

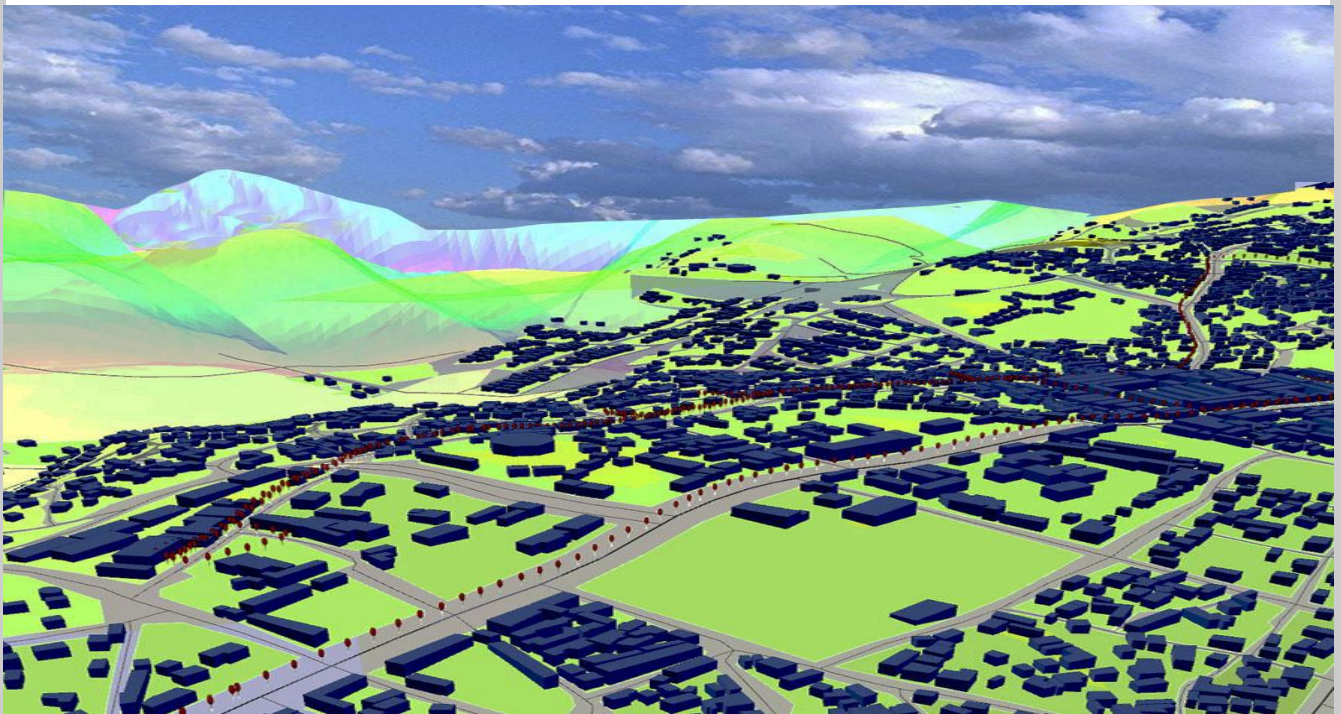
ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
FACULTY OF SCIENCE, SCHOOL OF EARTH AND PLANETARY SCIENCE

Addis Ababa
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**ANALYSIS OF URBAN GROWTH AND SPRAWL MAPPING USING REMOTE
SENSING AND GEOGRAPHIC INFORMATION SYSTEM**

(CASE STUDY OF DEBRE BIRHAN TOWN)



**A THESIS SUBMITTED TO SCHOOL OF GRADUATE STUDIES OF ADDIS
ABABA UNIVERSITY, IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR
THE DEGREE OF MASTER OF SCIENCE IN REMOTE SENSING AND
GEOGRAPHIC INFORMATION SYSTEM**

BY

ZEWDU ALEBACHEW

JUNE 2011

**ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
FACULTY OF SCIENCE, SCHOOL OF EARTH AND PLANETARY SCIENCE**

**URBAN SPRAWL MAPPING AND LAND USE CHANGE ANALYSIS USING
REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM
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BY: ZEWDU ALEBACHEW ABEBE

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**A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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SYSTEM AND REMOTE SENSING**

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DECLARATION OF ORIGINALITY

The work has not previously been submitted in any form to the Addis Ababa University or to any other institutions. This thesis is a presentation of my original research work. Wherever contributions of others are involved, every effort is made to indicate this clearly, with due reference to the literature, and acknowledgement of collaborative research and discussions.

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This is an original work by Zewdu Alebachew under my supervision.

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Abstract

This study focused on the use of Remote Sensing and Geographic Information System in mapping of urban growth and sprawl a case study of Debre Birhan town. A high spatial resolution of Ikonos image and topographic map were used to study urban sprawl at housing level between 1995-2008. Landsat (TM) satellite images for year 1986 and Landsat (ETM+) for the years 2000 and 2005 have been utilized to quantify the land-use /land-cover changes and the trend of urban growth. From the Land-use/land-cover maps, the built-up structures growth was 131% between 1986 and 2000, and 89.7% between 2000 and 2005. Annually the growth rate of built-up area for these study years was 9.38% and 17.94% respectively. The land-use/land-cover change statistics showed that the annual conversion rate of agricultural land and bare soil to built-up area between 2000 and 2005 accounts more than 50%. The Getis-Ord G_i^* hotspot analysis toolsets of ArcGIS 10 was used for the analysis of spatial clusters and hot spot analysis of building footprints. Weighted Overlay Analysis using multicriteria decision technique is implemented to produce the urban sprawl expansion map of the area. The validation based on of Ikonos image 2008 revealed that the result is in good conformity with the model of suitability map. Generally, the visual comparison of land-cover 2005 and Ikonos image 2008 indicated that all agricultural land and grass land are under the influence of urban expansion.

Key words: Remote sensing-GIS integration, urban growth, Land-cover change

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LISTS OF ABBREVIATIONS

CSA	Central Statistics Agency
DEM	Digital Elevation Model
ENVI	Environmental for Visualizing Images
ERDAS	Earth Resource Data Analysis System
ESRI	Environmental Systems Research Institute
ETM	Enhanced Thematic map per
FAO	Food and Agricultural Organization
GIS	Geographical Information System
GPS	Global Positioning System
SRTM	Shuttle Radar Topography Mission
TM	Thematic Mapper

INTRODUCTION

1.1. Background of the Study

Several studies show that urbanization is increasing in both the developed and developing countries. However, rapid urbanization is a characteristic of developing countries due to high population growth. Studies show that the expansion of cities and towns, and the associated problems of unemployment, poverty, inadequate health, poor sanitation, urban slums and environmental degradation create unmanageable challenge in many developing countries.

Unchecked urbanization is often referred as sprawl which poses serious problems in infrastructure planning and implementation that leads to unforeseen consequences. Although both developing countries and developed countries have common urbanization processes, formerly the problem of urban sprawl was restricted to developed countries. The reason for urban sprawl for developed countries was mainly a result of higher incomes that make people preferring to live in the outskirts of the city, with open spaces at reasonable distances from cities. For developing countries sprawl is largely a result of necessity- people move to the city in search of better employment and opportunity which leads to an increase in size well beyond the limits of the city (Haregewoin, 2005).

Due to the dynamic urban growth trends, town administrations and planners are faced with difficulties to supply basic amenities like sanitation, treated water supply, primary health center, etc., as planners were unable to visualize such growth during planning, policy and decision-making. These difficulties are caused by spontaneously construction of unplanned informal houses in and beyond the administrative boundaries of towns and cities. Moreover, the implications of these profound changes cause a change in landuse patterns. Such highly dynamic urban growth makes urgent town planning inevitable.

Maintaining up-to-date urban land cover information is both costly and time-consuming using traditional field and air photo methods. Remote sensing technology provides an efficient and less-expensive way for urban growth mapping (Hu, 2010).

Therefore, the focus of this study is to prepare historical Land-use /land-cover maps from Landsat archive images, analyzing the urban land cover change statistics, extracting GIS vector data from high resolution image and topographic map, analyzing the residential house pattern and sprawl, and finally mapping the physical landscape suitability for future urban expansion.

1.2. Statement of the Problem

Ethiopia as many of the developing countries has a problem with the unplanned urban expansion and residential houses sprawl in many of its towns and cities. Therefore, there is a need for, mapping, analyzing and continuously monitoring of the phenomena of urban growth patterns because it is the responsibility of urban administrators, and planners to give the entire infrastructure and service facilities in a complex urban area. The conventional method of mapping urban growth is the use of ground survey and aerial photographs which is costly and slow process to get the necessary information such as the direction where urban growth occurs and the level of services needed on the new developmental sites.

Debre Birhan is one of the towns of Ethiopia in which various changes have been occurring for more than 5 centuries. The town has no regularly updated maps to indicate those urban growth changes. Although the town doesn't have a detailed updated map, a regularly updated map with an acceptable resolution can at least give an impression about the physical changes and growth rate of the urban area of the town. Therefore, Satellite and GIS technologies can help the urban planners and engineers as an alternative means of rapidly assessing the dynamic urban expansion of the town.

In this research, it was intended to study the urban growth and the degree of sprawl that occurs in Debre Birhan town comparing the land use changes occurred for the study years 1986, 2000, 2005 and distribution of residential houses between 1995 and 2008. For this purpose, first multi-temporal Remote Sensing and GIS data sets were used to map the urban land use changes, because one of the prerequisite for understanding urban sprawl is successful land use change detection. To work out the change detection Landsat satellite imageries of three time period were used. Secondly high resolution satellite image and

topographic map were used to quantify and analyze the urban sprawl that might occur in the town. Finally, the future urban lands that would be used for urban expansion will be predicted by combining suitability factors and constraints. The suitability model will predicts the possibility of land use conversion for future urban sprawl.

1.3. Objectives

1.1.1. Main objectives

- To investigate the basic urban land-use/ land-cover changes and patterns of urban sprawl over the study area based on the analysis of high and medium resolution satellite images and ancillary data.
- To suggest suitable planning measures to counter the undesirable consequences of urban sprawl on the town' sustainable development

1.1.2. Specific Objectives

- To assess the urban growth in 23 years (1986-2008)
- To assess the spread/sprawl of residential houses
- To examine impacts of land-use/land-cover change on urban environment
- To study the land requirement for urban expansion using GIS based Multi-Criteria Evaluation.

1.4. Research Questions

The study is guided by two research hypothesis:

- Did urban sprawl takes place in the study area based on characteristics of urban growth and population growth? The population of Debre Birhan town is increasing roughly by 2 times by the year 2007(65214) from the 1994(38717) census. This indicated that the study area has undergone a tremendous change in urban growth during the study period.
- Is GIS and Remote Sensing used to investigate the urban land-use/land-cover change and urban sprawl on the study area? There was no study made on the urban sprawl and land use changes on the study area, therefore, this study uses GIS and Remote sensing techniques to study the change in land-cover/land-use and housing sprawl.

1.5. Significance of the Study

One of the major impacts of urban sprawl is a shrinking amount of cultivated land through the development of infrastructures and various development projects. Therefore, residential sprawl and land-use/land-cover change studies are important tools for urban or regional planners and decision makers to consider the impacts that can occur on sustainable urban development of the study area. The results of this study would provide information relevant to contribute in the environmental management plans and urban planning processes. Generally, the study after the completion of the research will have the following significances:

It will help the concerned bodies understand the sprawl/scatter development of residential houses and the rate of continuous land-use/ land-cover change in the study area. This may provide some idea to find appropriate solutions for scattering or non regulated urban housing sprawl and problems of unwise use of land resources.

- It will provide local engineers, urban planners and policy makers with the necessary information to depend on
- It will serve as an input for further studies

1.6. The Scope of the Study

Currently, most of the towns of the country have little attention in terms of physical expansion and dynamic population growth which create a burden on basic supply of public services and infrastructural developments. Given the fact of current and future unmanageable urban growth problems, there is a need of decision making and planning to maintain at least some control of urban expansion. This is not possible without up-to-date information about various aspects in the urban areas. Remote sensing and GIS techniques can help to get up-to-date information of the urban expansion with frequent coverage and low cost. Therefore, this research will investigate the rate of land use/ land-cover change that occur in the study area over those 19 years (1986 to 2005). Similarly, it was intended to investigate the level of urban sprawl in the study area between 1995 and 2005. The study also includes urban expansion suitability map to identify the most probably growth area of urban development in the future.

LITERATURE REVIEW

2.1. Urbanization, urban growth and Land Use/Land Cover Changes

Although urban growth is a common phenomenon almost in all countries in the world, currently, the rapid urban growth and the associated urban land cover changes caused by rapid population growth are a characteristic of cities and towns of developing countries.

According to the United Nations, it is predicted that by 2030, the number of city dwellers will reach 60% of the world's population. This urban population growth will be most significant in low income countries, notably in Africa and Asia. Among African countries, East Africa will experience urban population growth rates significantly higher than the African average. In descending order, Addis Ababa, Nairobi, Dares Salaam, Antananarivo, Kampala and Mogadishu will remain the region's largest cities in the foreseeable future. Comparing to the world cities, Dare Salaam, Kampala, Nairobi, Antananarivo and Addis Ababa already rank among the 31 fastest growing cities. (UN-HABITAT, 2008)

UN-HABITAT (2010) stated that the uncontrolled physical expansion of cities and towns in developing country create an impact on urban environment and economy. This unplanned and uncontrolled development makes provision of housing, roads, water supply, sewers and other public services too expensive. The other impact mentioned on the report was the loss of agricultural land as most cities and towns built on productive agricultural land.

In contrast to urban growth in developed country which is characterized by industrialization, the urbanization process in many developing countries is characterized by demographic changes such as, rapid natural population growth and rural-urban migration. This type of rapid urban growth make specially poor African countries incapable of supplying services such as land allocation and infrastructure(Haregewoin ,2005).

This rapid urban growth rate is attributed to population growth in urban residents and rural urban migration. The high population growth which does not match with the socio-economic growth and infrastructure service requirement creates high demand for housing which leads to unplanned and uncontrolled horizontal expansion and contributes to urban land use changes. The extent of urbanization or the sprawl is one such phenomenon that

drives the change in urban land use patterns. These changes caused by anthropogenic activities on land are a result of rapid urbanization and industrialization.

Remote sensing and Geographic Information Science (GIS) technologies have been utilized to detect and quantify changes in the landscape and the consequential environmental impacts. In modern times, several studies have utilized remote sensing data to examine urban land changes of different patterns of urban expansion and development (Longley *et al* 2005).

2.1.1. Urban Sprawl Definition and Patterns

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

Urban sprawl is an extent of urbanization mainly caused by population growth and large scale migration (Sudhira, *et al* 2004). But urban sprawl is not to be considered as increase of urban lands in a given area. Urban sprawl is a scatter development which is mainly unplanned and uncontrolled. Glaster, *et al* (2007), describes urban sprawl as one of the dimensions of land use patterns such as low density, continuity, concentration, nuclearity, diversity, proximity and centrality, decentralization from of urban core to the periphery.

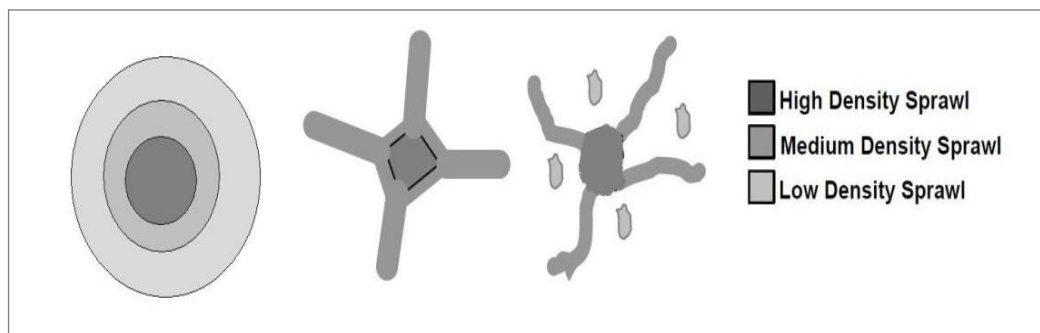
Urban growth takes place either in radial direction around the core of the city/town or linearly along the highways. The form of development along highways, or surrounding the city and in rural countryside is often referred as urban sprawl (Theobald, 2001).

The spatial development of urban sprawl can be divided in to three basic forms (Barnes *et al.*, 2001)

- **Low density sprawl:** This type of sprawl is characteristic by exploitative use of land for housing purpose along the margins of existing urban areas. This type of expansion is always supported by services like water, power and roads.
- **Ribbon sprawl:** The development of this type of sprawl is following major road corridors outward from the urban centers. Lands adjacent to the major roads and

highway are developed but lands with some distant from the roads and highway remain undeveloped.

- Leapfrog Sprawl: This development of sprawl is sporadic or an irregular pattern which consists of patches of developed land that is widely separated. It is more expensive to give services such as water, power and roads for this form of development.



Radial Sprawl

Ribbon Sprawl

Leapfrog Sprawl

Figure 2. 1: Forms of sprawl

(Adapted from Sudhira, 2004))

2.1.2. Cause of urban sprawl

In developing country, population growth is considered as the main causes of urban sprawl. From an economist point of view, as population raises in an urban area it becomes more difficult to locate the same percentage of residential houses and business activity if the urban boundaries remain fixed. In addition, higher income residents generally demand larger quantities of housing and the inexpensive land to build it on is more likely on the fringe of developed urban areas (Ewing, 1997).

Another cause of urban sprawl to occur as stated by UN-Habitat (2010) report was because authorities pay little attention to slums, land, services and transport. Moreover, they lack the ability to predict urban growth and, as a result, fail to provide land for the urbanizing poor. In addition, the urban poor are denied land rights which are one of the main factors driving people to the periphery of towns, associated with urban sprawl in developing countries.

In developing country the causes of urbanization are twofold: people migrate from rural areas to cities for employment opportunities, and fertility rates of the people already living there are high.

There is a critical key difference between urban sprawl development in developed and developing countries. In developed countries, people do not want to live in the cities and they choose to move out. However, in developing countries, people move out because there is not enough space for them to live in the city (Haregewoin, 2005). The movement of the people from the city center to the sub urban part due to lack of space results spread of development without sufficient infrastructural provision. This pattern of development crates problems such as the wastage of agricultural land become a burden for service provision.

Currently, the high population growth in cities is seen to create pressure and competition for land related resources, which has also caused upward pressure on land values, particularly in sub-urban areas. Clearly, not enough attention is paid to developing solutions to the expansion of cities in sub-urban areas and the challenge this is causing in regard to the delivery of sustainable land management, services and governance (UN-Habitat (2010).

In many African cities the urban land market is skewed against the poor. The rising costs of urban land and other factors prevent poor people and other vulnerable and disadvantaged groups from gaining access to suitable land, which does not pose economic, environmental or health risks to the residents (UN-Habitat 2010).

Another cause for urban sprawl is lack of clear regulation mechanism of the new development in sub urban area. The majority of local land use regulation is accomplished with zoning. The goal of zoning land is to regulate the use and intensity of development such as housing type and density. Although technical in their implementation, zoning regulations are often a community's expression of the unwritten rules of social order (Harris, 2002).

