remote Sensing Reviews*, 9(1): 161–173.
- Caselles, V., Coll, C., Valor, E., 1995. Mapping Land Surface Emissivity Using AVHRR Data: Application to La Mancha, Spain. *Remote Sensing Reviews*, 12: 311-333.
- Chander, G., Markham, B. L., and Helder, D. L., 2009. Summary of Current Radiometric Calibration Coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors, *Remote Sensing of Environment*, 113: 893–903.

- Changnon, S.A., 2001. Assessment of Historical Thunderstorm Data for Urban Effects: the Chicago case. *Clim Change* 49:161–169. doi: 10.1023/A:1010797013336.
- Chavez, P. S., 1996. Image-based Atmospheric Corrections-revisited and Improved, *Photogrammetric Engineering and Remote Sensing*, 62:1025–1036.
- Chen, D., Brutsaert, W., 1998. Satellite-sensed Distribution and Spatial Patterns of Vegetation Parameters over a Tall Grass Prairie. *Journal of the Atmospheric Sciences*, 55 (7): 1225-1238.
- Chen, X., 2000. Using Remote Sensing and GIS to Analyze Land Cover Change and its Impacts of the Regional Sustainable Development. *International Journal of Remote Sensing*, 23(1): 107-114.
- Chrysoulakis, N., Kamarianakis, Y., Farsari, Y., Diamandakis, M., Prastacos, p., 2004. Combining Satellite and Socioeconomic Data for Land Use Models Estimation. In Goossens, R.(Editor), Proc.Of 3<sup>rd</sup> Workshop of EARSeL Special Interest Group on Remote Sensing for Developing Countries(in press).
- Civco, D.L., 1989. Topographic Normalization of Landsat Thematic Mapper Digital Imagery. *Photogrammetric Eng. and Rem. Sensing*, 55(9): 531-537.
- Civco, D. L., Hurd, J. D., Arnold, C. L., Prisloe, S., 2002. Characterization of Suburban Sprawl and Forest Fragmentation through Remote Sensing Applications. *Proceedings of the ASPRS 2000 Annual Convention*.
- Conese, C., Gilabert, M.A., Maselli, F., Bottai, L., 1993. Topographic Normalization of TM Scenes through the Use of an Atmospheric Correction Method and Digital Terrain Models. *Photogrammetric Engineering and Remote Sensing*, 59(12): 1745-1753.
- Coppin, P., Jonckheere, I., Nackaerts, K., Muys, P., Lambin, E., 2004. Digital Change Detection in Ecosystem Monitoring. A Review, *International Journal of Remote Sensing* 25(9): 1565-1596.
- CSA, 1995. The 1994 Population and Housing Census of Ethiopia Results for Addis Ababa, Vol. Statistical Report. Addis Ababa: Central Statistical Authority.
- CSA, 1999. The 1994 Population and Housing Census of Ethiopia; Result at country level, Vol. II, Analytic Report, Addis Ababa.
- CSA, 2006. Statistical Abstract Report, Addis Ababa.

- CSA, 2010. The 2007 Population and Housing Census of Ethiopia; Result for Addis Ababa City Administration Statistical Report. Addis Ababa.
- Crummey, D., 1998. Deforestation in Wollo: Process or Illusion? *Journal of Ethiopian Studies* 31(1): 1–41.
- Deer P.J., 1995. Digital Change Detection Techniques Civilian and Military Applications International Symposium on Spectral Sensing Research Report. <http://ltpwww.gsfc.nasa.gov/ISSSR-95/digitalc.html>.
- Dendena Tufa., 1995 Urban Development of Addis Ababa, Plans and Realities, Master's Thesis, Post Graduate Center Human Settlement, K.U.L Belgium.
- Dousset, B., and Gourmelon, F., 2003. Satellite Multi-sensor Data Analysis of Urban Surface Temperatures and Land Cover. *ISPRS Journal of Photogrammetry and Remote Sensing, Algorithms and Techniques for Multi-Source Data Fusion in Urban Areas*, 58(1-2): 43- 54.
- Du, Y., Teillet, P.M., and Cihlar, J., 2002. Radiometric Normalization of Multi-temporal High-resolution Satellite Images with Quality Control for Land Cover Change Detection. *Remote Sensing of Environment*, 82: 123–134.
- Durieux, L., Machado, L.A.T., and Laurent, H., 2003. The Impact of Deforestation on Cloud Covers over the Amazon arc of Deforestation. *Remote Sensing of the Environment*, 86:132-140.
- Ehlers, M., Jadcowski, M.A., Howard, R.R., and Brousten, D.E., 1990. Application of SPOT Data for Regional Growth Analysis and Local Planning. *Photogrammetric Engineering and Remote Sensing*, 56: 175–180.
- Elnazir, R., Xue-zhi, F. and Zheng, C., 2004. Satellite Remote Sensing for Urban Growth Assessment in Shaoxing City, Zhejiang Province. *Journal of Zhejiang University SCIENCE* 5(9).
- Ewing, R.H., 1994. Characteristics, Causes, and Effects of Sprawl: a Literature review. *Environ Urban Stud* 21:1–17.
- FAO, 2000. Land covers Classification System (LCCS): Classification Concepts and User Manual. Retrieved 1-July-2003.
- Franca, G. B., and Cracknell, A. P., 1994. Retrieval of Land and Sea Surface