Urban zoning is a device of land-use planning used by local government. Zoning regulations can restrict the supply of land available for development operates to increase land prices. This can be useful to maintain environmental quality open space or agricultural use, for commercial or industrial activities.

However, absence of strict zoning regulations leads to rich men to buy a land on sub-urban area and to build houses for rental purposes. This provides cheap accommodation for other

low-income resident or migrants who lack the means of constructing their own house. However, unregulated development is always aggravating scatter development.

2.1.3. Consequences of Urban Sprawl

Myers & Kitsuse, (1999) point out that “accelerated urban sprawl has an enormous environmental, social, and economic costs”, these include:

- Loss of agricultural land and destruction of unique and sensitive environmental areas
- Poor air quality
- Over drafting of water supply
- Decline of central city neighborhoods and older suburbs due to disinvestment, as people and dollars flow to new suburbs
- Decline of farm communities
- Diminished capacity to attract and retain business in the state due to deterioration in quality of life
- The cost of building and maintaining new suburban infrastructure become high
- Underutilized or abandoned investments in older neighborhoods

The UN-Habitat report says, urban sprawl has a negative impact on infrastructure and the sustainability of cities. In most cases, sprawl translates to an increase in the cost of transport, public infrastructure and of residential and commercial development. Moreover, sprawling metropolitan areas require more energy, metal, concrete and asphalt than do compact cities because homes, offices and utilities are set farther apart (UN-Habitat, 2010).

In recent years the fiscal problems of many municipal governments have rapidly increased. The large investments in road, water and sewerage and other public services made in the last decade in many countries often comes from encouragement and financial assistance of the major international development donor agencies. The external aid helped to provide the initial capitalization for these extensive projects, but left the problem of their maintenance and repair to local governments. As time has passed, the costs of maintenance have increased, forcing the government units responsible to search for new sources of revenue (Dobele, 1984).

2.2. GIS and Remote Sensing in Urban Growth Studies

2.2.1. Remote Sensing

In broad terms remote sensing is the field of study associated with extracting information about an object without coming into physical contact. Schowengerdit (2007) defined Remote sensing as the measurement of object properties on the earth's surface using data acquired from aircraft and satellites.

Although the earth is the most frequent target in remote sensing study, the science of remote sensing in its broadest sense includes aerial, satellite, and spacecraft observations of the surfaces and atmospheres of the planets in our solar system (Smith, 2006).

The modern era of earth remote sensing from satellites began when the Landsat Multispectral Scanner System (MSS) provided, for the first time, in 1972. Currently, the available remotely sensed images, ranges from high resolution panchromatic images provided by IKONOS (1m) to medium-resolution panchromatic images provided by SPOT (10m) and the 15-m low-resolution panchromatic images by Landsat 7. These satellites have become one of the most important sources of spatial data used in the GIS community.

The most common application of remotely-sensed images is to produce a land-use/land-cover map. The basic ideas are that the spectral characteristic in a multi-band image can separate different land- use/land-covers. Land-use/land-cover can be classified in many ways, depending on the needs. The most widely used satellite image for land-cover/land change analysis is Landsat images due to the existence of historical archives.

In a given area, land-use/land-cover change may result in environmental, social and economic impacts of greater damage than benefit to the area (Mohsen, 1999). Therefore data derived from satellite images on land-use/land-cover change are of great importance to planners in monitoring the consequences of changes that could occur on a given place.

Although urban monitoring and modeling applications usually rely on extensive historic archives of land-use/land-cover maps, most remote sensing research in urban environments tends to focus on high resolution satellite imagery. High resolution images such as Ikonos include a large variety of regions occurring in complex configurations that are challenging to interpret with low resolution image such as Landsat images.

2.2.2. Geographic Information System

Different types of GIS definitions exist in different areas and disciplines. But all GIS definitions recognize the use of spatial data. Many alternative definitions of GIS have been suggested, but a simple definition is that a GIS is a computer-based system for the capture, storage, retrieval, analysis and display of spatial data.

"A geographic information system (GIS) is a computer-based tool for mapping and analyzing things that exist and events that happen on earth. GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps.

["http://www.gis.com/content/what-gis](http://www.gis.com/content/what-gis)

What differentiated GIS from other spatially related systems is by its analytical capacity and possible operations on the spatial data (Skidmore, 2002).

Currently, the GIS field is characterized by a great diversity of applications including, agriculture, computer science, medicines, mathematics, surveying, statistics cartography, geology, geography, etc. GIS works with many types of data. The spatial data in GIS databases are predominately generated from remote sensing through the direct import of images and classified images, but also through the generation of conventional maps (e.g. topographic maps) using photogrammetry. Today, remote sensing is an integral part of GIS. Remote sensing data, such as satellite images and aerial photos allow us to map the variation in terrain properties, such as vegetation, water, and geology, both in space and time. Satellite images give a synoptic overview and provide very useful environmental information for a wide range of scales, from entire continents to details of a meter (Longley, *et al.*, 2005).

2.2.3. GIS based urban growth and sprawl metrics

The use of Geographic Information Systems has become quite prevalent within the field of urban sprawl research. Progress in modern Remote Sensing and Geographic Information Systems allow us to collect a lot of physical data with relatively low cost and high speed and on repetitive basis than the traditional ground surveying method. The remote sensing data together with GIS helps us to analyze the data spatially and very important to make reasonable urban planning and land use management.

Therefore, it is ideal to use a tool such as a GIS as part of research on urban sprawl because of its capacity to handle many different types of spatial data. Several spatial and non spatial techniques of estimating the urban sprawl level exist. However, all techniques used are subjective and in debate.

Galster and Cutsinger (2007) examined six different measures of urban sprawl development:

- 1 Density:- the average number of residential units per square mile
- 2 Concentration:-the degree to which development is located within a relatively few square miles of the urbanized area
- 3 Compactness:- the degree to which development has been clustered;
- 4 Centrality:- the degree to which development is located close to the central business district;
- 5 Nuclearity:- the extent to which an urbanized area is characterized by a single center of development;
- 6 Proximity of land uses: - the degree to which different land uses is close to one another.

The above mentioned measure of urban sprawl is summarized by Ewing, *et al.*, 2002 in to four factor of sprawl Index which each of these factors is in turn composed of several measurable components, a total of 22 in all:

- 1 Residential density;
- 2 Neighborhood mix of homes, jobs, and services;
- 3 Strength of activity centers and downtowns;
- 4 Accessibility of the street network.

2.2.3.1. Measuring urban sprawl with density

Many researchers agreed that, urban density is universally accepted components of urban sprawl. However, there is a debate which variable is best to use in representing density, the density level at which a city can be regarded as sprawling, the scale at which density should be measured and the extent of the space over which density should be characterized (Alberti and Torrens, 2000).

Concerning the scale to be used to calculate density, different form of urban density measurement is available. The some type of density that is commonly used includes:

- 1 The gross density: The calculation is based on the total area of to the city/town understudy.
- 2 Net density: a density figure for a given area of land that excludes land not directly related to the figure
- 3 Floor-to-area ratio: The Floor Area Ratio or Floor Space Index is the ratio of the total floor area of buildings on a certain location to the size of the land of that location.
- 4 Residential density: the number of dwelling units in any given area.
- 5 Population density: Population density is a measurement of population per unit area or unit volume. http://www.absoluteastronomy.com/topics/Urban_density

Density varies greatly depending on the base land area used in the density calculation. The parcel or site density is almost always higher than the neighborhood density, because at a neighborhood scale much land is included in the base land area calculation that does not have houses (Forsyth, 2003).

The gross density is calculated by considering the total area of the city or a town including open spaces and sometimes non habitable area. The argument behind this calculation is the different use of the base area calculation where more and more nonresidential uses added into the calculation considered. The difference between these numbers is that as the base land area being considered increases there are more and more nonresidential uses added into the calculation (Forsyth, 2003).

Table 2. 1: Base area type in the same location and density measurement difference.

Dus=Dwelling Units	
Density type	Measurement
Site density	10 DUs per acre
Block density	8 DUs per acre
Net residential density	10 DUs per acre
Net neighborhood density	6 DUs per acre
Gross neighborhood density	5 DUs per acre
City density	4 DUs per acre
Metropolitan density	3 DUs per acre

(Adopted from Forsyth, 2003)

Density, measures overall activity intensity in urban area and is the most commonly used variable in characterizing urban form as well as intensity-based compactness/sprawl although density by itself, does not address the pattern of activity distribution (Tsai, 2005).

2.2.3.2. Measuring sprawl with spatial statistics

Geographic information systems (GIS) and the underlying geographic information science that advances these technologies have a strong influence on spatial statistics. Classic spatial autocorrelation statistics include Moran's I and Geary's C.

The classic spatial autocorrelation is related to Tobler's first law of geography". Waldo Tobler, a Swiss-American geographer and cartographer, stated "first law of geography" in 1970. Tobler's first law of geography states: "everything is related to everything else, but near things are more related than distant things". In recent years it has become even popular and important in geography and GIS science which is the basis of spatial auto-corelation and geo-statstics (Irwin et al., 2006). Spatial autocorralation refers to a geographical dependence structure for observations. The term "correlation" refers to a relationship between entities, and "auto" refers to the fact that a single variable is being related to itself (Griffith, 1984).

The importance of housing to both the ecological and social sciences has focused increasing attention on the spatial patterns of housing growth. Furthermore, because housing growth is not a spatially random process, understanding its patterns requires a spatially explicit view (Rutledge et al., 2001).

In spatial data analysis, especially in order to get additional hints for the existence of urban sprawl, it is necessary to determine whether or not an identifiable spatial pattern exists. Currently, new measures of local and global spatial statistics have been developed.

The Global Moran I Spatial autocorrelation is used to identify the overall patterns or trends of spatial data. It works by comparing the feature locations or attributes to a theoretical random distribution in order to determine if they have statistically significant clustering or dispersion. Global Moran's I tool in desktop ArcGIS software can be used to calculate the overall pattern of data to indicate clustering or positive spatial autocorrelation if high values cluster together, and/or if low values cluster together. Similarly, Global Moran I statistics the High/Low Clustering (Getis-Ord General G) tool assess the overall pattern and trend of spatial data. Global spatial statistics, including the High/Low Clustering tool, are most effective when the spatial processes being measured are consistent across the study area (ESRI, 2010).

The Local Moran I pattern analysis and Local statistics tools (like Hot Spot Analysis) assess each feature within the context of neighboring feature. Local analysis is based on the Local Moran statistic visualized in the form of significance and cluster maps (Anselin 1995). Spatial autocorrelation index such as Moran's I and Geary's C requires measuring a spatial weights matrix that defines a local neighborhood around each geographic unit. The value at each unit is compared with the weighted average of the values of its neighbors. A weights file identifies the neighbors. Weights can be constructed based on spatial relationship of objects such as contiguity to the polygon boundary (shape) files, or calculated from the distance between points (points in a point shape file or centroids of polygons).

Some of the most common spatial relationship of features includes:

- Inverse distance: The impact of one feature on another decrease with distance
- Fixed band distance: Everything with specified critical distance is included in the analysis, everything outside the critical distance is excluded.
- Polygon contiguity: The neighbor of each feature is only those neighbors which share a boundary.

A. Local Getis Ord G^*

Hot Spot Analysis (Getis-Ord G_i^*) (Spatial Statistics) identifies statistically significant spatial clusters of high values (hot spots) and low values (cold spots). It creates a new output feature class with a z-score and p-value for each feature in the input feature class. At the same time, it returns the z-score and p-value field names as derived output values for potential use in custom models and scripts. The z-scores and p-values are measures of statistical significance which indicates whether or not to reject the null hypothesis, feature by feature. In effect, they indicate whether the observed spatial clustering of high or low values is more pronounced than one would expect in a random distribution of those same values. A high z-score and small p-value for a feature indicates a spatial clustering of high values. A low negative z-score and small p-value indicates a spatial clustering of low values. The higher (or lower) the z-score, the more intense the clustering and a z-score near zero indicates no apparent spatial clustering (ESRI, 2010).

2.3. Related Works

Today the use of modern Remote Sensing and Geographic Information Systems techniques has significant success in monitoring and managing urban land-use/land cover changes and to measure the degree of urban sprawl. A number of urban sprawl- related studies were conducted using GIS and Remote Sensing. For example, Yeh and Li (2001) used remotely sensed data to measure and monitor the degree of urban sprawl for cities and towns in China. Sudhira et al. (2003) integrated IRS 1C and LISS satellite imagery product with Survey of India (SOI) topo-sheets to develop temporal metrics of sprawl in Karnataka, Mangalore and Udupi region in India. Gu(2006) used Spatial Analysis and Spatial Statistics tools to analyze urban growth patterns in Alachua County, Fla.

There are many examples of related works that can be mentioned. However, it is important to understand that the accuracy of the techniques used to measure urban sprawl largely depend on the input data used and the scale. In this thesis, housing density and GIS based spatial statistics techniques will be used to measure urban sprawl.

DESCRIPTION OF THE STUDY AREA

3.1. Location

Debre Birhan town is the capital of North Shoa Zone and is located 130 km North East of Addis Ababa city. The town was established during the regime of Atse Zara Yakob in 1454 which is 4 centuries older than Addis Ababa City (1889).

The study area covers 181 km² (Figure 3.1) and lies between UTM Zone 37, 552083, 563954 Easting and 1064175, 1075864 Northing and has an average elevation of 2750m meters above sea level.

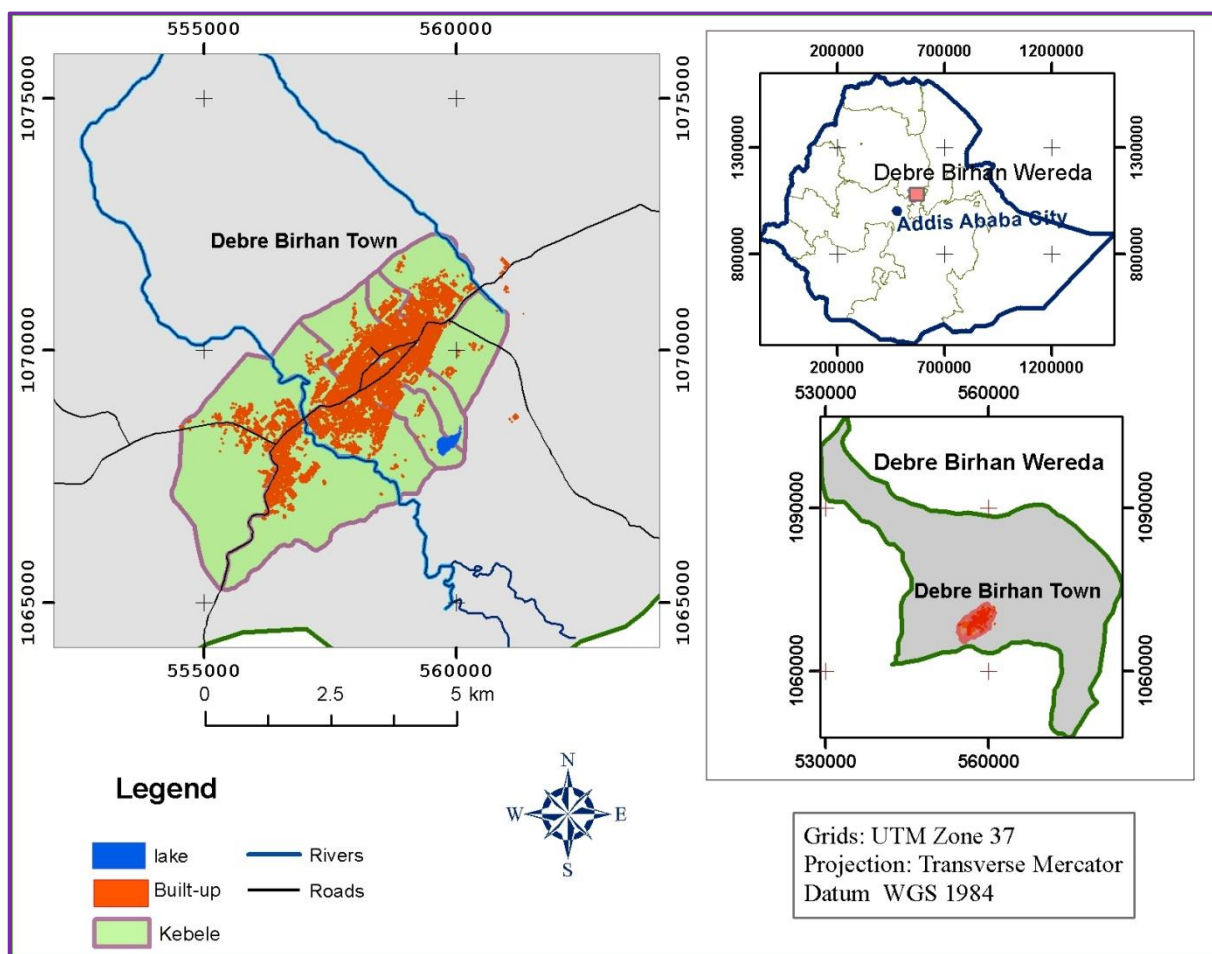


Figure 3. 1: Location Map of the study area

3.2. Topography

Based on the local topographic characteristic (the difference between highest and lowest elevation) of the study area, the major landform elements were mapped using SRTM 30m DEM. The major land form components of the study area include plateau, valley, and some undulating hills and mountains.

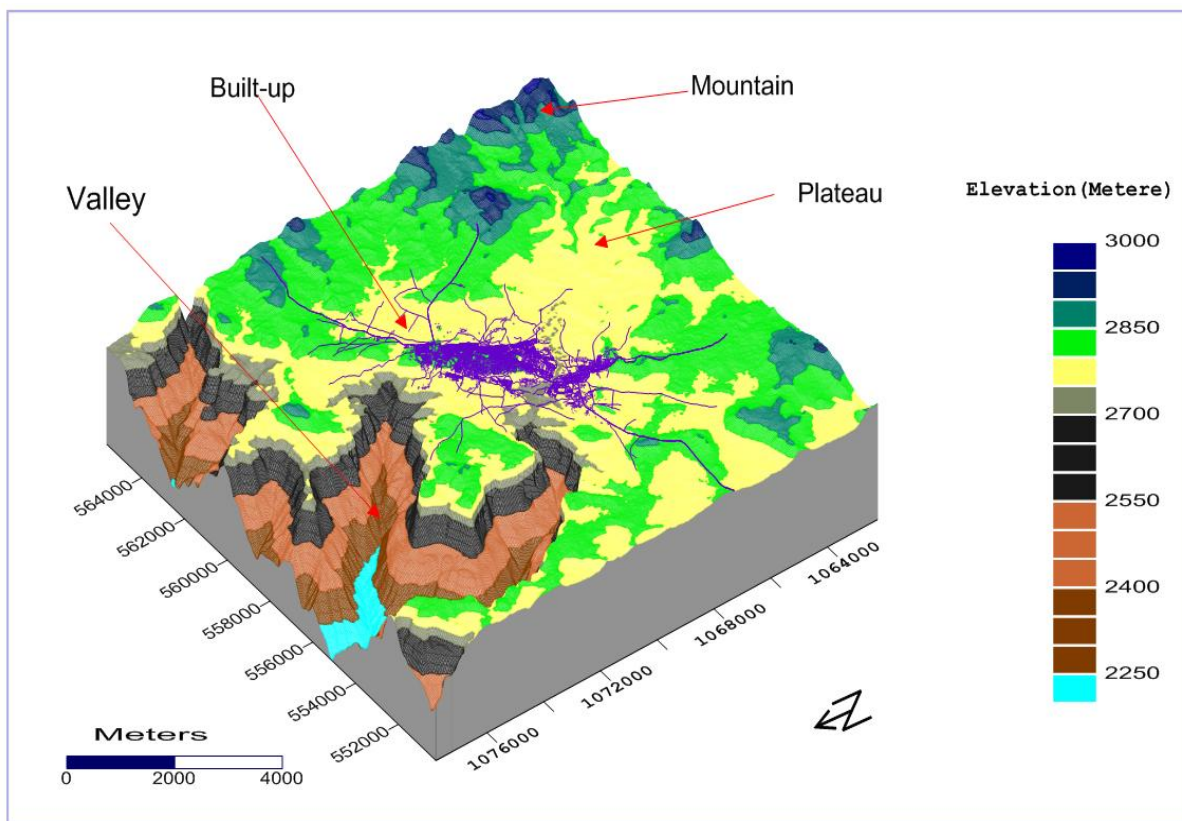


Figure 3. 2: General topography of the study area

3.2.1. Plateau

The study area lies on an extensive upland region at high elevation ranging from 2050m and 2850m a.s.l. The plateau area (Figure 3.2) is surrounded by escarpments, undulating ridge chains and deeply dissected valleys. Studies show that the flat lying topography (plateau) is mostly represented by the Tertiary basalts and Quaternary sediments and some irregular small hills formed by trachyte and erosion remnant of ignimbrites (Daniel,*et al.*, 2010).

3.2.2. Valleys/gorges

Most of the northern and north western part of the study area is characterized by valley depression (Figure 3.3) which is not far from the town. The part of the Jama canyon is one of the known dissected valleys in the study area.

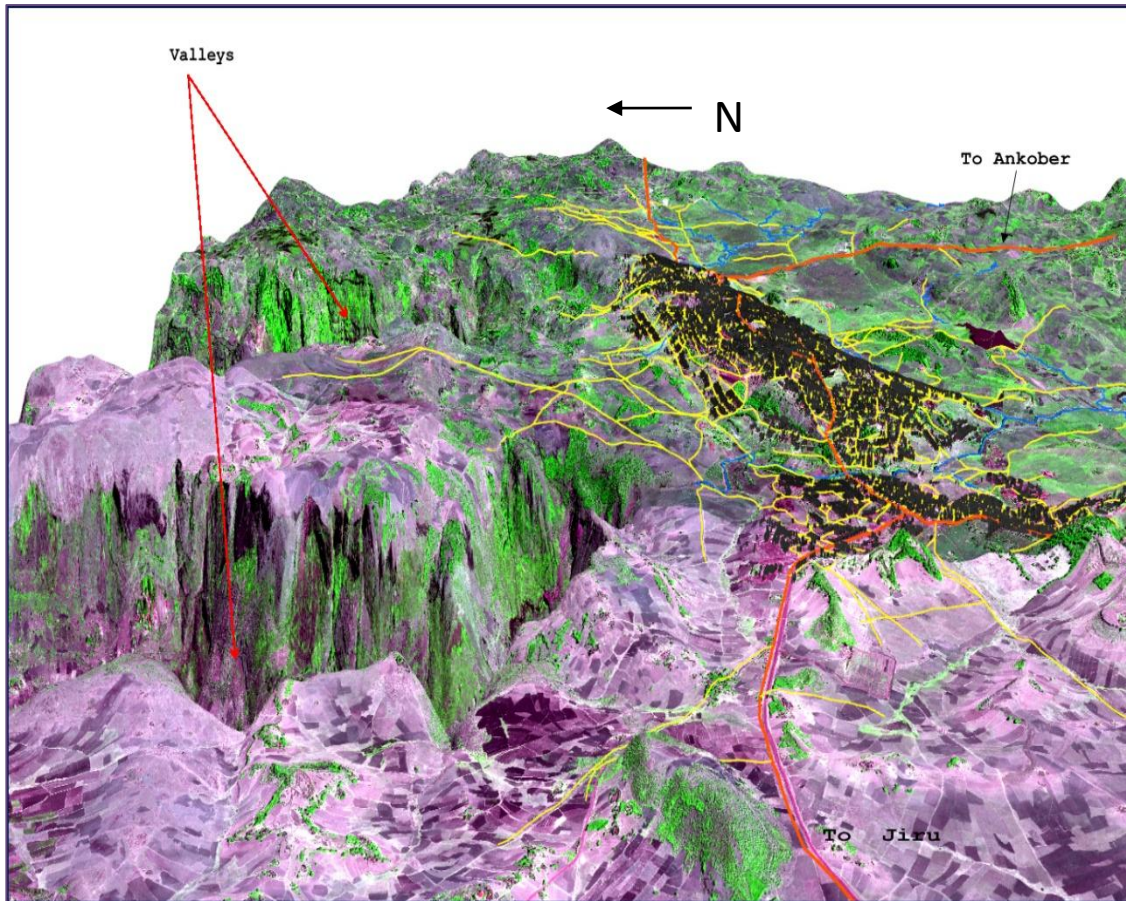


Figure 3. 3: Valleys/gorges in the vicinity of the town.

3.2.3. Drainage

There are rivers and streams that cross Debre Birhan town. These streams and rivers start from the eastern part of the plateau and drained from southeast to northwest -towards Jema River. Among the rivers that cross Debre Birhan town, Bersinaa is a perennial river and Dalecha is an intermittent river. The drainage pattern of the study area has a form of dendrite drainage patterns (Figure 3.4).

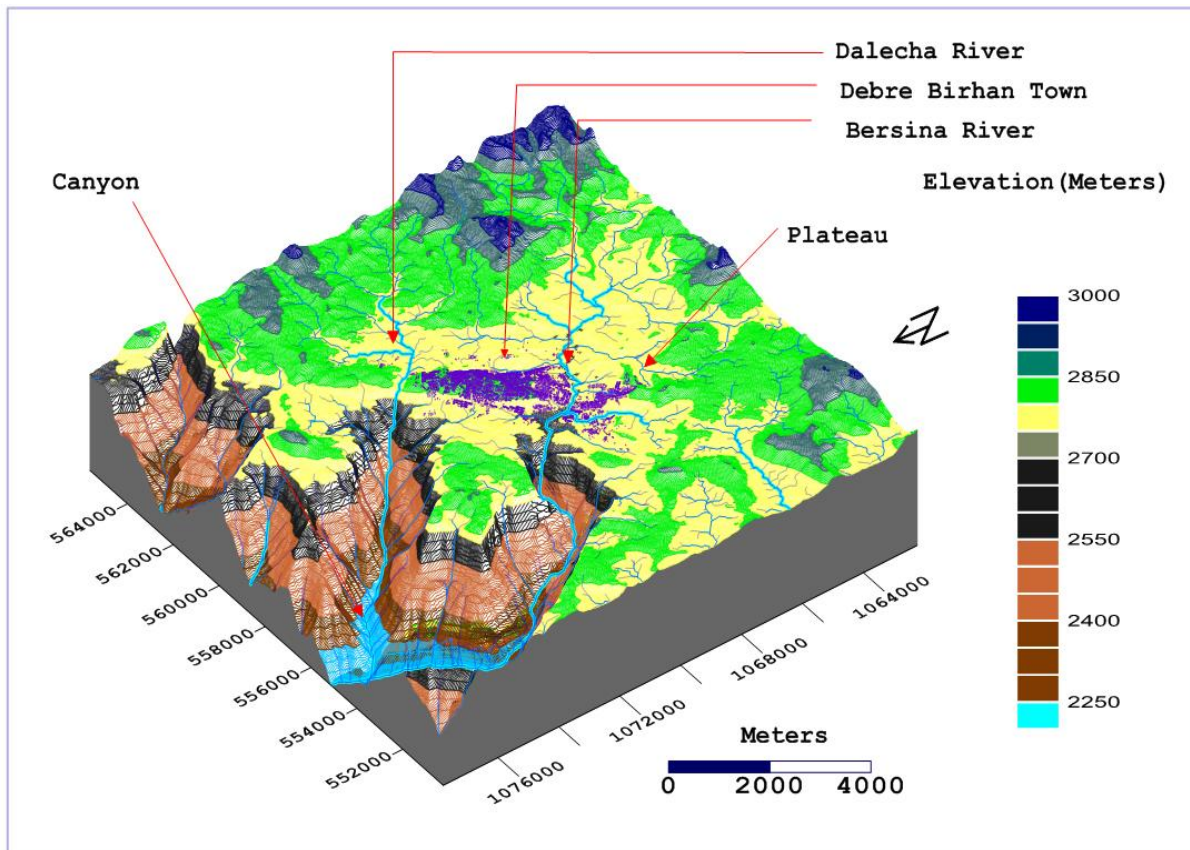


Figure 3. 4: Drainage map in 3d view

3.3. Climate

3.3.1. Rainfall Distribution

The study area has two rainy seasons, the long rainy season from June to the beginning of September, and the short rainy season which usually falls between January and April. The short rainy season however, is highly unreliable being characterized by variability, and absence of rains. The monthly rainfall for 10 years is presented in Figure 3.5. The maximum and minimum monthly average rainfall varies from year to year. The highest monthly rainfall was registered in 2006. In 2008, the mean annual rainfall was 946mm. The analysis of rainfall data for 10 years (Appendix 2) revealed that there was high annual average rainfall in 2007(1083.8mm) and the lowest annual rainfall noticed in 2002(830mm).

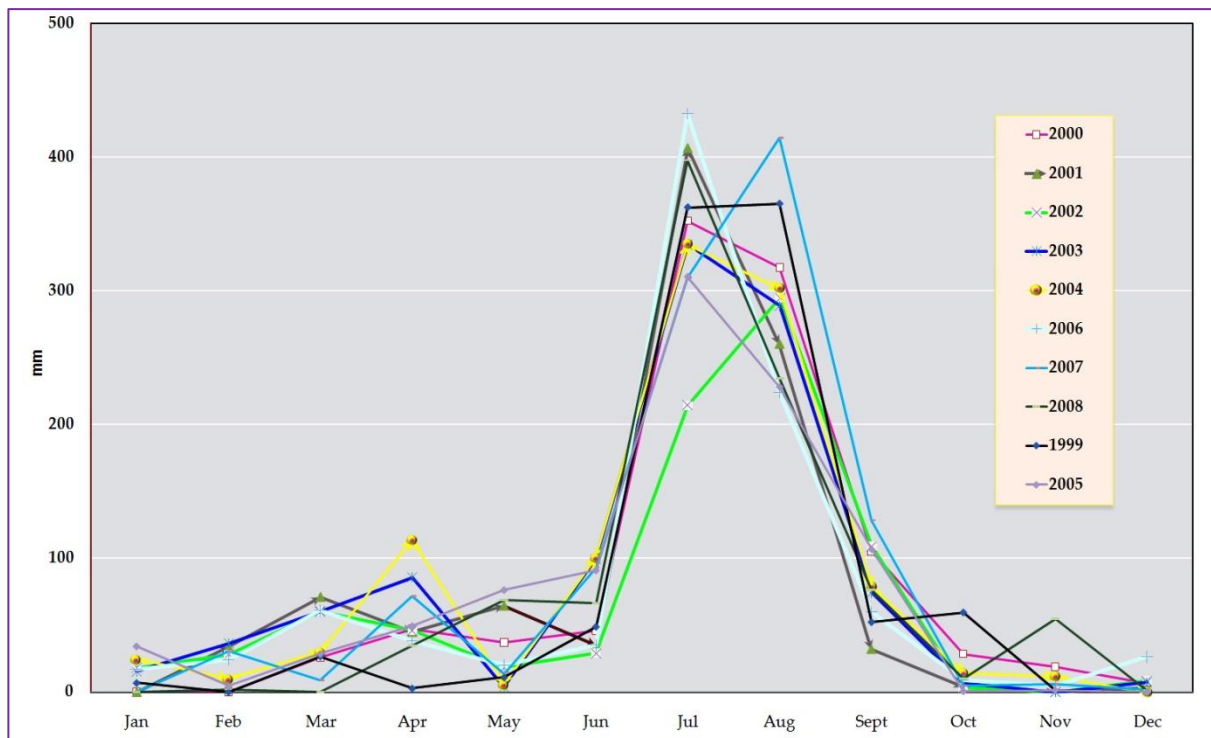


Figure 3. 5: Monthly Rainfall (1999-2008)

3.3.2. Temperature

Debre Birhan's 10 year average temperatures graph shows that there was a decrease in 2000, 2005, and 2007. The lowest average temperature was registered during November 1999 and the highest average monthly temperature was July 2004 (Figure 3.6).

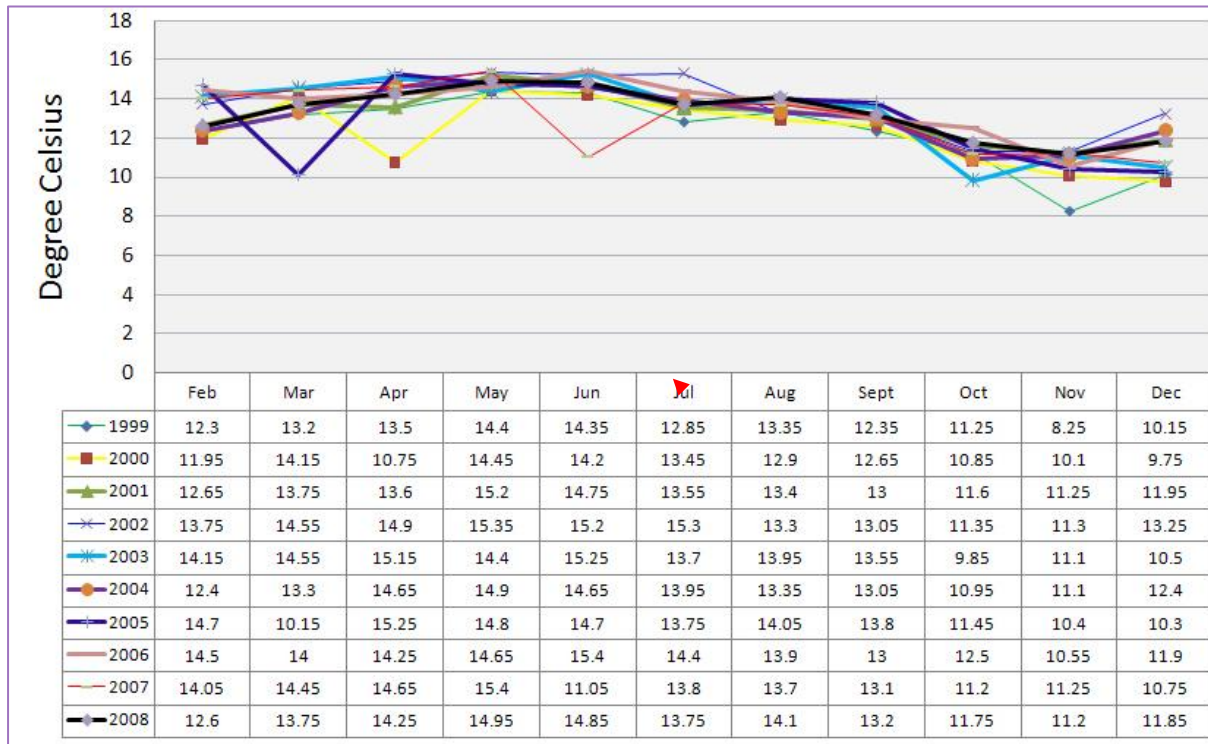


Figure 3. 6: Ten-year monthly average temperature (1999-2008)

3.4. Water supply

Debre Birhan town has been twinned with the French municipality of Blanc Mesnil since 1993. Speaking at Durban's International Conference Center, Jam Gibson said the relationship of the town with Blanc Mesnil has resulted in significant investments in the town from the Blanc Mesnil municipality and other French agencies. One of the investments that have been realized was the upgrade of the town's water and sewerage systems. This makes residents of Debre Birhan town to get a reliable water service 24 hours per day (Gibson, 2010).

Table 3. 1: Water Production Capacity

Well Field	Water Pump Capacity	Aquifer Capacity
Beresa	30 l/s	76 l/s
Dalecha	52 l/s	46 l/s
Total	82 l/s	122 l/s

(Adapted from Gibson, 2010)

3.5. Soil

Currently, there is no large scale digital soil map for the study area. For general information, the soil map description was taken from FAO Digitized Soil and Terrain Database of East Africa (Burundi, Djibouti, Egypt, Eritrea, Ethiopia, Kenya, Somalia, Sudan, Rwanda, and Uganda) at as scale 1:1 Million. The ARC/INFO version (7.3) of the SEA (Soil and Terrain Database of East Africa) files has a summary info of dominant soil type, dominant texture and dominant slope class with its Mapping Unit Identifiers.

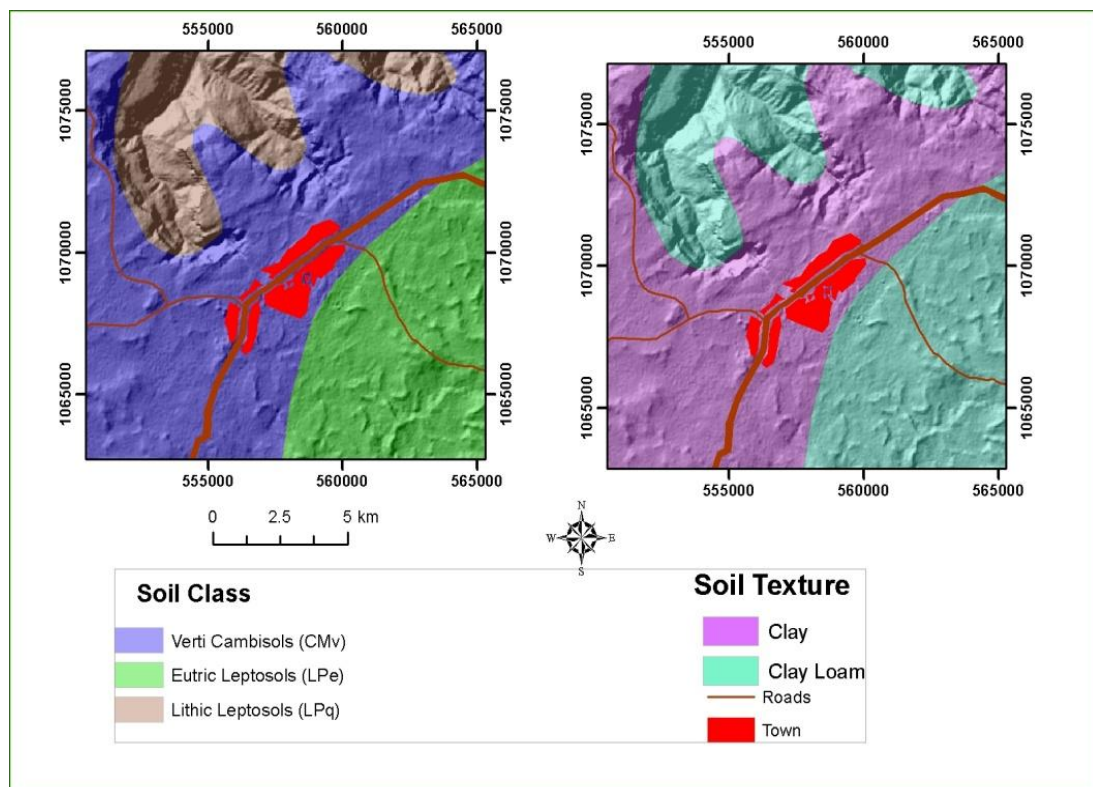


Figure 3. 7: Soil map of the study area

(Adapted from FAO soil class 1997)

The two dominant soil classes in the study area are Leptosols(Lp) and Vertisols(CM)(Appendix 2:). Studies show that vertisols develop mainly on the gentle slopes-usually less than 3%-of terraces, plains and valley floors in association with vertic inceptisols. Vertisols are important to Ethiopian agriculture. They are dark-colored clays and account for 24% of all highland soils. Vertisols develop cracks when expanding and contracting with changes in moisture content. The physical properties of Vertisols and their moisture regime create production constraints. Workability of these soils is also hampered by their stickiness when wet and hardness when dry, and water-logging and erosion greatly affect crop production (Bull 1987). Vertisols occupy more than 10% of the soils in all administrative zones of the country. The Central Zone of the country (Shawa), comprises 35% vertisols among other soil classes (Table 3.3).