- Temperature using NOAA-11 AVHRR data in north-eastern Brazil. *International Journal of Remote Sensing*, 15: 1695–1712.
- Fung, I.Y., Tucker, C.J., Prentice, K.C., 1987. Application of Advanced very High Resolution Radiometer to Study Atmosphere-biosphere Exchange of CO<sub>2</sub>. *Journal of Geophysical Research*, 92: 2999–3015.
- Gallant, A., Hennessy, K., Risbey, J., 2007. Trends in Rainfall Indices for Six Australian Regions: 1910-2005. *Australian Meteorological Magazine*, 56:223-239.
- Gallo, K.P., Owen, T.W., 1998. Assessment of urban heat island: a multi-sensor perspective for the Dallas-Ft. Worth, USA region. *Geocarto Int* 13:35–41.
- Gallo, K.P., Owen, T.W., Easterling, D.R., and Jamason, P.F., 1999. Temperature Trends of the US Historical Climatology Network based on Satellite-designated Land Use and Land Cover. *J. Climate*, 12: 1344-1348.
- Gao, X., Luo, Y., Lin, W. T., Zhao, Z. C., and Giorgi, F., 2003. Simulation of Effects of Land Use Change on Climate in China by a Regional Climate Model. *Advances in Atmospheric Sciences*, 20(4): 583-592.
- Garcia, M., Alvarez, R., 1994. TM Digital Processing of a Tropical Forest Region in Southern Mexico. *International Journal of Remote Sensing*, 15 (8): 1611–1632.
- Geist, H.J., and Lambin, E.F., 2002. Proximate Causes and Underlying Driving Forces of Tropical Deforestation. *Bioscience*, 52 (2).
- Gillespie, A. R., 1985. Lithologic Mapping of Silicate Rocks Using TIMS. The TIMS data users' workshop, JPL Publication, Vol. 86–38: 29–44.
- Gillies, R. R., and Carlson, T. N., 1995. Thermal Remote Sensing of Surface Soil Water Content with Partial Vegetation Cover for Incorporation into Climate Models. *Journal of Applied Meteorology*, 34(4): 745–756.
- Gillies, R. R., Carlson, T. N., Cui, J., Kustas, W. P., and Humes, K. S., 1997. A Verification of the 'Triangle' Method for Obtaining Surface Soil water Content and Energy Fluxes from Remote Measurements of the Normalized Difference Vegetation Index (NDVI) and Surface Temperature. *International Journal of Remote Sensing*, 18: 3145–3166.
- Gobin, A., Campling, P., Feyen, J., 2002. Logistic Modelling to Derive Agricultural Land

- Use Determinants: A case study from southeastern Nigeria. *Agriculture, Ecosystems and Environment*, 89(3): 213–228.
- Goldewijk, K. K., 2001. History Data Base of the Global Environment-HYDE. Netherlands: National Institute for Public Health and Environment (RIVM).
- Goward, S.N., 1981. Thermal Behavior of Urban Landscapes and the Urban Heat Island, *Physical Geography*, 1(2):19–33.
- Goward, S. N., Cruickshank, G. D., and Hope, A. S., 1985. Observed Relation between Thermal Emission and Reflected Spectral Radiance of a Complex Vegetated landscape. *Remote Sensing of Environment*, 18: 137–146.
- Goward, S. N., Xue, Y., and Czajkowski, K. P., 2002. Evaluating Land Surface Moisture Conditions from the Remotely Sensed Temperature/Vegetation Index Measurements: An exploration with the Simplified Simple Biosphere Model. *Remote Sensing of Environment*, 79(2–3): 225–242.
- Gugler, J., 1996. *The Urban Transformation of the Developing World*, Oxford University Press.
- Hale, R.C., Gallo, K.P., Owen, T.W., Loveland, T.R., 2006. Land use and land cover change effects on temperature trends at U.S. Climate Normals stations. *Geophysical Research Letters* 33: L11703. DOI: 10.1029/2006GL026358.
- Hardoy, J., Satterthwaite, D. et al., 2001. *Environmental Problems in an Urbanized World. Finding Solutions for Cities in Africa, Asia and Latin America*, London.
- Harris, P.M., and Ventura, S.J., 1995. The Integration of Geographic Data with Remotely Sensed Imagery to Improve Classification in an Urban Area. *Photogrammetric Engineering and Remote Sensing*, 61: 993–998.
- Holben, B. N., and Justice, C. O., 1980. The Topographic Effect on Spectral Response from Nadir Pointing Sensors, *Photogramm. Eng. Rem. S.*, 46:1191–1200.
- Houghton, R.A., 1994. The Worldwide Extent of Land-use Change. *Bio-Science*, 44(5): 305-313.
- Horvath, R.J., 1966. *Around Addis Ababa: Geographic Study of the Impact of a City on its Surroundings*, PhD Dissertation. Los Angeles: University of California.
- Hu, X. F., Wu, H. X., Hu, X., Fang, S. Q., and Wu, C. J., 2004. Impact of Urbanization on Shanghai's Soil Environmental Quality. *Pedosphere*, 14(2): 151-158.