Table 3. 2: Areas of (in million ha) of the major soil classes in Ethiopia.

Soil Class	CEN	NW	W	S	SE	E	NE	N
Nitosols	0.8	3.7	8.1	1.2	0.4	0.1	0.1	-
Cambisols	1.3	0.8	0.5	3.1	1.8	1.2	1	2.3
Vertisols	1.6	2.7	2	1.6	1.6	1.2	0.3	0.9
Luvisols	0.4	2.3	0.1	1.3	0.7	0.5	0.1	0.6
Fluvisols	0.2	0.1	1.6	1.4	0.2	1	0.2	1.3
Xerosols	-	-	-	0.9	0.9	2.5	-	1.1
Solonchaks	0.1	-	-	0.1	-	-	-	--
Acrisols	-	0.4	1.3	0.1	-	-	-	-
Others	0.2	0.1	0.4	-	0.3	1.3	0.1	-
Total	4.6	10.1	14	9.7	6.1	9	2.9	7.2
%Vertisols	35	27	14	16	26	13	10	13

NE	North East (Wello)
N	North (Tigray and Eritre)
NW	North West(Gojam)
SE	South East (Arsi and Bale)
E	East (Harerge)
CEN	Central (Shawa)
W	West (Kaffa, Ilibabor, Welega)
S	South (Sidamo,Gamogofa)

(Adapted from Bull, 1987)

3.6. Geology

The geology of the study area can be generalized from geological study of Debre Birhan area which is associated to the Mesozoic and Cenozoic Era. The two lithographic units mentioned on this page include:

- The Mesozoic Sediments exposed in highly dissected plateau area, within the gorge and canyon of Jama drainage basin which comprises stratified mud-stone and cross bedded sandstone,
- The Cenozoic volcanic rocks of Tertiary and quaternary age which covers the largest part and exposed on the plateau and the NE-SW rift margin. These volcanic rocks consist of Kesem basalt (Tkb), Sela Dengay-Debre Birhan-Gorge ignimbrite (Tdig) and Tarmaber-Megezez basalt. According to the report, the most widely expanding geological rock in the study area is the Tertiary Debre Birhan Ignimbrite (Tdig) (Daniel, *et al.*, 2010).

Debre Birhan town is completely, within the ignimbrite lithology which is locally called Sela Dingay Debre Birhan. The eastern part of the town is within quaternary eluvial lithology. Kessem Basalt is found on the low land part of the study area. The Tarmaber Megeze Basalt is mostly located on the Eastern, Western and North western part of the study area (Figure 3.8).

Table 3. 3: Classification of lithologies and stratigraphy of the map sheet (Debre Birhan Map sheet).

Age		Lithographic units	lithologies
Cenozoic		Superficial Deposits	Alluvium (Qal) Eluvium (Qel)
	Quaternary	Volcanic rocks	Dofan basalt (Qdb) vesicular basalt, aphanitic basalt, olivine phyric basalt and recent scoria cones Fantale Trachyte (Qft) Fentale-Alay Dege ignimbrite (Qfig) ignimbrite, tuffs, ash flows, agglomerate and minor obsidians
	Tertiary		Tarmaber-Megezez basalt (Ttb) plagioclase phyric and olivine-plagioclase phyric basalts with minor olivine phyric, pyroxene phyric, plagioclase-pyroxene-olivine phyric and aphanitic basalts. Trachyte (Tt) Kesem basalt (Tkb) aphanitic basalt intercalated with plagioclase phyric basalts and thin beds of ignimbrite
Mesozoic	Sediments		Sandstone (Msst)

Source: Daniel, *et al.*, 2010

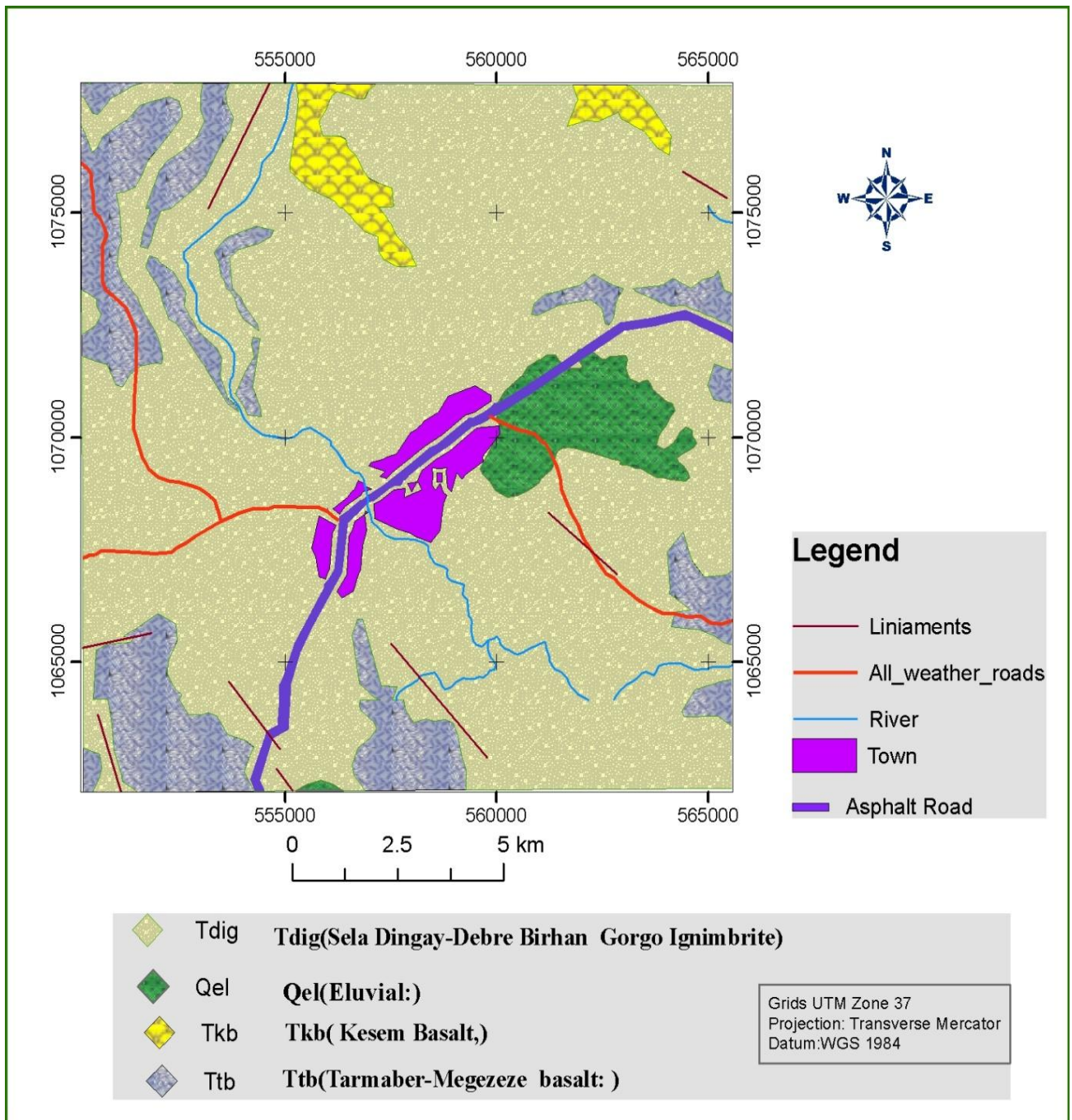


Figure 3. 8: Geological map

(Adapted from Daniel et al., 2010)

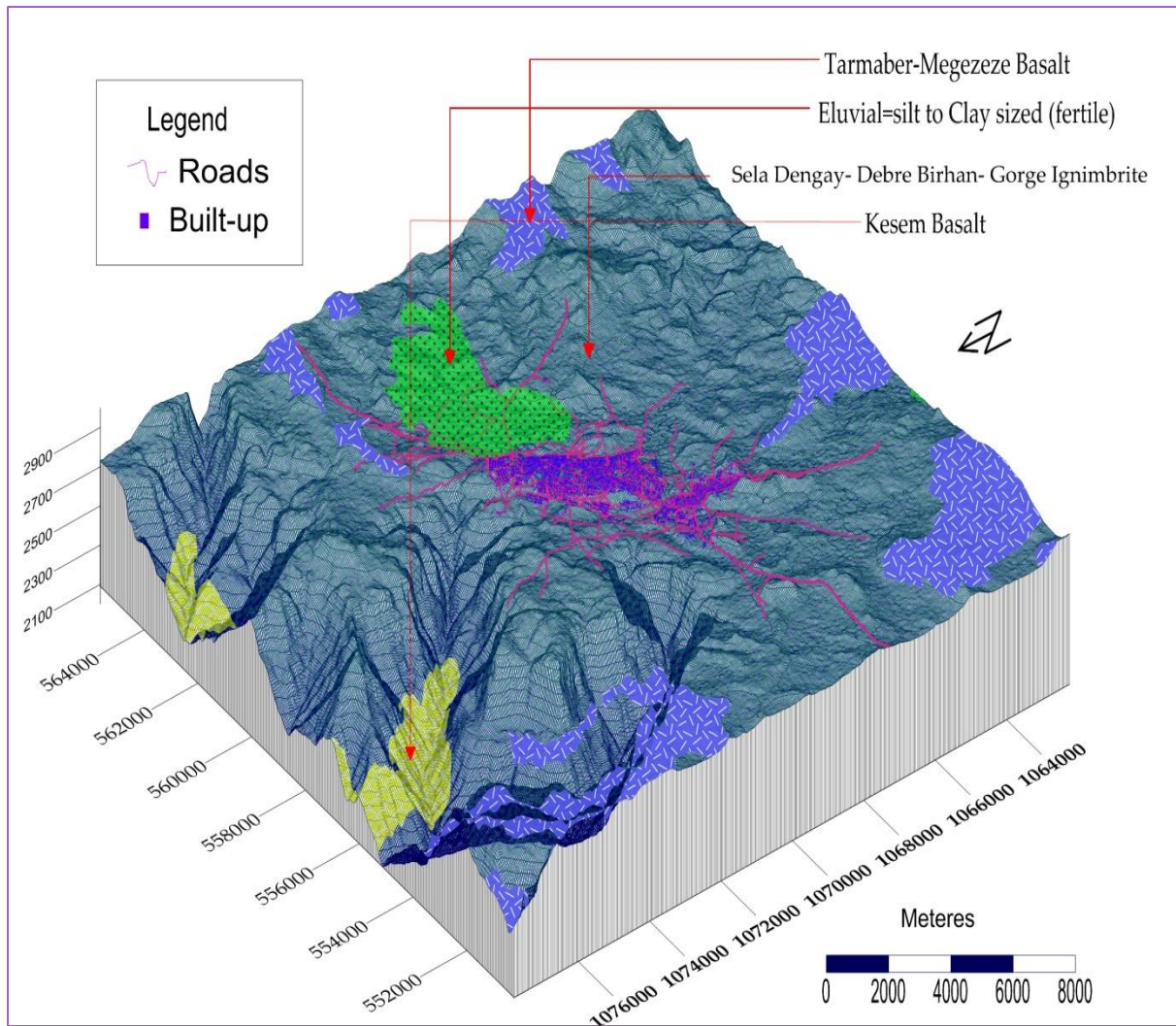


Figure 3. 9: Geology of the study area in 3d view.

METHODS AND MATERIALS

4.1. Materials and Sources

4.1.1. Landsat Satellite image archives

Landsat imagery of 1986 (TM), 2000 (ETM+) and 2005 (ETM+) with Path 168 and row 53 acquired from one of the best source of free satellite imagery on the web: Global Land Cover Facility (GLCF) <http://www.glcg.umiacs.umd.edu>. These data were used to produce the historical land-use/land-cover maps of the study area. Source and acquisition date of this data is given in Table 4.1.

Table 4. 1: Satellite data and sources

Sensor	Acquisition Date	Source
Landsat(ETM+)	2005	Global Land Cover Facility
Landsat(ETM+)	2002	Global Land Cover Facility
Landsat(ETM+)	2000	Global Land Cover Facility
Landsat(TM)	1986	Global Land Cover Facility
Ikonos_2	2008	GeoEye Foundation

4.1.2. Ikonos Satellite Imagery

Satellite imagery of a 326 square kilometer region surrounding Debre Birhan town in North Shawa District, Central Ethiopia was donated by the GeoEye Foundation as part of an initiative to support my academic research.

Table 4. 2: Ikonos satellite data description

Ikonos satellite image		
Sensor type		Ikonos-2
Processing level		Standard Geometrically Corrected
Acquisition Date/Time:		2008-03-22 07:55 GMT
pan sharpened imagery pixel size		1 meters
Multispectral imagery pixel size		4m
Band	1-m PAN	4-m MS & 1-m PS
1 (Blue)	0.45-0.90 μm	0.445-0.516 μm
2 (Green)		0.506-0.595 μm
3 (Red)		0.632-0.698 μm
4 (Near IR)		0.757-0.853 μm

4.1.3. Ancillary data source

Other secondary data were collected from Central Statistics Agency of Ethiopia (Demography data), and Meteorological Agency of Ethiopia (meteorological data). As the population data were not available at spatio-temporal scales, population density information was calculated using the old town boundary and the population data of each Kebele.

Table 4. 3: Ancillary data source

Data	Source
Topographic map(1995)	Debre Birhan town Municipality
Soil Map	FAO(1997)
Geological Map	Geological Survey Of Ethiopia
Population Data	Central Statistics Agency
Metrological Data	Meteorological Agency of Ethiopia

A 30m SRTM Digital elevation model (DEM) was used for the derivation of slope and stream features across the study area. Digital Elevation Model was also used for the visualization of other data sets in 3 dimensional views.

4.2. Methods of Data Processing

4.2.1. Land-Use/Land-Cover classification

One of the requirements for understanding urban sprawl is successful land-use/land-cover change detection. The amount of land-use/land-cover change over the study years and the land-use/land-cover category loss and gain were investigated by mapping the land-use/land-cover of the study area for 1986, 2000 and 2005 with Landsat image archives.

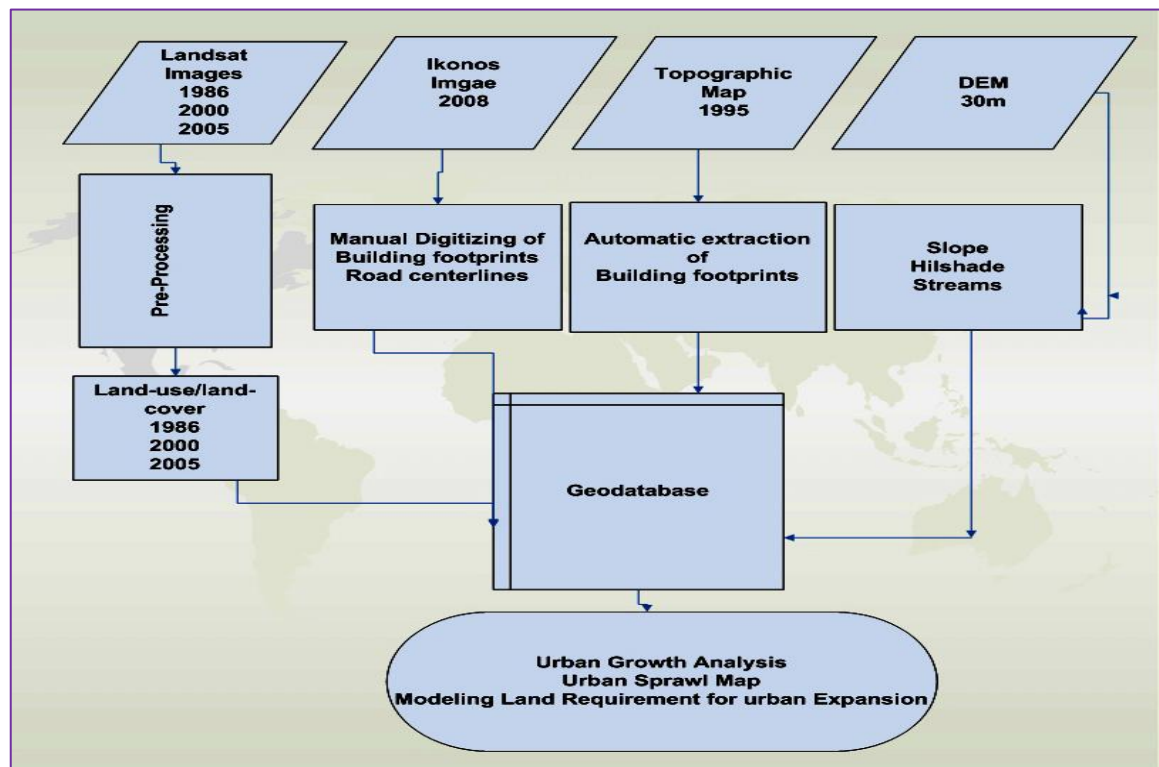


Figure 4. 1: Procedural Flowchart for urban growth and change map

From Landsat images, seven land use categories were identified including built-up, agricultural land, grass and pasture, vegetation, shrub land, bare land and water (lake). The class name agricultural land includes, crop land, fallow land, etc. After post classification processing has been done for each land-cover/land-use maps, accuracy assessment has been performed. Then, the land-cover/ land-use change statistics was performed and the rate of change of land-cover/land-use was mapped. The overall land-use/land-cover classification processes were discussed in this chapter.

4.2.1.1. Pre Processing of Landsat images

The digital image processing is largely concerned with four basic operations: image restoration, image enhancement, image classification, and image transformation (Eastman, 1999). The image restoration is concerned with the correction and calibration of images in order to achieve a faithful representation of the earth surface as possible. Image enhancement is predominantly concerned with the modification of images to optimize their appearance to the visual system.