- Hu, X., and Weng, Q., 2009. Estimating Impervious Surfaces from Medium Spatial Resolution Imagery Using the Self-organizing Map and Multi-layer perception Neural Networks. *Remote Sensing of Environment*, 113(10): 2089–2102.
- Hung, T., Uchihama, D., Ochi, S., and Yasuoka, Y., 2006. Assessment with Satellite Data of the Urban Heat Island Effects in Asian Mega Cities. *International Journal of Applied Earth Observation and Geo information*, 8(1): 34-48.
- Ichii, K., Kawabata, A., Yamaguchi, Y., 2002. Global correlation analysis for NDVI and climatic variables and NDVI trends: 1982–1990. *International Journal of Remote Sensing*, 23: 3873–3878.
- Jensen, R., Gatrell, J., and Mclean, D., 2005. *Geo-spatial Technologies in Urban Environments*, Springer.
- Jianquan, C., 2003. *Modelling Spatial and Temporal Urban Growth*. PhD dissertation Utrecht University, The Netherlands.
- Jime´nez-Mun´oz, J.C., Sobrino, J.A., 2003. A Generalized Single Channel Method for Retrieving Land Surface Temperature from Remote Sensing Data. *Journal of Geophysical Research*, 108.
- Jin, S., and Sader, S. A., 2005. MODIS time-series Imagery for Forest Disturbance and Quantification of Patch Effects. *Remote Sensing of Environment*, 99:462–470.
- Kalnay, E., and Cai, M., 2003. Impact of Urbanization and Land Use Change on Climate. *Nature*, 423: 528-531.
- Kaufmann, R.K., D’Arrigo, R.D., Laskowski, C., Myneni, R.B., Zhou, L., Davi, N., 2004. The Effect of Growing Season and Summer Greenness on Northern Forests. *Geophysical Research Letters*, 31.
- Kebrom Tekele., and Hedlund, L., 2000. Land Cover Changes Between 1958 and 1986 in Kalu District, Southern Wello, Ethiopia. *Mountain Research and Development* 20: 451.
- Lambin, E.F., Turner II, B.L., Geist, H., Agbola, S., Angelsen, A., Bruce, J.W., Coomes, O., Dirzo, R., Fischer, G., Folke, C., George, P.S., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E.F., Mortimore, M., Ramakrishnan, P.S., Richards, J.F., Skanes, H., Steffen, W., Stone, G.D., Svedin, U., Veldkamp, T., Vogel, C.,



- Lunetta, R. S., and Elvidge, C. D. E., 1999. Applications, Project Formulation, and Analytical Approach, Remote Sensing Change Detection: Environmental Monitoring Methods and Applications. London: Taylor and Francis., 1-20.
- Markham, B.L., Barker, J.K., 1985. Spectral Characteristics of the LANDSAT Thematic Mapper sensors. *International Journal of Remote Sensing*, 6: 697–716.
- Mas, J., 1999. Monitoring Land-cover Changes: a Comparison of Change Detection Techniques. *International Journal of Remote Sensing*, 20 (1): 139–152.
- McColl, C., 2007. Improved Land Use Decision Support, Land Use Forecasting and Hydrologic Model Integration, RGIS Pacific Northwest, Central Washington university.
- McHugh, O. V., McHugh, A. N., Eloundou-Enyegue, P. M., and Steenhuis, T. S., 2007. Integrated Qualitative Assessment of Wetland Hydrological and Land Cover Changes in a Data Scarce Dry Ethiopian Highland Watershed, *Land Degrad. Dev.*, 18: 643–658
- Mengesha Tefera., Tewodros Chernet and Workneh Haro., 1996. Geological Map of Ethiopia (1:2000000), Second Edition and Explanatory notes. Bulletin N0. 3. GSE.
- Meyer, W.B., 1996. *Human Impact on the Earth*. Cambridge University Press, Cambridge.
- Meyer and Turner II., 1994. *Change in Land Use and Land Cover; A Global perspective*. Cambridge University press. New York.
- Millan, M. M., Estrela, M. J., Sanz, M. J., Mantilla, E., Martín, M., Pastor, F., Salvador, R., Vallejo, R., Alonso, L., Gangioti, G., Ilardia, J. L., Navazo, M., Albizuri, A., Artiñano, B., Ciccioli, P., Kallos, G., Carvalho, R. A., Andrés, D., Hoff, A., Werhahn, J., Seufert, G., and Versino, B., 2005. Climatic Feedbacks and Desertification: The Mediterranean Model. *J. Climate*, 18 (5): 684-701.
- Minwuyelet Melese., 2005. *City Expansion, Squatter Settlement and Policy Implications in Addis Ababa*, Trondheim, Norway.
- Nemani, R. R., and Running, S. W., 1989. Estimation of Regional Surface Resistance to Evapotranspiration from NDVI and Thermal-IR AVHRR data. *Journal of Applied Meteorology*, 28: 276–284.

- Nichol, J., 2005. Remote Sensing of Urban Heat Islands by Day and Night. *Photogramm Eng Rem S*, 71: 613-261.
- Oke, T.R., 1982. The Energetic Basis of the Urban Heat Island. *Q J R Meteorol Soc* 108:1–24.
- OPHCC, 1984. The 1984 'Population and Housing Census of Ethiopia Analytical Report on Results for Addis Ababa'. Addis Ababa: Office of the Population and Housing Census Commission.
- ORAAMP, 1999. Land Use City Structure Studies of Addis Ababa and the Metropolitan Area: Executive Summary Report of Land Use and City Structure Study Team. Addis Ababa: Office for the Revision of the Addis Ababa Master Plan.
- ORAAMP, 2001. Land Use and City Structure Studies of Addis Ababa and the Metropolitan Areas. Addis Ababa.
- ORAAMP, 2002. Proposed Division of Weredas and Kebeles of Addis Abaa Summary. Addis Ababa: Office for The Revision of the Addis Ababa Master plan.
- Owen, T. W., Carlson, T. N., and Gillies, R. R., 1998. An Assessment of Satellite Remotely Sensed Land Cover Parameters in Quantitatively Describing the Climatic Effect of Urbanization. *International Journal of Remote Sensing*, 19(9): 1663–1681.
- Pankhurst, R., 1962. The Foundation and Growth of Addis Ababa to 1935', in *Ethiopian Observer*, 4(1): 35-36.
- Pielke, R.A.Sr., Walko, R.L., Steyaert, L.T., Vidale, P.L., Liston, G.E., Lyons, W.A., and Chase, T., 1999. The Influence of Anthropogenic Landscape Changes on Weather in South Florida. *Monthly Weather Review*, 127: 1663-1673.
- Pielke, R.A. Sr., Marland, G., Betts, R.A., Chase, T.N., Eastman, J.L., Niles, J.O., Niyogi, D., and Running, S.W., 2002. The Influence of Land Use Change and Landscape Dynamics on the Climate System: Relevance to Climate Change Policy beyond the Radiative Effects of Greenhouse Gases. *Phil. Trans. Roy. Soc. London*, 360: 1-15.
- Pongrácz, R., Bartholy, J., Dezső, Z.s., 2006. Remotely Sensed Thermal Information Applied to Urban Climate Analysis. *Advances in Space Research*, 37:2191-2196.
- Prata, A.J., 1993. Land Surface Temperatures Derived from the Advanced very High

- Resolution Radiometer and the Along-track Scanning Radiometer: 1.Theory. *Journal of Geophysical research*, 98: 16689-16702.
- Prata, A. J., Caselles, V., Coll, C., Sobrino, J. A., and Otle, C., 1995. Thermal Remote Sensing of Land Surface Temperature from Satellites: Current status and future prospects. *Remote Sensing Reviews*, 12: 175–224.
- Price, J., 1984. Land Surface Temperature Measurements from the Split-window Channels of the NOAA 7 AVHRR," *Journal of Geophysical Research*, 89.
- Price, J. C., 1990. Using Spatial Context in Satellite Data to Infer Regional Scale Evapotranspiration, *I.E.E.E. Transactions on Geoscience and Remote Sensing*, 28: 940–948.
- Population Reference Bureau (PRB), 2001. *Healthy People Need Healthy Forests: Population and Deforestation*. Washington, DC.
- Qin, Z., and Karnieli, A., 1999. Progress in the Remote Sensing of Land Surface Temperature and Ground Emissivity using NOAA-AVHRR data. *International Journal of Remote Sensing*, 20(12): 2367-2393.
- Qin, Z., Karnieli, A., Berliner, P., 2001. A mono-algorithm for Retrieving Land Surface Temperature from Landsat TM data and its Application to the Israel–Egypt Border region. *International Journal of Remote Sensing* 22 (18): 583–594.
- Quentin F. B., Jim, C., Julia, C., Carole, H., and Andrew, S., 2006. *Drivers of Land Use Change, Final report: Matching Opportunities to Motivations*, ESAI project05116, Department of Sustainability and Environment and primary industries, Royal Melbourne Institute of Technology. Australia.
- Ramachandra, T. V., and Kumar, U., 2004. *Geographic Resources Decision Support System for Land Use, Land Cover Dynamics Analysis*.
- Ray, D.K., Nair, U.S., Welch, R.M., Su, W., and Kikuchi, T., 2001, Influence of Land Use on the Regional Climate of Southwest Australia. *EOS Transactions* 82 (20). AGU Spring 2001, San Francisco, CA.
- Rembold, F., Carnicelli, S., Nori, M., and Ferrari, G.A., 2000. Use of Aerial Photographs, Landsat TM Imagery and Multidisciplinary Field Survey for Land Cover Change Analysis in the Lakes Region, Ethiopia. *International Journal of Applied Earth Observation and Geoinformation*. 2(3-4): 181-189.

- Roberts, D. A., Gardner, M., Church, R., Ustin, S., Scheer, G., and Green, R. O., 1998). Mapping Chaparral in the Santa Monica Mountains using Multiple Endmember Spectral Mixture Models. *Remote Sensing of Environment*, 65:267–279.
- Rong-bo, X ., Zhi-yun, O., Hua, Z., Wei-feng, L., Erich, W. S., Xiao-ke, W., 2007. Spatial Pattern of Impervious Surfaces and their Impacts on and Surface Temperature in Beijing, *Chin Journal of Environmental Sciences* 19: 250-256.
- Roth, M., Oke, T.R., Emery, W.J., 1989. Satellite Derived Urban Heat Islands from Three Coastal Cities and the Utilization of such Data in Urban Climatology. *Int J Remote Sens.*, 10:1699-1720.
- Rubio, E., Caselles, V., and Badenas, C., 1997. Emissivity Measurements of several Soils and Vegetation Types in the 8-14 $\mu$ m Wave Band: Analysis of Two Field Methods, *Remote Sensing of Environment*, 59: 490-521
- Rutchev, K., Vilcheck, L., 1994. Development of an Everglades Vegetation map using a spot image and the global positioning system. *Photogrammetric Engineering and Remote Sensing* 60 (6): 767–775.
- Salisbury, J. W., and D'Aria, M., 1992. Emissivity of Terrestrial Materials in the 8–14  $\mu$ m Atmospheric Window, *Remote Sens. Environ.*, 42, 83– 106.
- Schadlich, S., Gottsche, F.M., Olesen, F.S., 2001. Influence of Land Surface Parameters and Atmosphere on Meteosat Brightness Temperatures and Generation of Land Surface Temperature Maps by Temporally and Spatially Interpolating Atmospheric Correction. *Remote Sensing of Environment*, 75 (1):39- 46.
- Schmidt, H., Karnieli, A., 2000. Remote Sensing of the Seasonal Variability of Vegetation in a Semi-arid Environment. *Journal of Arid Environments*, 45 (1): 43–60.
- Sege, C., 1994. Population and Income. In Meyer WB, Turner BL II, eds. *Change in Land Use and Land cover. A Global Perspective* Cambridge University Press: Cambridge.
- Settle, J. J., and Drake, N. A., 1993. Linear Mixing and the Estimation of Ground Cover Proportions. *International Journal of Remote Sensing*, 14:1159–1177.
- Singh, A., 1989. Digital Change Detection Techniques Using Remotely Sensed Data. *International Journal of Remote Sensing*. Vol. 10, No. 6: 989-1003.