The challenges of urban mapping using Landsat imagery include spectral mixing of diverse land cover components within pixels and spectral confusion with other land cover features (Lu and Weng 2006). To get a better enhanced image, different image enhancement techniques are available with different digital image processing software. One of the image enhancement works done in landsat image in this work was the spectral enhancement technique called principal component analysis.

4.2.1.2. Training Data Collection

To get a land-cover/land-use map at reasonable accuracy, training areas have been chosen with the help of different sources such as high resolution images (Ikonos), Google Earth and topographic map.

- A high resolution Ikonos image was used to access the low resolution Landsat image.
- Google Earth provides an access of high resolution image on the internet. The study area has a high resolution Google Earth image, dated 2007. Clearly recognized objects on Google earth image were digitized and taken as AOI (Area of Interest) and used to classify Landsat images.
- GPS points and digital camera were used to locate some sample ground cover situation at the time of field visit. Some land-use/land-covers in urban area, like water body, woodlots, and built-up area stay for long time without change to other land-use/land-covers. Therefore, some ground photographs and sample GPS points were used to minimize the processes of land-use/land-cover classification and as the same time used to validate the accuracy of land-use/land-cover results.

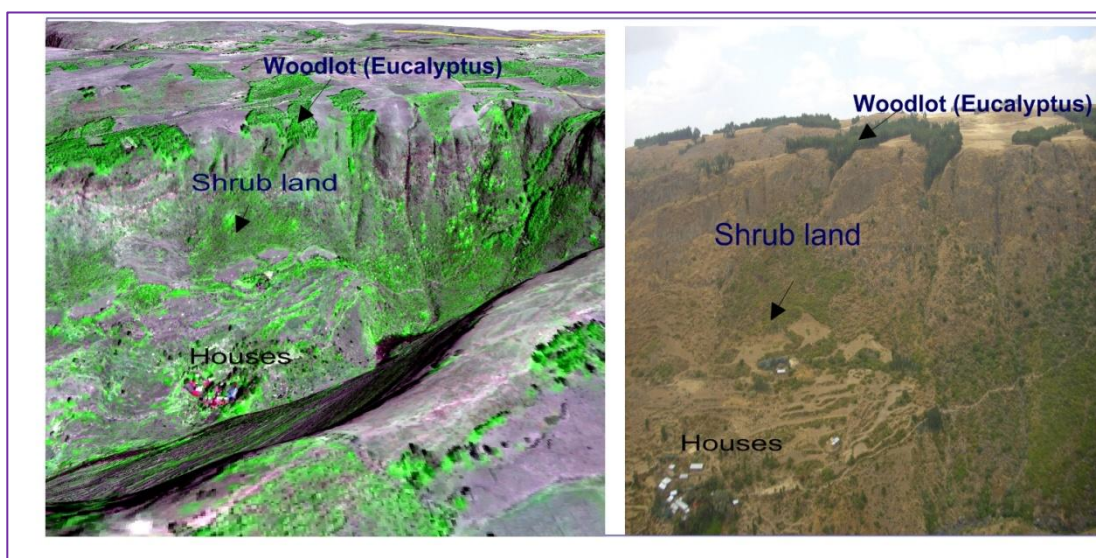


Figure 4. 2: Field photograph (right) and the same area with Ikonos-2 image in 3d view (left)

4.2.1.3. Supervised Classification

Land cover /land-use map for 1986, 2000, and 2005 were produced by supervised classification using maximum likelihood classifier. Seven land-cover/land-use classes were intended to be mapped for the study area. These classes include: Built-up, agricultural, vegetation, grass and pasture, shrub land, bare land and water body.

Table 4. 4: Land Use/Land Cover Classes descriptions

Land use class	Description
Agricultural land	including crop fields and Fallow land
Grass land	including pasture and open grass lands
Water body	including river and lake
Bare land	including sandy, rocky and bare soil
Built up area	Including urban, rural settlements and Asphalted roads.
Vegetation	Economic forests such as timber and fuel woodland other natural forests.
Shrub land	Scattered trees and bush land

- **Built-up**

Urban or Built-up land is comprised of areas of intensive use with much of the land covered by structures. Included in this category are all manmade features such as houses, roads, transportation, power, and communications facilities,

- **Agricultural land**

Agricultural Land for the purpose of this study defined broadly as land used primarily for production of food. On high spatial resolution imagery, agricultural activity can be seen with distinctive geometric field and road patterns on the landscape. However, on Landsat images, the agricultural land is classified based on pixel reflectance properties

- **Grass and pasture**

From Landsat imagery alone, it generally is not possible to make a distinction between Cropland and Pasture with a high degree of accuracy. However, grass land and pasture had different pixel reflectance property on Landsat imagery used for this work. High resolution image was referred for the spatial location of grass and pasture. Therefore, grass and pasture in this work includes open field with grass and land used for grazing purpose.

- **Shrub land**

Shrub land in this study defined as land where the potential natural vegetation is predominantly shrubs and scatter trees.

- **Bare Land**

Bare land includes bare soil, rocky land without vegetation.

- **Vegetation**

In this study the vegetation includes planting of trees around compounds, eucalyptus wood lots and road side tree planting

- **Waterbody**

The water body in this thesis was the water dam which is clearly seen on landsat images.

4.2.1.4. Post Classification

Classified data often manifest a salt-and-pepper appearance due to the inherent spectral variability encountered by a classification when applied on a pixel-by pixel basis (Lillesand and Kiefer, 1994). It is often desirable to “smooth” the classified output to show only the dominant classification.

One means of classification smoothing involves the application of a majority filter. In such operations a moving windows is pass through the classified pixel in the window is not the majority class, its identity is changed to the majority class. If there is no majority class in the window, the identity of the center pixel is not changed. As the windows progresses through the data set, the original class code are continually used, not the labels as modified from the previous window position (Eastman, 1999).

Majority filters can also incorporate some form of class and/or spatial weighting function. Data may also be smoothed more than once. Certain algorithms can preserve the boundaries between land cover regions and also involve a user-specified minimum area for any given land cover type that will be maintained in the smooth output (Lillesand and Kiefer, 1994).

The Spatial Analyst extension in ArcGIS software was used for the post-classification processing task. Three tasks have been employed to smooth the classified output from Landsat images.

- Filtering the classified output. By using Majority filter tool, the isolated pixels were removed from the classified map.
- Smoothing class boundaries and clumping classified output. These steps smooth the ragged class boundaries and clump the classes. The Boundary Clean tool is used.
- Generalizing classified output by removing small isolated regions. This step reclassifies small isolated regions of pixels to the nearest classes. The Region group, Set Null and Nibble tools are used.

4.2.1.5. Accuracy Assessment

In order to determine classification accuracy, it is necessary to determine if the output map meets, exceeds, or does not meet certain predetermined classification accuracy criteria. One of the most common and typical method used to assess classification accuracy is the use of an error matrix (sometimes called a confusion matrix or contingency table (Lillesand and Kiefer, 1994)). Currently, accuracy assessment is considered as an integral part of any image classification. This is because image classification using different classification algorithms may classify pixels or group of pixels to wrong classes. The most obvious types of error that occurs in image classifications are errors of omission or commission.

After classification process is completed, accuracy assessment for each land-cover/land-use has been done to make sure the classification is accurate enough for use. To assess classification accuracy the classified map derived from remotely sensed data and the existing sources of reference information such interpretations from Ikonos image, topographic map, and ground truth data were used as a means of time and cost-efficient error checking.

To do this a set of randomly selected pixels whose true values well known were used and ERDAS Accuracy Assessment tool was used to conduct an accuracy assessment. ERDAS IMAGINE uses a square window to select the reference pixels. Among the three different types of distribution parameters namely random (no rules will be used), stratified (the number of points will be stratified based on the extent and area of each thematic class), and equalized random (each class will have an equal number of random points regardless of its extent), simple random was used to evaluate the accuracy assessment of the land-cover/land-cover classes.

The study assessed accuracy of the classification results with 100 randomly sampled reference points for each classified image. The error matrix for each classification was created and then overall accuracy and Kappa coefficient were calculated and evaluated (Table 4.5).

Table 4. 5 : Overall accuracy and Kappa (K^{\wedge}) statistics for the classifications

Accuracy statistics	1986	2000	2005
Overall classification accuracy (%)	85.00%	88.75%	87.65%
Overall Kappa (K) statistics	0.7903	0.8297	0.7968

Table 4. 6: Producer's and User's accuracy for individual land-use/land-cover classes

Class Name	1986(%) Accuracy		2000(%) Accuracy		2005(%) Accuracy	
	Producer's	User's	Producer's	User's	Producer's	User's
Built-up	83.00%	71.00%	80.00%	80.00%	75.00%	75.00%
Agricultural	95.00%	92.00%	98.00%	91.00%	98.00%	92.00%
Grass & Pasture	67.00%	89.00%	78.00%	88.00%	60.00%	86.00%
Vegetation	85.00%	73.00%	67.00%	80.00%	83.00%	71.00%
Waterbody	-	-	-	-	-	-
Shrub land	75.00%	75.00%	80.00%	89.00%	78.00%	88.00%
Bare Soil	75.00%	86.00%	88.00%	86.00%	80.00%	80.00%

The results show that the achieved overall classification accuracies were 85.00 %, 88.75% and 87.65% and overall Kappa (κ^{\wedge}) statistics were 0.7903, 0.8297 and 0.7968 respectively for the classification of 1986, 2000 and 2005 Landsat images (Table 4.4). The producer's and User's accuracy for individual land classes presented with table 4.5

For individual classes, the producer's accuracy ranges from 66.7% -94.6 % (1986), 77.8% - 91.8 % (2000) and 60% - 97.8% (2005) whereas user's accuracy were 71.4% - 92 % (1986), 80-91 % (2000) and 71%-92 % (2005). Higher producer's and user's accuracies were achieved mostly for vegetation and agricultural land.

4.2.2. Automatic feature extraction and digitizing

Most of GIS applications to urban planning and modeling have relied upon vector GIS and polygon data. Vector GIS includes points, lines and areas with attached various attributes. Features in a vector GIS have a very high graphic resolution and they are often used to make informative and visually appealing maps. Therefore, vector GIS is the main part of this work. To find the existence of residential and commercial housing sprawl, buildings footprints and roads were digitized from toposheet of Debre Birhan town (1995) and Ikonos image 2008. These data were used to show the growth of urban area and the pattern of development relatively at a better scale map than data from Landsat image. The urban sprawl metrics were computed based on the digitized vector files on Ikonos image and topographic map.

4.2.2.1. Manual digitizing of vector data on Ikonos satellite image

A. Pre-processing

The availability of a 1m panchromatic band, in conjunction with 4m multispectral bands, provides the opportunity to create a 1m multispectral pansharpened image by fusing these images. The spatial enhancement tools of ERDAS Imagine software used to merge these separate orthorectified images to get a better quality of data (Figure 4.3).

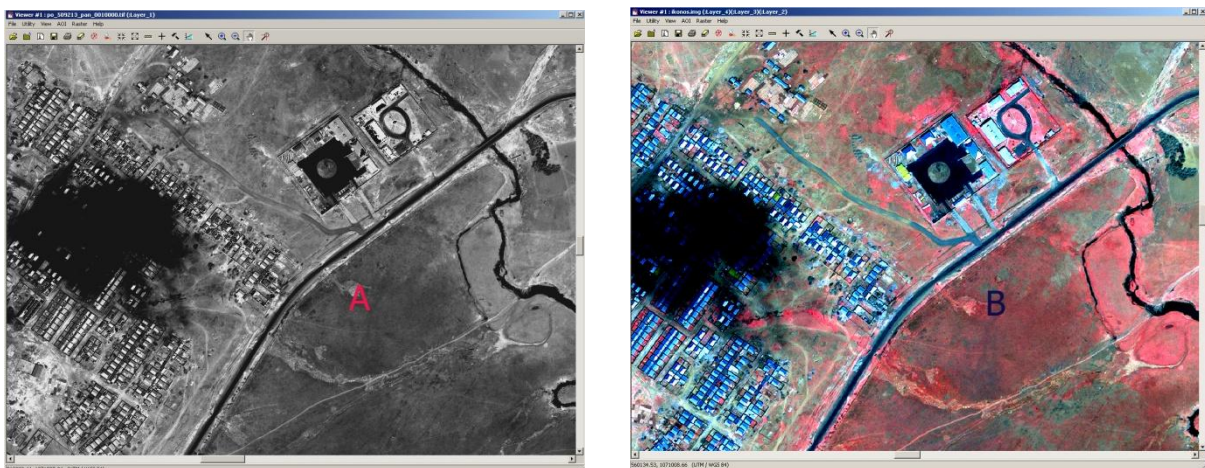


Figure 4. 3: Panchromatic 1 meter (A) and False color Multispectral pan-sharpened Ikonos image (B)

B. Manual digitize of building footprints and road features.

Geospatial features and buildings in particular are required for varieties of applications such as urban planning, creation and updating of Geographic Information Systems (GIS) databases and creation of urban city models. To get this data, numerous efforts have been made in the past few years to automate building extraction from digital images (Gulch, 2000).

For mapping from high resolution space imagery such as Ikonos, automatic object-based image analysis using GIS has been generally used for remote sensing applications in recent years. However, in practice, the extraction of buildings from digital images is complex because buildings can have various complex forms and roofs of various compositional materials.

Therefore, a high resolution Ikonos image was used to digitize building footprints and road centerlines with the Savedit module of SAVGIS software. The GIS data layers include road layer, street blocks and building footprints (Figure 4.4. Street Blocks were generated from streets using the data analysis and mapping module the Savene 9.05 of SavGIS software.

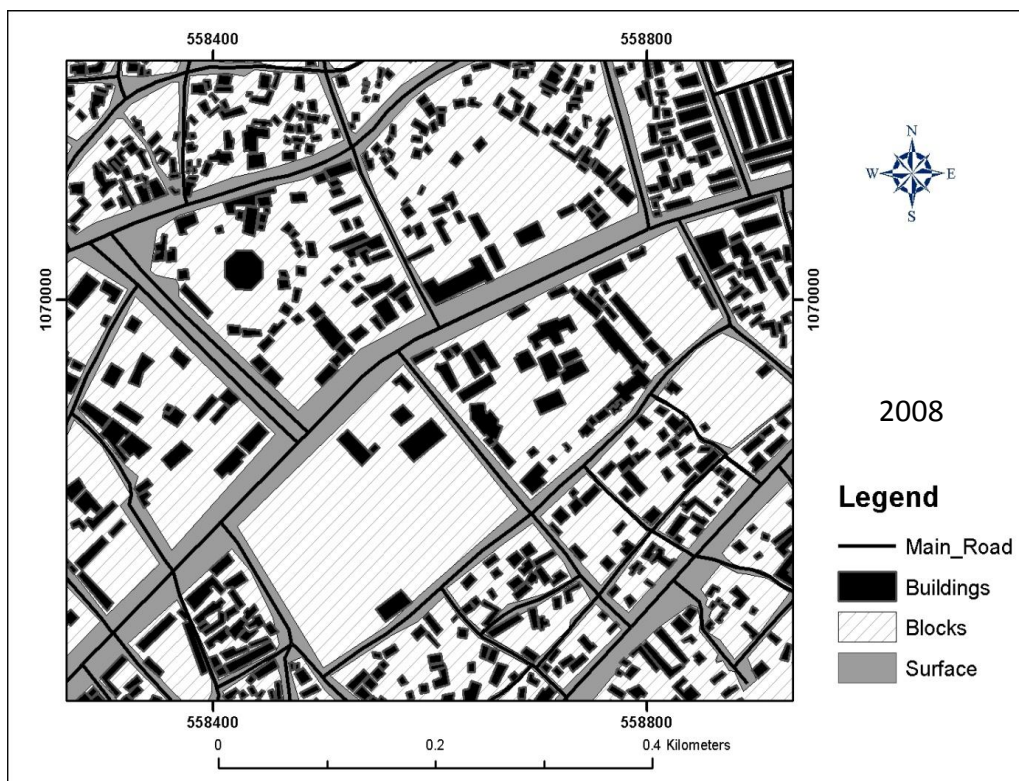


Figure 4. 4: Roads center lines, blocks and building footprints layers (2008)

To evaluate the quality of spatial information digitized from the image, it was necessary to measure the accuracy of the data with information from an independent source. Therefore, the reference data that was used include GPS points (Figure 4.5), topographic map and visual assessment of digitized data layers on Google Earth image (Figure 4.6).