- Sisay Zenebe, 2002. A Preliminary Assessment on Urban Land Market in Addis Ababa. Addis Ababa: Office for the Revision of the Addis Ababa Master Plan.
- Skole D.L., Chomentowski W.H., Salas W.A., and Nobre A.D., 1994. Physical and Human Dimensions of Deforestation in Amazonia. *BioScience* 44: 314–322.
- Small, C., 2001. Estimation of Urban Vegetation Abundance by Spectral Mixture Analysis. *International Journal of Remote Sensing*, 22:1305–1334.
- Snyder, W.C., Wan, Z., Zhang, Y., and Feng, Y. Z., 1998. Classification Based Emissivity for Land Surface Temperature Measurement from Space *International journal of remote sensing*,21:353-2774.
- Sobrino, J.A., Li, Z.L., Stoll, M.P., Becker, F., 1994. Improvements in the Split-window Technique for Land Surface Temperature Determination. *IEEE Transactions on Geoscience and Remote Sensing*, 32(2):243-253.
- Sobrino, J. A., Jimenez-Munoz, J.C et al., 2004. Single-channel and Two-channel Methods for Land Surface Temperature Retrieval from DAIS data and its Application to the Barrax site. *International Journal of Remote Sensing*, 25(1): 215-230.
- Soil Conservation Service, 1975. Urban Hydrology for Small Watersheds, USDA Soil Conservation Service Technical Release, 55. Washington, DC.
- Solomon Mulugeta .,1985. Meeting the Housing Shortage in Addis Ababa: the case of Housing cooperatives, MA Thesis. Addis Ababa: Addis Ababa University.
- Song, Y. L., Zhang, S. Y., 2003. The Study on Heat Island Effect in Beijing During Last 40 years. *Chinese Journal of Eco- Agriculture*, 11: 126-129.
- Stabler, L.B., Martin, C.A., Brazel, A.J., 2005. Microclimates in a Desert City were related to Land Use and Vegetation index. *Urban Forestry and Urban Greening*, 3:137–147, DOI:10.1016/j.ufug.2004.11.001.
- Streutker, D. R., 2003. Satellite Measured Growth of the Urban Heat Island of Houston, Texas. *Remote Sens Environ*, 85: 282-289.
- Svirejeva-Hopkins, A., Schellnhuber. H.J., and Pomaz,V.L., 2004. Urbanized Territories As a Specific Component of the Global Carbon Cycle. *Ecological Modelling*, 173:295-312. DOI:10.1016/j.ecolmodel.2003.09.022.

- Tamiru Alemayehu., Tenalem Ayenew., Dagnachew Legesse., Yirga Tadesse., Solomon Waltenigus., Nuri Mohamed., 2006. Groundwater Vulnerability Mapping of the Addis Ababa Water Supply Aquifers, Ethiopia.
- Tardie, P. S., and Congalton, R.G., 2004. A change-detection Analysis: Using Remotely Sensed Data to Assess the Progression of Development in Essex country, Massachusetts from 1990 to 2001.
- Techeste, A., 1987. Basic Planning Principles and Objectives taken in the Preparation of the Addis Ababa Master Plan, Past and Present. In Ahmed, Z.; Bahru, Z.; and Tadesse, B. (Eds). Proceedings of the International Symposium on the Centenary of Addis Ababa.
- Tegegne Gebre Egziabher., 2000. Urban Poverty and the Environment: illustrations From Addis Ababa, in Ethiopian development Forum, 1(1): 76-84.
- Tesfaye Beza., 1987. Historical development of Addis Ababa. Addis Ababa.
- Thenkabail, P., Schull, M., and Turrall, H., 2005. Ganges and Indus River Basin Land Use Land Cover (LULC) and Irrigated Area Mapping Using Continuous Streams of MODIS data, Remote Sens. Environ., 95:317–341.
- Togtohyn, C., Denmsi, O., 2002. Land Use Change and Carbon Cycle in Arid and Semi-arid Lands of East and Central Asia. Science in China (Series D), 45: 48–54
- Treitz, P.M., and Hobbs, N.T., 1992. Forecasting Rural Land Use Change: a Comparison of Regression and Spatial Transition based Models. Geographical and Environmental Modelling, 2: 65–82
- Turner II, B.L., and Meyer, B.L., 1994. Global Land use and Land cover Change: An Overview. In McColl, C., 2007. Improved Land Use Decision Support, Land Use Forecasting and Hydrologic Model Integration, RGIS Pacific Northwest, Central Washington university.
- Turner, II. B.L., Ali, A.M.S., 1996. Induced Intensification: Agricultural Change in Bangladesh with Implications for Malthus and Boserup. Proceedings of the National Academy of Sciences of the United States of America, 93:14984–14991.
- UN-Habitat, 2004. Revision of the United Nations (UN) World Urbanisation Prospects. Annual Report. Earthscan, London.
- Unger, J., Sumeghy, Z., Gulyas, A. et al., 2001. Land Use and Meteorological Aspects of



- the Urban Heat Island. *Meteorol Appl*, 8: 189-194.
- United Nations Environmental Protection, 2002. *Global Environmental Outlook 3. Past, Present and Future Perspectives*.
- UN Population Division, 2004. *World Urbanizations Prospects: the 2003 revision. Data, Tables and Highlights*. New York, USA.
- United State Environmental Protection Agency, 1999. *Land Cover Trends: Rates, Causes, and Consequences of Late-Twentieth Century U.S. Land*.
- Valor, E., and Caselles, V., 1996. Mapping Land Surface Emissivity from NDVI: Application to European, African, and South American areas *Remote Sensing of Environment*, 57:167- 184.
- Van de Griend, A. A., and Owe, M., 1993. On the Relationship between Thermal Emissivity and the Normalized Difference Vegetation Index for Natural Surfaces; *Int. J. Rem. Sens.* 14: 1119– 1131.
- Vermote, E. F., Tanré, D., Deuzé, J. L., Herman, M., and Morcrette, J. J., 1997. Second Simulation of the Satellite Signal in the Solar Spectrum, 6S: an overview, *IEEE Transactions on Geoscience and Remote Sensing*, 35:675–686
- Verstraeten, W.W., Veroustraete, F., van der Sande, C.J., Grootaers, I., and Feyen, J., 2006. Soil Moisture Retrieval Using Thermal Inertia, Determined with Visible and Thermal Spaceborne Data, Validated for European Forests. *Remote Sensing of Environment*, 101(3): 299-314.
- Voogt J. A, Oke, T. R., 1998. Effects of Urban Surface Geometry on Remotely Sensed Surface Temperature. *Int J Remote Sens.*, 19: 895-920.
- Voogt, J. A., Oke, T. R., 2003. Thermal Remote Sensing of Urban Climates. *Remote Sens. Environ*, 86: 37Ck-384.
- Walker, B., and Steffen. W., 1997. An Overview of the Implications of Global Change for Natural and Managed Terrestrial Ecosystems. *Conservation Ecology*.
- Wang, W. W., Zhu, L. Z., Wang, R. C., 2004. An Analysis on Spatial Variation of Urban Human Thermal Comfort in Hangzhou, China. *J Environ Sci*, 16(2): 332-338.
- Watson, K., 1992. Two-temperature Method for Measuring Emissivity. *Remote Sensing of Environment*, 42: 117–121.
- Weng, Q., 2001. A Remote Sensing GIS Evaluation of Urban Expansion and its Impact

- on Surface Temperature in Zhujiang Delta, China. *International Journal of Remote Sensing*, 22(10):1999–2014.
- Weng, Q., Lub, D., Schubring, J., 2004. Estimation of Land Surface Temperature Vegetation Abundance Relationship for Urban Heat Island studies. *Remote Sensing of Environment*, 89: 467–483.
- Weng, Q., Yang, S., 2004. Managing the Adverse Thermal Effects of Urban Development in a Densely Populated Chinese city. *Journal of Environmental Management*, 70 (2): 145–156.
- World Meteorological Organization, 2005. *Climate and Land Degradation. Soil Conservation- Land Management- Flood forecasting- Food Security*. WMO, 989.
- World Resources Institute, 2000. *Domesticating the World: Conversion of Natural Ecosystems*. <http://www.wri.org/wr2000/index.html>
- Wu, C., 2004. Normalized Spectral Mixture Analysis for Monitoring Urban Composition using ETM+ imagery. *Remote Sensing of Environment*, 93(4): 480–492.
- Wu, C., and Murray, A. T., 2003. Estimating Impervious Surface Distribution by Spectral mixture analysis. *Remote Sensing of Environment*, 84(4): 493–505.
- Xiao, H., and Weng, Q., 2007. The Impact of Land Use and Land Cover Changes on Land Surface Temperature in a Karst area of China. *International Journal of Environmental Management* 85:245–257.
- Yang, X., 2002. Using a Time Series of Satellite Imagery to Detect Land Use Land Cover Changes in the Atlanta, Georgia metropolitan area. *International Journal of Remote Sensing* 23: 1775–1798.
- Yang, L., Huang, C., Homer, C. G., Wylie, B. K., and Coan, M. J., 2003. An Approach for Mapping Large Area Impervious Surfaces: Synergistic Use of Landsat-7 ETM+ and High Spatial Resolution Imagery. *Canadian Journal of Remote Sensing*, 29(2): 230–240.
- Yang, X., and Liu, Z., 2005. Use of Satellite Derived Landscape Imperviousness Index to Characterize Urban Spatial Growth. *Computers, Environment and Urban Systems*, 29 (5): 524–540.
- Yeh, A. G.O., Xuequiang. X., and Huaying. H., 1995. The Social Space of Guangzhou City, China, in *Urban Geography*, 16:7.