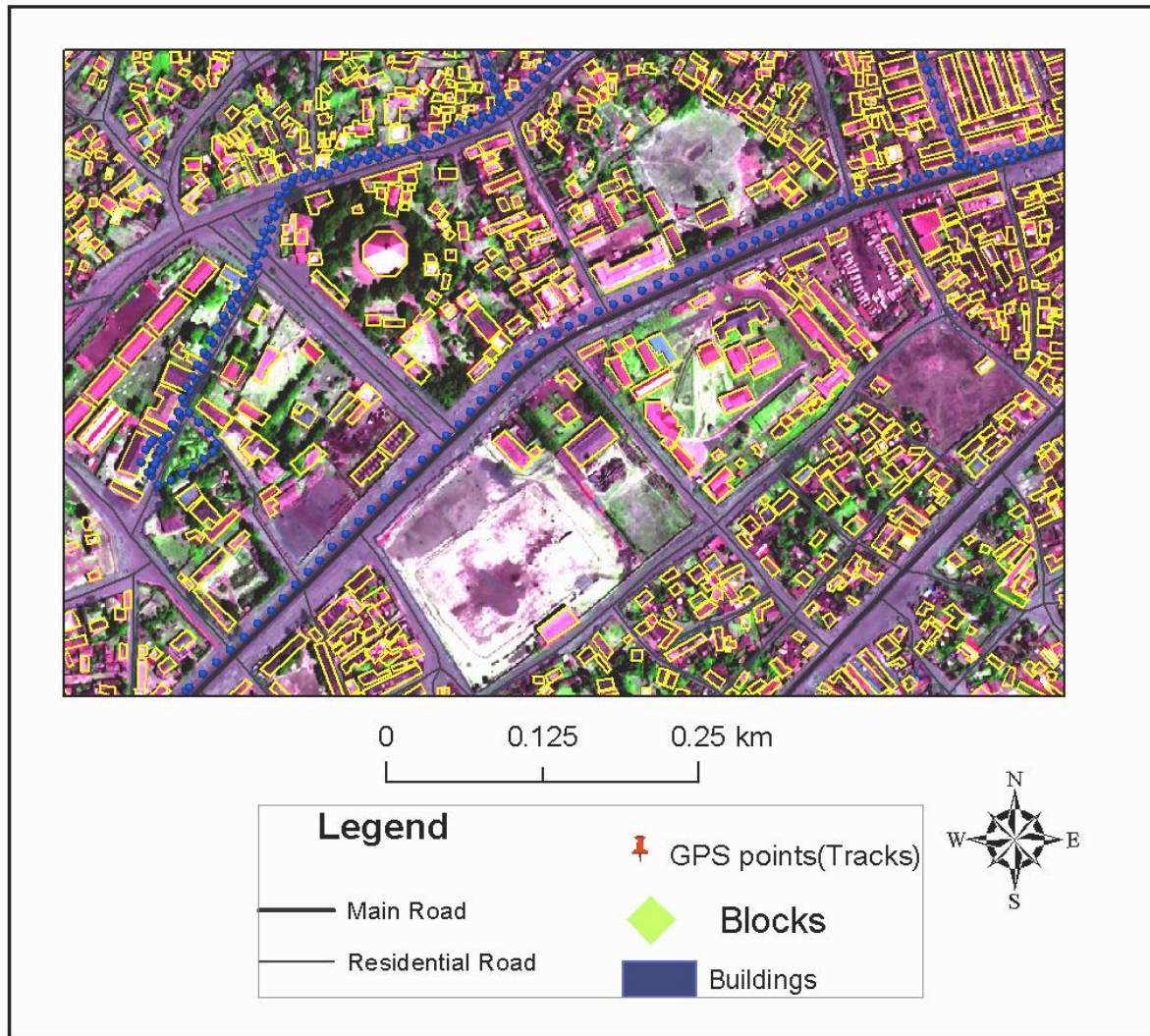


Figure 4. 5: GPS points, road centerline and building footprints overlaid on Ikonos image (2008)



Figure 4. 6: Vector layers overlaid on Google Earth Image (2007)

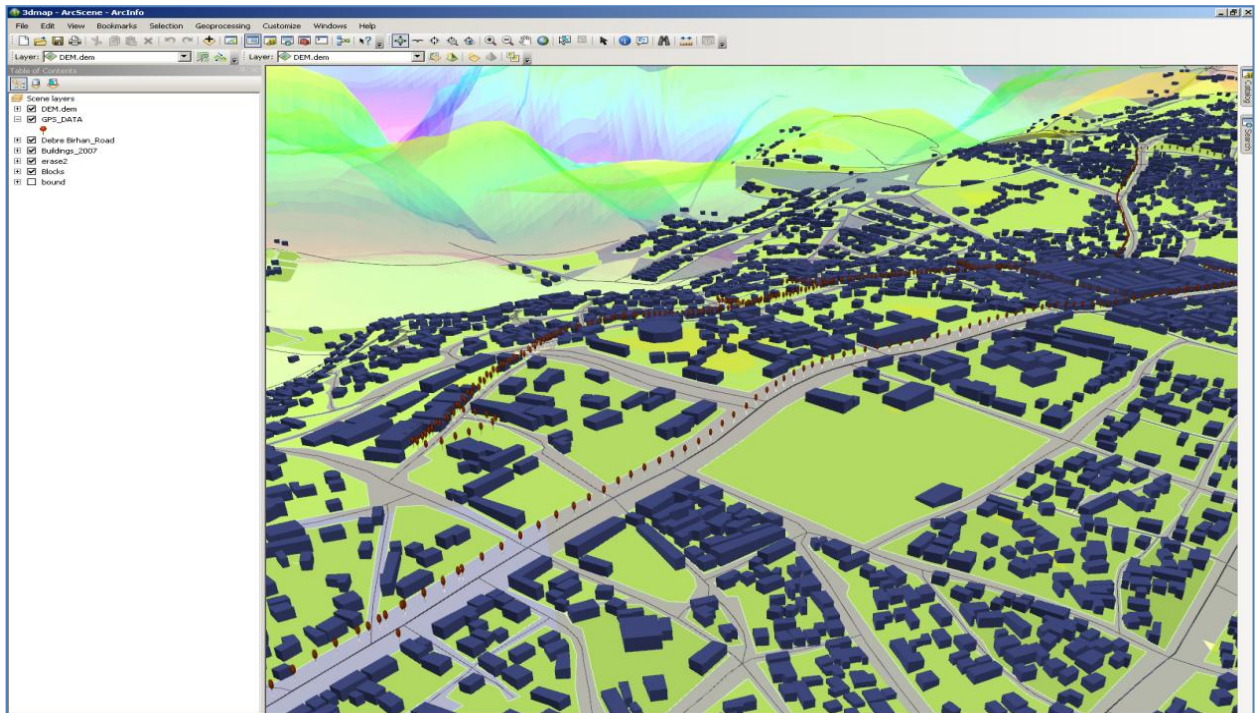


Figure 4. 7: GPS points, road centerline and building footprints draped over DEM

4.2.2.2. Automatic feature extraction from Topographic Maps

Deriving GIS data from historical map will provide the ability to compare historical geographic pattern to more recent layers (Junk, 2000). One of the input data sources for Geographic Information System is the paper-based maps. The information from paper based maps has been digitized to be used in GIS. But manual tracing of paper maps is costly and tedious process, therefore, an effective way for conversion of paper maps to vector data was needed.

Currently, raster to vector conversion software are available. ESRI offers a wide range of GIS software with a high emphasis on vector applications. ArcScan is an ArcGIS extension used to extract vectors from scanned images. Another tool which was used for vectorization of scanned raster maps was WinTopo pro software.

In this work, both WinTopo pro and ArcScan tools were used to extract vectors from the scanned topographic map (Figure 4:8).

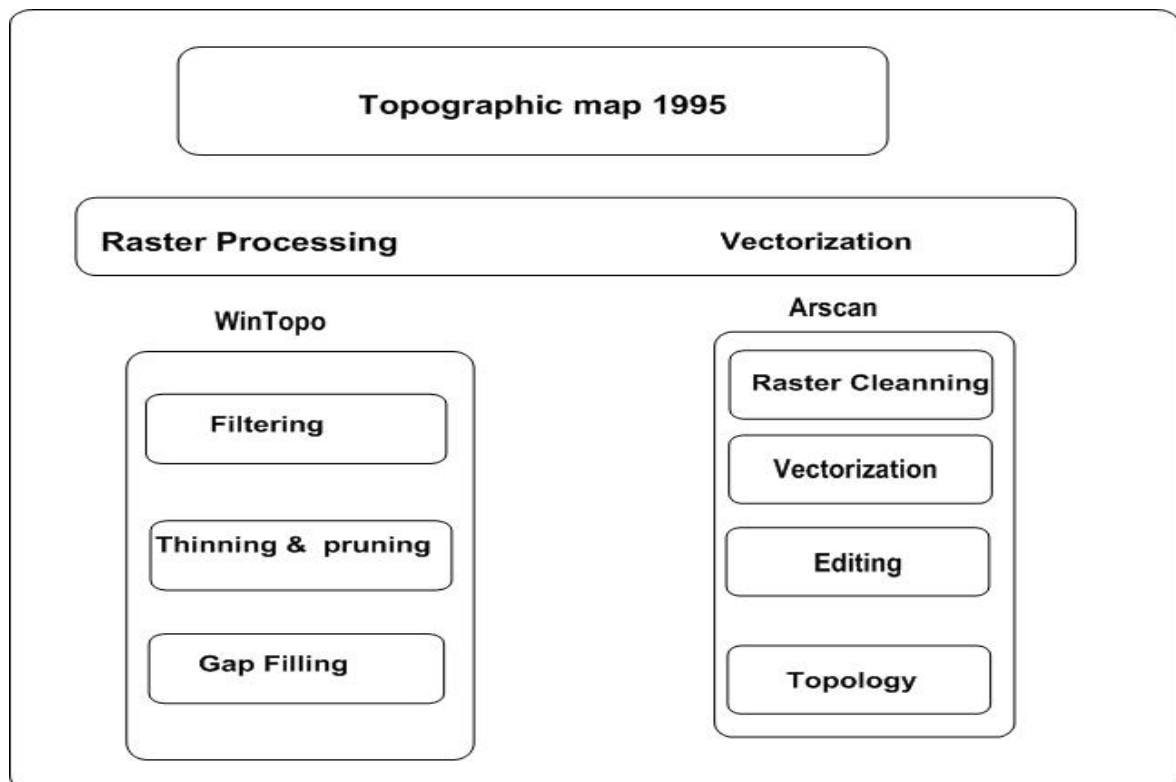


Figure 4. 8: Flow chart showing raster vectorization processes

A. Pre- Processing of raster image

The first process for raster vectorization is preparing the raster for vectorization. After the scanned image has been digitized (converted to digital image), it was converted to gray level scale to work on it. All the processes filtering, thinning, pruning and Gap filling were applied for the scanned image using winTop software.

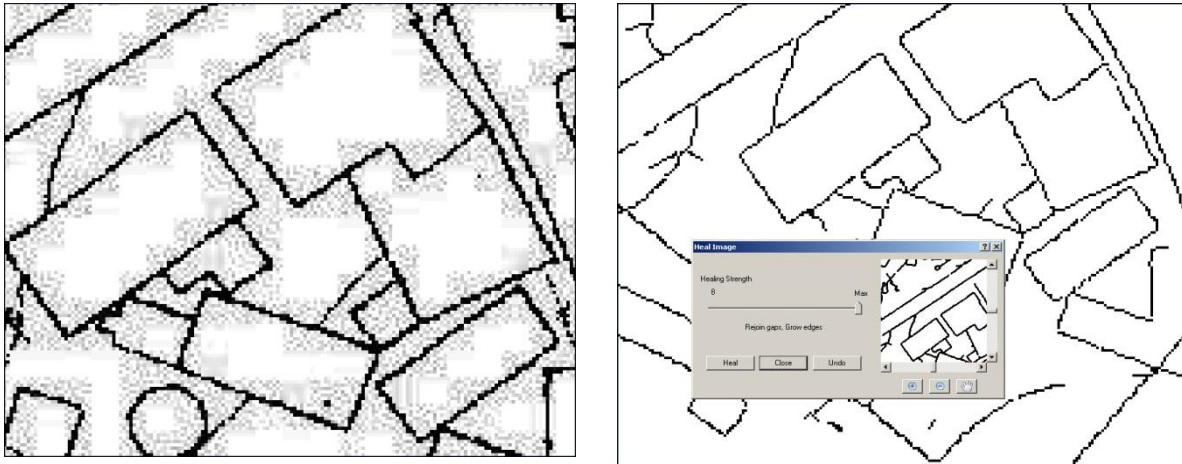


Figure 4. 9: removing spots, splash and blemish with WinTopo software.

Pruning removes shorter lines that prude out of the longer line while thinning helps to smoothing the lines. The gap filling process is one of the most important task that used to reconnect or recover the missing part of lines that are disconnected by unwanted cells that were removed by pruning information layers like symbols, grids and other non outline features in this study case.

Thinning is another most important process that can be used to reduce a shape to a simpler version without distorting the essential features of the original object.

B. Raster Vectorization

The raster painting and cleaning toolbar of ArcScan were used to remove unwanted cells from the raster cells. Finally, the vectorization of the raster accomplished with user defined sitings. These settings affect the geometry of the feature that can be produced unless the vectorization settings are carefully done. The polygon outline features of the topographic image produced by semi-automated process of ArcScan were presented with figure 4.10.

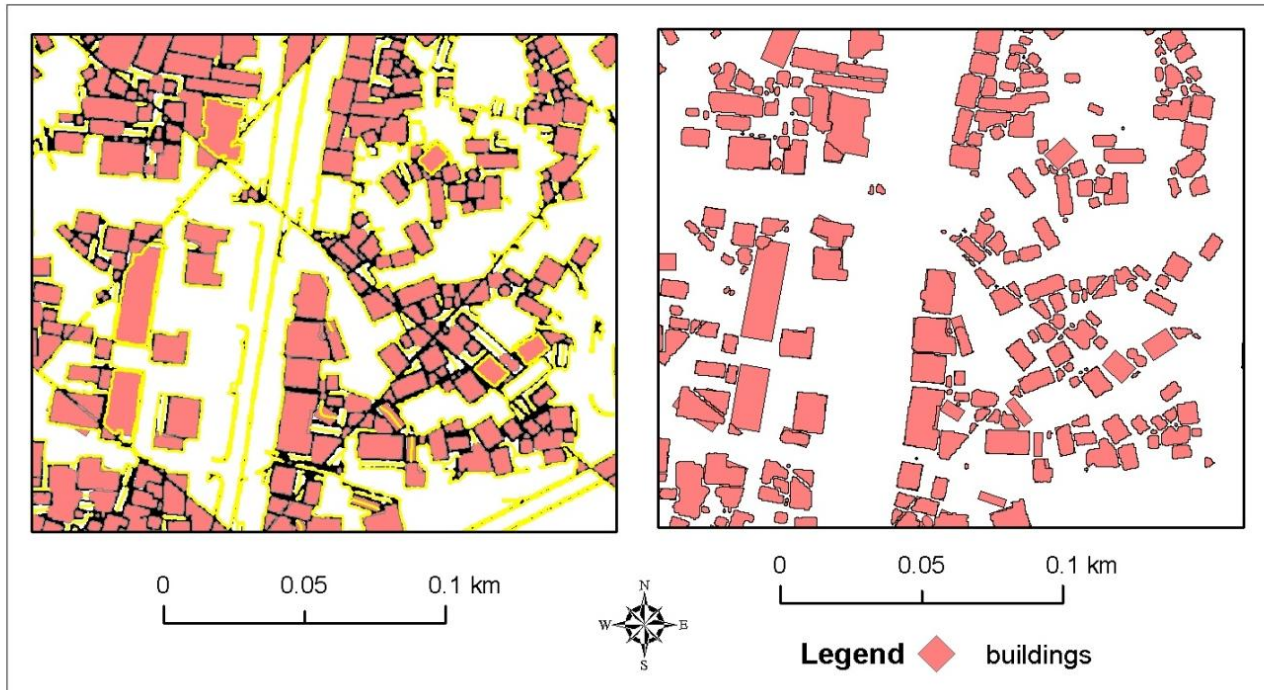


Figure 4. 10: Raster vectorization with ArcScan (ArcGIS 10.0)

4.2.3. Data Generation from Digital Elevation Model (Dem)

The physiographic characteristics of a given area can determine the amount, pattern and direction of land-use/ land-cover change on a given urban environment. Spatial data used in GIS analysis come from a wide variety of sources, in a number of different formats, resolutions, scales, and projections. One of the data source for GIS is Digital Elevation. Digital elevation models are essential for a number of topographic and hydrological analysis including slope computation, stream generation and watershed delineation etc. This study will attempt to combine various forms of Digital elevation data to study urban spatial pattern and growth. The most important physiographic data that were extracted from DEM include slope, aspect, drainage, and hilshade.

4.3. METHOD OF DATA ANALYSIS

4.3.1. Land Use/Land-Cover Change Detection

Post classification land-use/ land-cover change statistics was used to measure land-use/land-cover change on the study area. Absolute change was calculated by subtracting the area of land-use/land-cover of the first from the area of later land-use/land-cover image (Area at Time 2)-(Area at Time 1) to get an aggregate of area change of each class.

Relative change is also another method to measure land-use/land-cover in terms of percentage ((% area at Time 2) – (% area at Time 1)). Thematic change analysis of the individual land-use/land-cover was performed using ENVI 4.7 software. The relative change detection matrix result shows results from one class change to another.

4.3.2. Housing approach urban growth Analysis

4.3.2.1. Population Growth Analysis

The total population of the town for census year of 1984 and 2007 was used to calculate the growth rate of population. A simple linear growth rate formula was used to calculate the annual rate of population growth for each Kebele which was used to compare the growth rate of housing unit at the same study years (1994-2007).

The density of the population at Kebele level and street block level was calculated in order to understand the population distribution within the administrative units. I assumed this data would help me to identify the location of population concentration and the concentration of housing units using both housing units derived from satellite data and topographic map.

The most common and useful method to calculate population growth rate is percentage growth rate. Percentage growth rate or growth rate is useful as an indicator to look at how much a population is growing or declining in a particular area. The rate of change (growth rate) of population of Debre Birhan town for the census years of 1994 and 2007 will be calculated using the following population growth rate formula.

$$\frac{y_2 - y_1}{y_1} \times 100 = PR \quad (1)$$

Where: y_2 = The present or future value

y_1 =The population of the past

PR=Percent rate (rate of growth)

Percent Rate= (value at end of period - value at beginning of period)/value at beginning of period).

4.3.2.2. Physical urban growth Analysis

The historical physical urban growth was analyzed using the Landsat image of 1986, 2000 and 2005. The rate of urban land cover change has been calculated from the Landsat images.

Data extracted from topographic map of 1995 and on screen digitized of housing units on Ikonos image of 2008 were used to study the urban growth at housing level. By comparing dwelling units from these two sources, the level of housing scatter (sprawl) has been identified.

a. Mapping and visualization of urban sprawl

The standard 2d maps and 3d maps were used to study the urban growth change at housing level over the study years (1995 and 2008). The pattern and distribution of housing units in 3d map is the easiest way to locate features on a given area.

b. Density as a measure of urban sprawl

Density has been one of the most employed variables to look at the spatial structure of cities and towns. Density, measures overall activity intensity in urban area and is the most commonly used variable in characterizing urban form as well as intensity-based compactness/sprawl.

In this thesis housing density using Kebele and street blocks as base land area was calculated. The gross density (considering all area of the urban administration boundary) was compared to the net density (considering all area bounded by street bock and excluding

roads, agricultural land and all non inhabitable area) of housing density. The result would help to understand the location of low density housing development and sprawl.

c. Spatial statistical approach urban growth

Spatial autocorrelation measures such as Moran's I require a weights matrix that defines a local neighborhood around each geographic unit. The value at each unit is compared with the weighted average of the values of its neighbors. A weights file identifies the neighbors. Weights can be constructed based on contiguity to the polygon boundary (shape) files, or calculated from the distance between points such as points in a point shape file or centroids of polygons (Anselin, 2003)

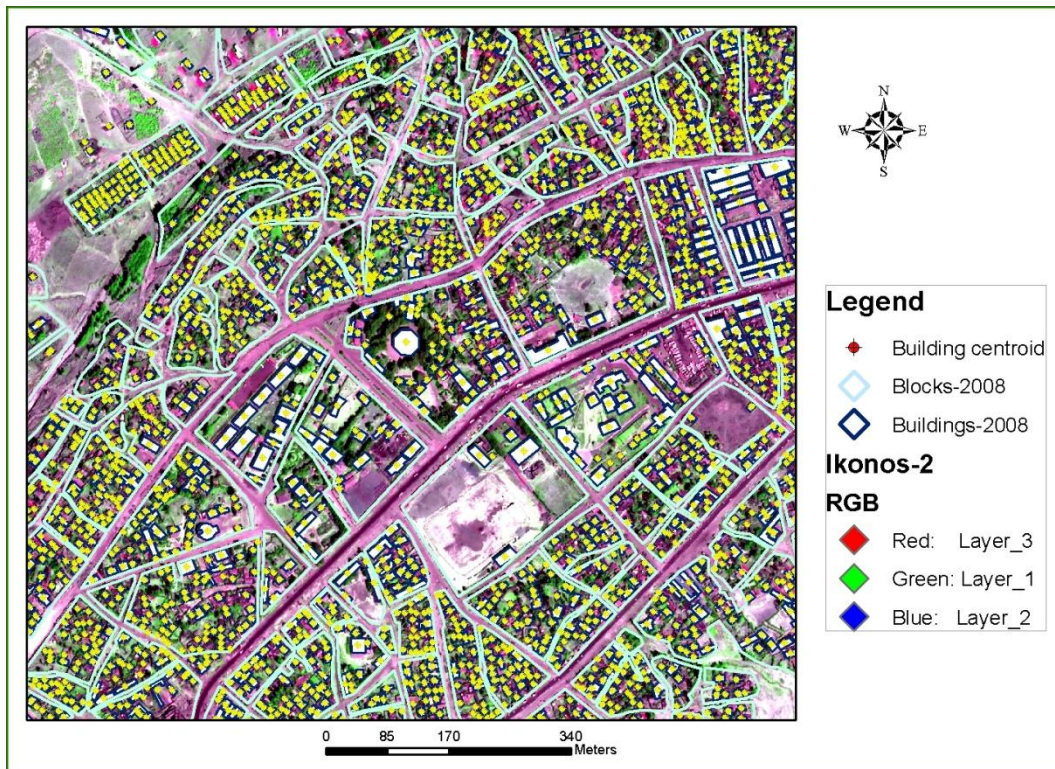


Figure 4. 11: Building footprints and corresponding centroids

Before the analysis of spatial clustering the polygon centroid of each the building footprint units was converted to polygon centroid to get the mean center of each polygon that represent housing units. That was because point data were straightforward to measure spatial distribution of data. All individual areal features of polygons were aggregated to its

own centroid to get the point data. The centroid of each building units were generated from the digitized buildings using ArcGIS software. Therefore, the polygon centroid represents point feature (shapefiles) that contains the number of dwelling units per point (Figure 4.11).

The Analyzing Patterns tool set in ArcGIS desktop contains methods that are most appropriate for understanding broad spatial patterns and trends of residential housing units. Spatial statistics tools of ArcGIS such as Mapping Clusters help to identify where spatial clustering occurs. Some standard global and new local spatial statistics, including the Moran I, Getis-Ord G were used to detect the sprawl pattern on the study area.

To implement this analysis, a spatial weights matrix, should be computed. Spatial weights matrix

4.3.3. Modeling land requirements for urban expansion

GIS and Remote Sensing techniques were used in Multi criteria evaluation suitability analysis to evaluate the suitability of the study area for urban expansion by examining and weighting different types of factors and constraints. The factors that influence the suitability of urban expansion include: topography, slope, land-use/land-cover, proximity to town, proximity to the main road and housing density. Constraints that restrict further expansion of urban area include: topography, water bodies (open water-body and rivers), and woodlots.

RESULTS AND DISCUSSION

5.1. Land-use/Land-cover change detection

Change Detection Analysis comprises a broad range of techniques. The most common land -use/ land-cover use change detection approaches are grouped in to two (Singh 1989). These are:

- a. Post classification comparative analysis of independent produced classifications from different dates (map-to-map comparison).
- b. Image-to -image comparison.

In the post-classification approach, images belonging to different dates are classified and labeled individually. In this thesis, Post-classification method is used. Post-classification comparison determines the difference between independently classified land-use land cover classes from each of the dates under study years.

After post classification, the absolute change and relative change were calculated using Envi 4.7 software. Absolute change is calculated by subtracting the area of land-use/land-cover of the first from the area of later land-use/land-cover image (Area at Time 2- Area at Time 1). This method was used to get an aggregate of area change of each class.

Relative change is also another approach to measure land-use/land-cover in terms of percentage (% area at Time 2 - % area at Time 1). The relative change method allows comparison between areas related to land cover indicators.

A. Absolute Area Change

The first process of land-use land cover change detection on the study area was to perform supervised image classification techniques on each image of 1986, 2000 and 2005. After performing an image classification, scattered individual pixels were filtered and cleaned up for better visual display. Then the subtractive change detection based on their area

extent was performed on the classified images. The summary of area extent of individual land-cover classes and percent in changes is given in table 5.1.

Table 5. 1: Area statistics and percentage of land-use/land-cover for each year

Class Name	1986		2000		2005	
	Area(km ²)	Area (%)	Area(km ²)	Area(%)	Area(km ²)	Area (%)
Built-up	1.05	0.60	2.43	1.40	4.61	2.55
Agricultural land	93.40	51.60	96.82	54.00	110.97	61.31
Grass and pasture	20.93	11.56	15.96	8.82	14.78	8.17
Vegetation	31.06	17.16	14.66	8.10	14.53	8.03
Waterbody	0.00	0.00	0.04	0.02	0.11	0.06
Shrub land	16.60	9.17	25.00	13.81	23.49	12.98
Bare land	17.90	9.89	26.12	14.43	12.55	6.93
Class Total	181	99.99	181	100.00	181	100

The built-up area (Table 5.1) in 1986 occupied the least area with 0.6% of the total class. Agricultural land occupied more than 90 % of the total area in each of the study year. This may be due to the conversion of grass land and bare soil to agricultural land. But the most probable reason might be the time of the year in which the area was imaged which could be a major contributing factor of the high percentage of the observed classification. The water body class (a dam) exists only for Landsat image scene of 2000 and 2005.

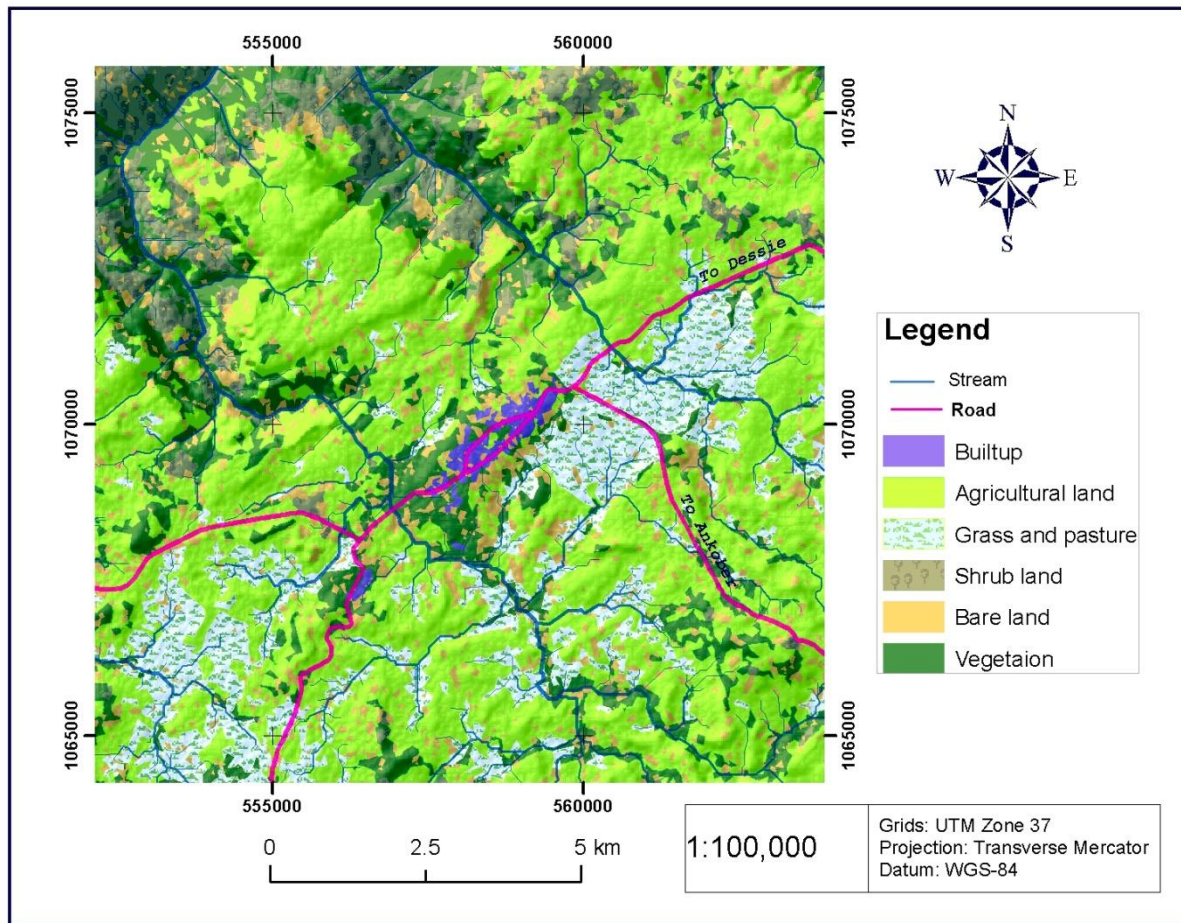


Figure 5. 1: Land-use/land-cover map (1986)

Table 5.2: Absolute area and percentage coverage of Land-use/land-cover (1986)

Land-use/Land-cover Category	1986	
	Area(km ²)	Area (%)
Built-up	1.05	0.60
Agricultural	93.40	51.60
Grass and Pasture	20.93	11.56
Vegetation	31.06	17.16
Water body	0.00	0.00
Shrub land	16.60	9.17
Bare land	17.90	9.89
Total	181	100

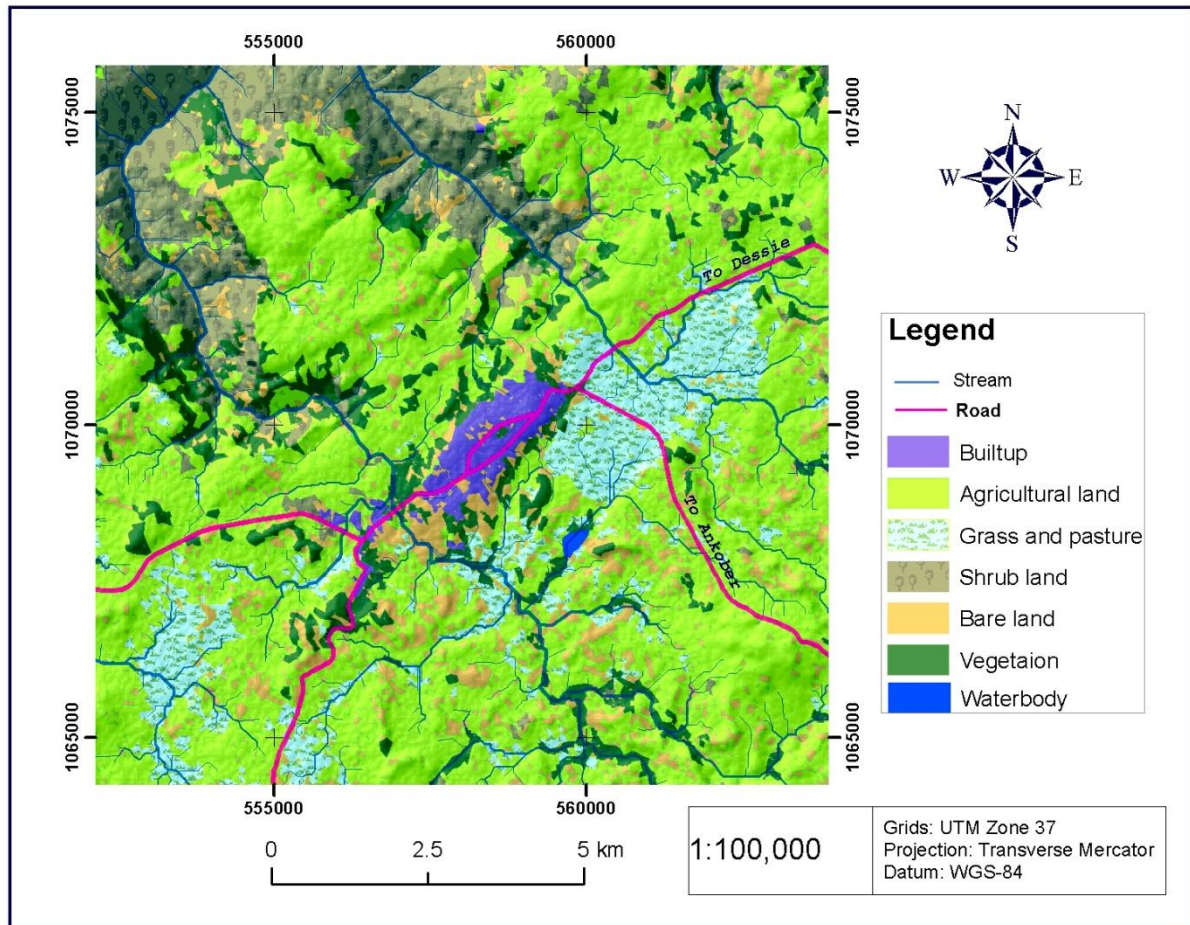


Figure 5. 2: Land-use/land-cover map of the study area (2000)

Table 5.3: Absolute area and percentage coverage of Land-use/land-cover (2000)

Land-use/Land-cover Category	2000	
	Area(km ²)	Area (%)
Built-up	2.43	1.34
Agricultural	96.82	53.49
Grass and Pasture	15.96	9.00
Vegetation	14.66	13.90
Water body	0.04	0.022
Shrub land	25.01	13.82
Bare land	26.12	14.48
Total	181	100

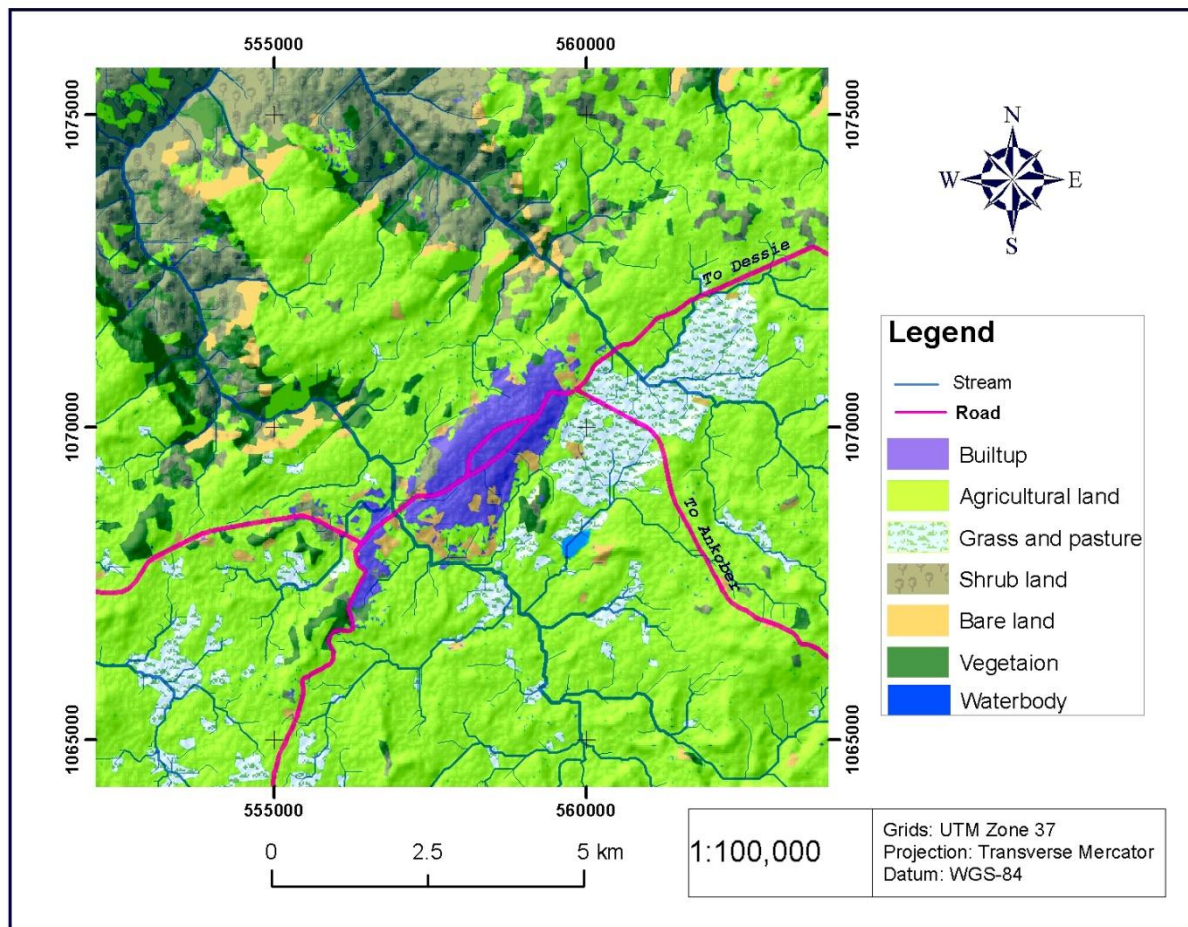


Figure 5. 3: Land-use/land-cover map of the study area (2005).

Table 5.4 Absolute area and percentage coverage of Land-use/land-cover (2005)

Land-use/Land-cover Category	2005	
	Area(km ²)	Area (%)
Built-up	4.61	2.55
Agricultural	110.97	61.31
Grass and Pasture	14.78	8.17
Vegetation	14.53	8.03
Water body	0.11	0.06
Shrub land	23.49	12.98
Bare land	12.55	6.93
Total	181	100

Table 5.4b: Land use/land-cover rate of changes % (1986-2000 and 2000-2005)

Class Name	1986		2000		2005		Change %	
	Area(km ²)	Area (%)	Area(km ²)	Area (%)	Area(km ²)	Area (%)	(1986-2000)	(2000-2005)
Built-up	1.05	0.600	2.430	1.400	4.610	2.55	131.429	89.712
Agricultural land	93.40	51.602	96.820	54.000	110.970	61.31	3.662	14.615
Grass and pasture	20.93	11.564	15.960	9.000	14.780	8.17	-23.746	-7.393
Vegetation	31.06	17.160	14.660	0.040	14.530	8.03	-52.801	-0.887
Waterbody	0.00	0.000	0.040	13.600	0.110	0.06	No data	175.000
Shrub land	16.60	9.171	25.000	8.000	23.490	12.98	50.602	-6.040
Bare land	17.90	9.890	26.120	0.030	12.550	6.93	45.922	-51.953
Class Total	180.94	99.987	181.030	100.000	181.040	100.02	0.050	0.006

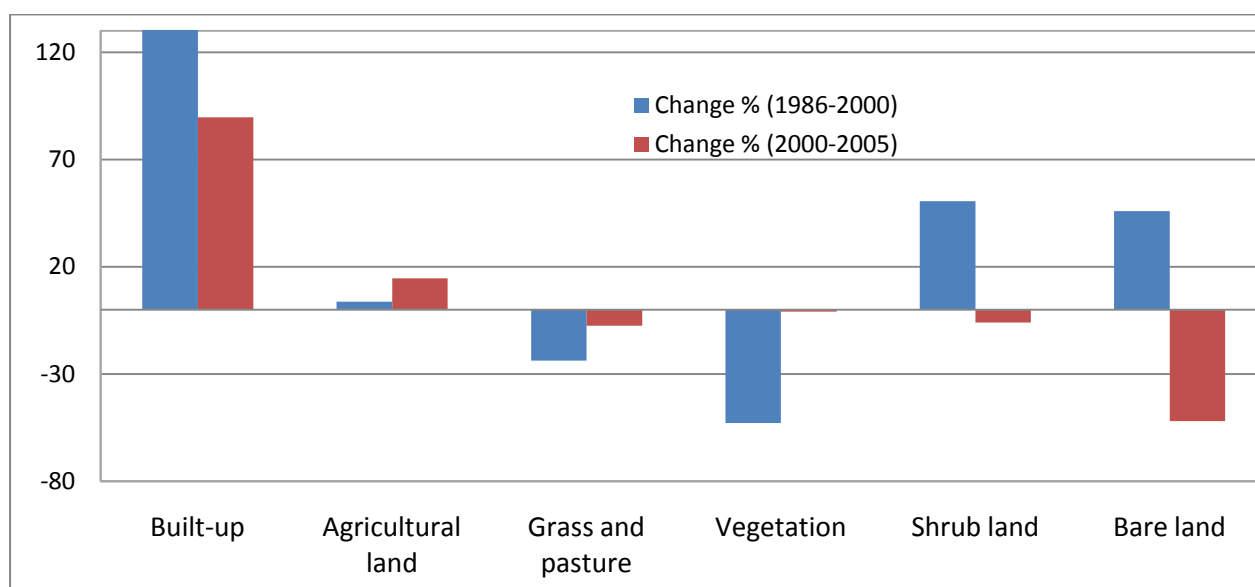


Figure 5. 4: Graph of change in area of land-use/land cover classes.