- Yongnian, Z., Wei, H., Benjamin, F. Z., Honghui, Z., Huimin, L., 2003. Study on the Urban Heat Island Effects and Its Relationship with Surface Biophysical Characteristics Using MODIS Imageries. *Geo-spatial Information Science* 13(1):1-7.
- Yu, X. X., Yang, G. S., 2002. The Advances and Problems of Land Use and Land Cover Change Research in China. *Progress in Geography*, 21(1): 51–57.
- Yuan, F., and Bauer, M. E., 2007. Comparison of Impervious Surface Area and Normalized Difference Vegetation Index as Indicators of Surface Urban Heat Island Effects in Landsat imagery. *Remote Sensing of Environment*, 106(3): 375–386.
- Zemba, A. A., Adebayo A. A., Musa A. A., 2010. Evaluation of the Impact of Urban Expansion on Surface Temperature Variations Using Remote Sensing-GIS Approach.
- Zewde Bahru.,1991. *A History of Modern Ethiopia*. Addis Ababa: Addis Ababa University.
- Zha, Y., Gao, J., and Ni, S., 2003. Use of Normalized Difference Built-up Index in Automatically Mapping Urban Areas from TM imagery. *International Journal of Remote Sensing*, 24(3): 583–594.
- Zhang, Y., Liu, C., Lei, Y., Tang, Y., Yu, Q., Shen, Y., and Sun, H., 2006. An Integrate Algorithm for Estimating Regional Latent Heat Flux and Daily Evapo-Transpiration. *International Journal of Remote Sensing*, 27 (1): 129-152.
- Zhao, M., Pitman, A.J., Chase, T., 2001. The Impact of Land Cover Change on the Atmospheric Circulation. *Clim Dyn*, 17: 467–477.
- Zhao, H. M., and Chen, X. L., 2005. Use of Normalized Difference Bareness Index in Quickly Mapping Bare Areas from TM/ETM+. *Geo-science and Remote Sensing Symposium*, 3(25–29): 1666–1668.
- Zhou, L., Tucker, C.J., Kaufmann, R.K., Slayback, D., Shabanov, N.V., Myneni, R.B., 2001. Variations in Northern Vegetation Activity Inferred from Satellite Data of Vegetation Index During 1981 to 1999. *Journal of Geophysical Research*, 106: 20069–20083.
- Zhou L, Dickinson R, Tian Y, et al., 2004. Evidence for a Significant Urbanization Effect

- on Climate in China [J]. Proceedings of the National Academy of Sciences of the United States of America, 101(26): 9540-9544.
- Zhou, X.L., and Wang, Y.C., 2011. Dynamics of Land Surface Temperature in Response to Land Use Land Cover Change. *Journal of Geographical Research*, 49(1):23–36 doi: 10.1111/j.1745-5871.2010.00686.x.
- Zubair, A. O., 2006. Change Detection in Land Use and Land Cover using Remote Sensing Data and GIS (A case study of Ilorin and its environs in Kwara State), Msc Thesis, University of Ibadan, Nigeria.

# Appendices

## I. Guideline for Key Informants

Kifele Ketema \_\_\_\_\_ Woreda \_\_\_\_\_

Name of the Respondent \_\_\_\_\_ Occupation \_\_\_\_\_

Position if any \_\_\_\_\_

Age \_\_\_\_\_ Sex \_\_\_\_\_ Marital Status \_\_\_\_\_ Religion \_\_\_\_\_

Level of Education \_\_\_\_\_

1. What does the term land use land cover change mean to you? Would you say that urban land use land cover change has taken place in city over the last 20- 30 years? If so, what would be some characteristics of changes as far as you are concerned
2. If changes were recognized, which land cover has been made susceptible and why?
3. What are the major drivers for land use land cover change in city?
4. What are the major consequences of land use land cover change?
5. Discuss the impact of urban land use land cover change on social, economic and environment.
6. What change have you observed in temperature when land use land covers changes?
7. Which land use land cover change is highly susceptible to land surface temperature change in the city?
8. Why urban land use land cover change subject to change in temperature? Mention the possible reasons?

9. What do you think about the possible solution to alleviate the current problem of temperature increase which leads to local climate change?
10. What do you think about the possible solution to alleviate the current problem of Land use land cover change?
11. What are the development institutions / organizations available in the area? Which are in support the land administration?
12. Is there any policy and direction in relation to land use land cover?
13. Which strategies the Municipality should adopt in order to contain urban sprawl and densification to achieve a more sustainable city in its Comprehensive Plan?
14. In what measures do you think the Municipality of Addis Ababa is influenced by the stakeholders, investors and citizens in the decision making process of the urban planning strategy?

\*These questions were used in the interviews with key informants from community, kebele administration and relevant sectorial offices of the City administration including Addis Ababa, Urban Planning and Information Agency, Land development Agency, EPA and other stakeholders. Each interview has been unique with each respondent answering the question in a different way and also these questions tailored during each interview according informants. Probing was important in exploring further deep in to ideas of people.

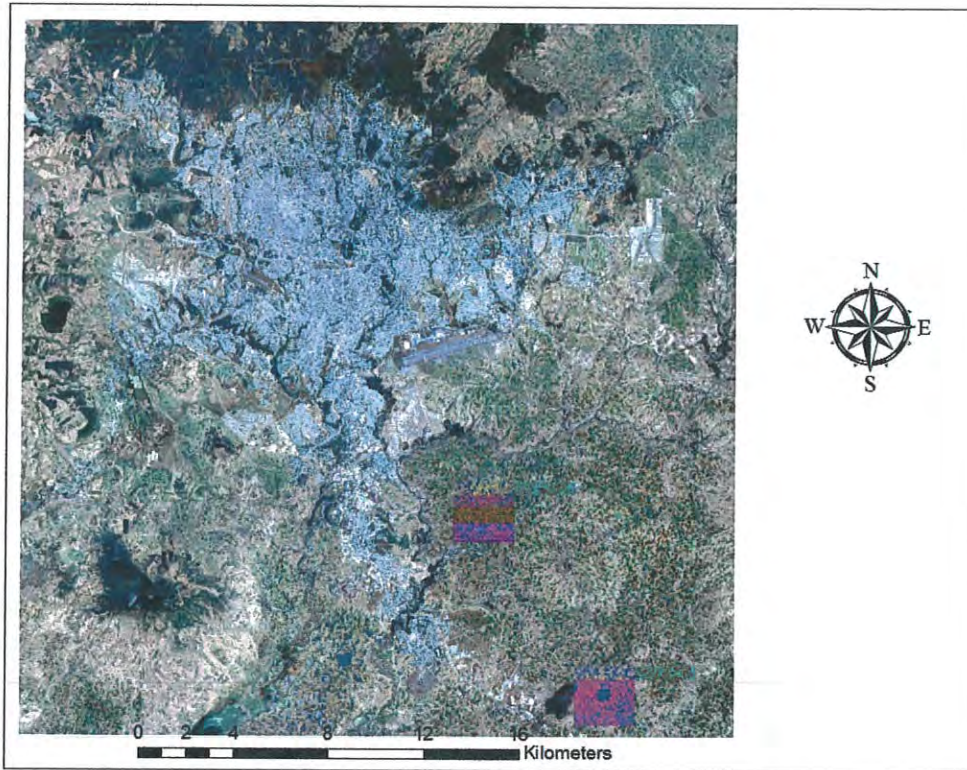


## **2. Guideline for Focus group Discussion**

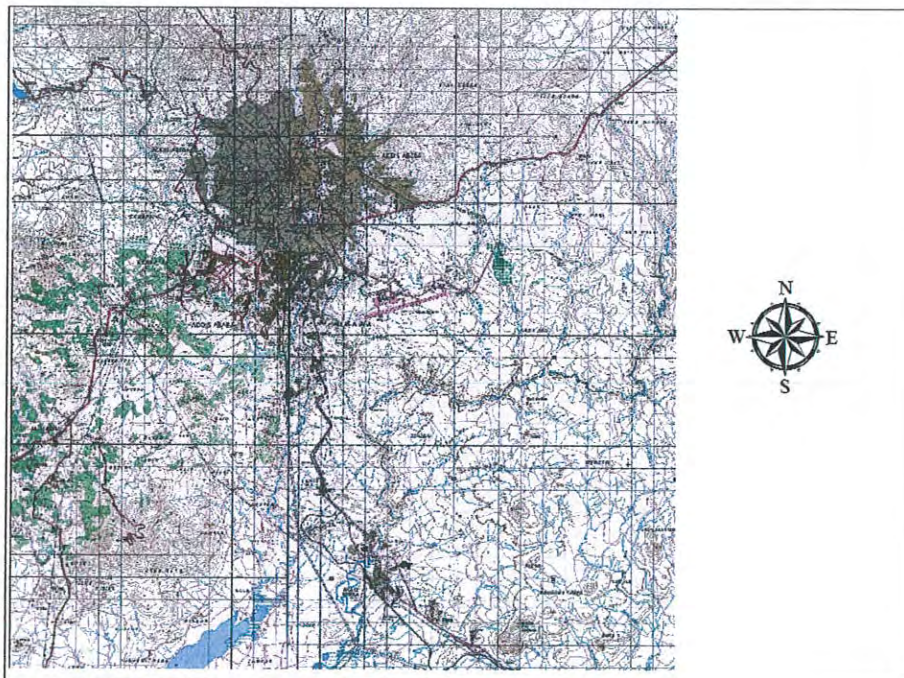
Warm-up: List the main land use land covers, changes and causes in your area.

1. Discuss on trends and patterns of land use land cover change compared to the conditions before 1986 and after 1986?
2. Discuss on the factors that contribute to urban land use land cover change (urban expansion and urban densification) to your area and level of the community's participation in the planning and implementation of the urban land use plan.
3. Discuss the impact of urban land use land cover change on urban climate in general and on land surface temperature in particular.
4. Discuss on the possible reasons behind urban land use land cover change that is subject to change in temperature.
5. Discuss on the possible solution to alleviate the current problem of temperature increase which leads to local climate change?
6. Discuss on which strategies and policies the Municipality should adopt in its comprehensive plan in order to hold urban sprawl and densification to achieve a more sustainable city.
7. Discuss on the responsibility and participation of the community to contain the impact of LULCC.

### 3. Spot-5 Image of Addis Ababa



### 4. Mosaic Topographic Map of the study area and surroundings



### 5. Google Earth high resolution image of Addis Ababa