B. Relative change matrix

Change detracting in area extent and percentage can tell us only the level of increase and decrease of a given land-use/land cover. But the change of one land-use/land-cover class to another land-cover class may not be known without further analysis. Therefore, the thematic change analysis of the individual land-use/land-cover was performed using

ENVI 4.7 software. 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 5.5(a): Land-use/ Land Cover changes (km²) from 1986 to 2000

Class Name	Built-up	Agricultural	Grass & pasture	Vegetation	Waterbody	Shrub land	Bare land	Raw Total
Built-up	0.88	0.38	0.00	0.51	0.00	0.02	0.63	2.42
Agricultural land	0.02	66.44	8.36	10.45	0.00	2.56	8.90	96.72
Grass and pasture	0.00	3.57	10.22	1.04	0.00	0.00	1.06	15.88
Vegetation	0.05	3.82	0.80	7.07	0.00	0.47	2.74	14.96
Waterbody	0.00	0.02	0.02	0.00	0.00	0.00	0.01	0.04
Shrub land	0.01	2.72	0.00	8.47	0.00	12.17	1.46	24.84
Bare land	0.08	16.44	1.54	3.52	0.00	1.38	3.11	26.07
Class Total	1.05	93.40	20.93	31.06	0.00	16.60	17.90	0.00
Class Changes	0.16	26.96	10.72	23.98	0.00	4.43	14.79	0.00
Image Difference	1.38	3.32	-5.05	-16.09	0.04	8.24	8.17	0.00

Table 5.5 (b): Land-use/ Land Cover changes by % from 1986-2000

Class Name	Built-up	Agricultural	Grass & pasture	Vegetation	Shrub land	Bare land	Row Total
Built-up	84.341	0.410	0.012	1.627	0.142	3.498	100.000
Agricultural land	1.860	71.133	39.917	33.648	15.391	49.714	100.000
Grass and pasture	0.000	3.824	48.803	3.340	0.005	5.911	100.000
Vegetation	5.039	4.095	3.822	22.776	2.833	15.312	100.000
Waterbody	0.000	0.018	0.085	0.000	0.000	0.045	100.000
Shrub land	0.853	2.915	0.016	27.277	73.323	8.153	100.000
Bare land	7.907	17.604	7.345	11.333	8.307	17.367	100.000
Class Total	100.000	100.000	100.000	100.000	100.000	100.000	0.000
Class Changes	15.659	28.867	51.197	77.224	26.677	82.633	0.000
Image Difference	131.395	3.553	-24.120	-51.820	49.606	45.617	0.000

The diagonal values from cross tabulation matrix (table 5.5 (a), 5.6 (a) and 5.7 a)) show land-use/land-covers that were unchanged in the given years. This thematic change detection was calculated by subtracting the area of each land cover classification of 1986 from 2000 and 2000 from 2005. The resulting thematic change detection statistics matrix shows how classes have changed from one class at time 1 to another class at time 2.

Class total shows the total area of each land-use/land-cover for the base year and row total shows the total area of the later year. Image difference shows the difference of the total area in each class between the study years. Class change is the total change for each land-

use/ land-cover between the later and the base year under study. The diagonal values shaded with orange color shows the unchanged total area of the land-use/land-cover categories.

Table 5. 6 (a) Land-use/ Land Cover changes (km²) (2000-2005)

Class Name	Built-up	Agricultural	Grass & pasture	Vegetation	Waterbody	Shrub land	Bare land	Raw Total
Built-up	2.26	0.29	0.08	0.83	0.00	0.09	1.05	4.61
Agricultural land	0.03	73.39	8.47	4.08	0.00	9.00	16.00	110.97
Grass and pasture	0.00	6.75	6.61	0.37	0.00	0.01	1.04	14.78
Vegetation	0.00	2.96	0.07	6.49	0.00	3.04	1.96	14.53
Waterbody	0.00	0.04	0.00	0.01	0.04	0.00	0.02	0.11
Shrub land	0.02	5.76	0.06	2.19	0.00	12.32	3.14	23.49
Bare land	0.12	7.62	0.67	0.68	0.00	0.54	2.91	12.55
Class Total	2.43	96.82	15.96	14.66	0.04	25.00	26.12	0.00
Class Changes	0.17	23.43	9.36	8.16	0.00	12.68	23.21	0.00
Image Difference	2.18	14.15	-1.19	-0.12	0.06	-1.51	-13.57	0.00

Table 5. 6(b): Land-use/ Land Cover changes (%) from 2000-2005

Class Name	Built-up	Agricultural	Grass & pasture	Vegetation	Waterbody	Shrub land	Bare land	Raw Total
Built-up	93.183	0.302	0.524	5.656	0.000	0.353	4.024	100.000
Agricultural land	1.112	75.803	53.070	27.842	2.128	35.984	61.255	100.000
Grass and pasture	0.000	6.970	41.377	2.518	0.000	0.050	3.990	100.000
Vegetation	0.037	3.062	0.468	44.298	0.000	12.180	7.487	100.000
Waterbody	0.000	0.038	0.000	0.043	97.872	0.000	0.083	100.000
Shrub land	0.815	5.949	0.372	14.971	0.000	49.276	12.015	100.000
Bare land	4.854	7.876	4.189	4.673	0.000	2.157	11.146	100.000
Class Total	100.000	100.000	100.000	100.000	100.000	100.000	100.000	0.000
Class Total	6.817	24.197	58.623	55.702	2.128	50.724	88.854	0.000
Image Difference	89.700	14.615	-7.431	-0.841	151.064	-6.038	-51.966	0.000

Table 5. 7 (a): Land-use/ Land Cover changes (km²) from 1986 to 2005

Class Name	Built-up	Agricultural	Grass & pasture	Vegetation	Waterbody	Shrub land	Bare land	Raw Total
Built-up	0.96	1.02	0.14	1.26	0.00	0.09	1.10	4.58
Agricultural land	0.01	70.05	12.79	13.40	0.00	4.68	9.81	110.73
Grass and pasture	0.00	5.04	6.87	1.58	0.00	0.03	1.17	14.68
Vegetation	0.02	4.41	0.09	6.79	0.00	1.42	1.68	14.41
Waterbody	0.00	0.03	0.05	0.01	0.00	0.00	0.02	0.11
Shrub land	0.03	5.53	0.11	5.92	0.00	9.66	2.41	23.66
Bare land	0.02	7.32	0.89	2.10	0.00	0.72	1.72	12.77
Class Total	1.05	93.40	20.93	31.06	0.00	16.60	17.90	0.00
Class Changes	0.08	23.35	14.06	24.26	0.00	6.94	16.19	0.00
Image Difference	3.53	17.33	-6.25	-16.64	0.11	7.06	-5.13	0.00

Table 5. 7(b): Land-use/ Land Cover changes (%) from 1986 to 2005

Class Name	Built-up	Agricultural	Grass & pasture	Vegetation	Waterbody	Shrub land	Bare land	Row total
Built-up	92.016	1.096	0.648	4.057	0.000	0.548	6.170	100.000
Agricultural land	1.008	74.997	61.092	43.134	0.000	28.208	54.768	100.000
Grass and pasture	0.000	5.394	32.816	5.092	0.000	0.161	6.533	100.000
Vegetation	2.016	4.726	0.427	21.878	0.000	8.542	9.364	100.000
Waterbody	0.000	0.029	0.244	0.031	0.000	0.000	0.100	100.000
Shrub land	2.946	5.920	0.528	19.048	0.000	58.177	13.479	100.000
Bare land	2.016	7.839	4.245	6.758	0.000	4.364	9.586	100.000
Class Total	100.000	100.000	100.000	100.000	0.000	100.000	100.000	0.000
Class Changes	7.984	25.003	67.184	78.122	0.000	41.823	90.414	0.000
Image Difference	336.977	18.555	-29.848	-53.586	0.000	42.493	-28.668	0.000

The primary focus of this study was to understand the level of change in built-up area for the given years. The major land-use/land-cover that contributed to the increase of built-up area is presented in table 5.8. Based on the land-use/land-cover change statistics between 1986 and 2000, 0.38 km² of agricultural land, 0.51 km², vegetation, and 0.02 km² of shrub land and 0.62 km² bare lands were converted to built-up area. Between 2000 -2005, 0.29 km² of agricultural land, 0.08 km², of grass land, 0.83 of km² of vegetation, 0.09 km² of shrub land and 1.05 km² of bare land were converted to built-up area (Figure 5.5).

Table 5. 8: Land-use/Land-cover class conversion to Built-up area in km²

Land-use/Land-Cover	1986-2000	%	2000-2005	%
Agricultural to Built-up	0.38	24.68	0.29	12.39
Grass to Built-up	0.00	0.00	0.08	3.42
Vegetation to Built-up	0.51	33.12	0.83	35.47
Waterbody to Built-up	0.00	0.00	0.00	0.00
Shrub land to Built-up	0.02	1.30	0.09	3.85
Bare Land to Built-up	0.63	40.91	1.05	44.87
Total	1.54	100.00	2.34	100.00

C. Change statistics errors

For the change matrix between 1986 and 2000, bare land contributes 41% and agricultural land 25% of the total area change converted to built-up land (Table 5.9). The vegetation (tree canopy along roads) cover converted to built-up was 33%. These changes may seem to be classification errors. But in some cases there is a probability that vegetation area may

be converted to roads. Roads are mostly included to built-up area when classified from low resolution image. But when tree canopies along the roads grow, it is common to see mixed pixels on low spatial resolution satellite image. Therefore, pixels near the roads may be generalized as vegetation or as built-up during post classification processing such as majority filters and boundary clean

Due to the heterogeneous nature of urban area, spectral based land-use/land-cover changes have always some drawbacks. One of the problems occurs is the existence of mixed pixels on different objects which become spectrally similar one another. For example, from land-use/land cover conversion statistics, there were errors indicating the conversion of built-up area to land-use/land-cover. However, the conversion of built-up area to other land cover classes is unlikely to happen especially within 5 years (2000 and 2005). One solution that has been done to correct this problem was to compare the result with high resolution Ikonos image.

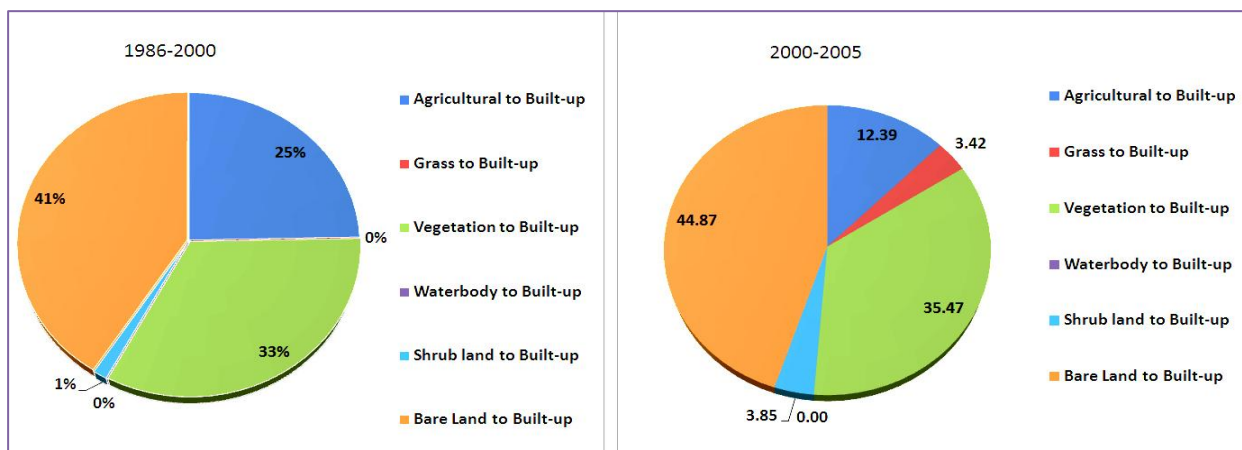


Figure 5.5: Land-use/ land-cover class contribute to net change to built-up area (1986-2005)

5.2. Housing Unit Approach Urban Growth Analysis

Understanding the urban growth analysis and population growth helps to plan for future and may help to identify the current problems, trends, and issues facing the sustainable development of the town. Urban growth

5.2.1. Urban population Growth

Knowledge of past and current population trends and projecting population growth into the future helps to determine the level of municipal services that will be needed for future growth of the town.

The population census data from Central Statistics Agency of Ethiopia were used to calculate total population growth between 1994 and 2007. The most recent census data (2007) show that Debre Birhan town grew by 65231 people, and had a growth rate of 5.3% annually. Table 5.10 presents population growth of the census years of October 1994 to May 2007.

Table 5. 2 Absolute growth and Annual growth rate of population

Year	Absolute Growth	Growth Rate%	Annual Growth Rate%
1984-1994	13080	51	5.1
1984-2007	39537	154.37	6.7
1994-2007	26497	68.4	5.3

Source:-Central Statistics Agency of Ethiopia

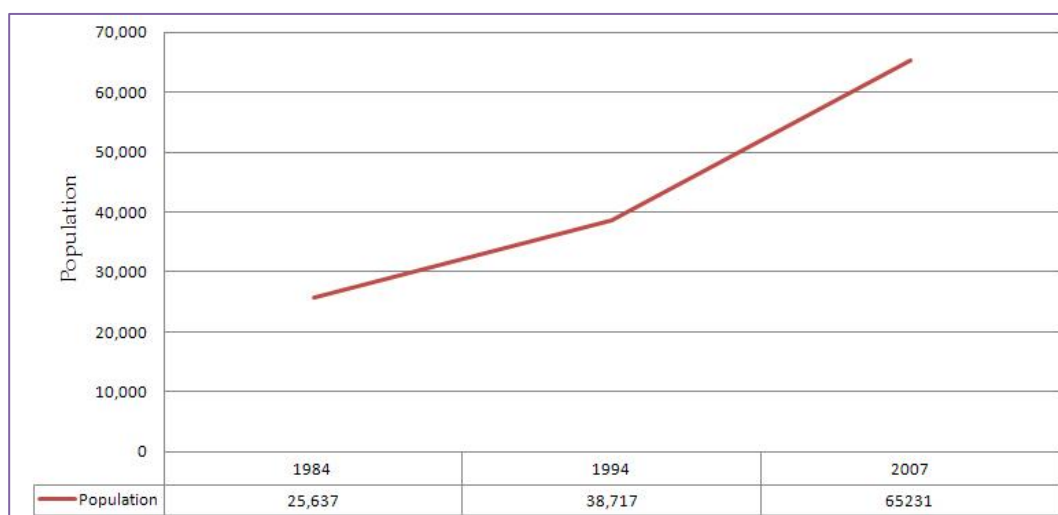


Figure 5. 6: Absolute population growth (1984-2007).

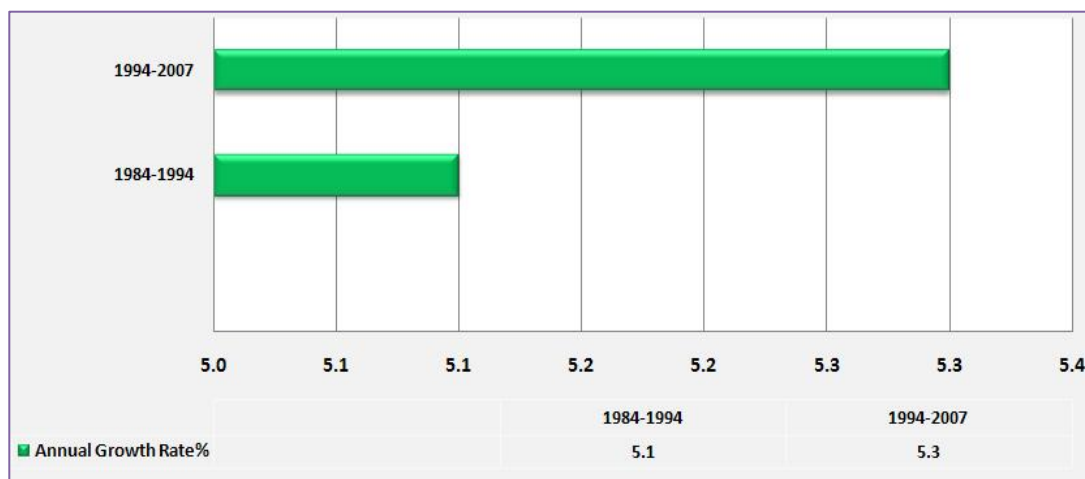


Figure 5. 7: Average annual growth rate of population (1984-2007)

The population grew 51% between 1984 and 1994, and 68.88% percent between 1994 and 2007. The annual growth rate between 1984 and 1994 and between 1994 and 2007 was 5.1% and 5.3% respectively (Table 5.10). Generally, the analysis of population statistics shows high population size and the average annual population growth rate of the town generally shows very fast. From this analysis it is understood that population pressures in the town might lead to stimulate residential development extensively.

A. Population and housing distribution by Kebele and Block

Table 5. 3: Population of Debre Birhan town by Kebele (1994 and 2007)

Kebele	1994			2007		
	Both	M	F	Both	M	F
001	3301	1448	1853	6853	3309	3544
002	4115	1900	2215	8286	3865	4421
003	4645	2082	2563	6218	3103	3115
004	6074	3228	2846	8675	4512	4163
005	3665	1677	1988	5579	2659	2920
006	4854	2204	2650	8007	3860	4147
007	2556	1135	1421	4183	2026	2157
008	4042	1795	2247	8292	3801	4491
009	5465	2449	3016	9138	4533	4605
Total	38717	17918	20799	65231	31668	33563

Source:-Central Statistics Agency of Ethiopia.

Table 5. 4 : Number of Housing units and annual growth rate by Kebele(1994-2007)

Kebele	Housing Units (1994)	Housing Units(2007)	Percentage change of housing units (1994-2007)	Housing Annual Growth rate%	Population 1994	Population 2007	Percentage change of population(1994-2007)	Population Annual Growth rate(%)
1	780	1780	1.2816	9.85%	3301	6853	107.50%	8.26%
2	989	2610	1.638	12.98%	4115	8286	101.20%	7.78%
3	1111	2039	0.8352	6.42%	4645	6218	33.84%	2.60%
4	1297	2680	1.2792	9.83%	6074	8675	42.84%	3.29%
5	874	1848	1.1144	8.57%	3665	5579	52.20%	4.01%
6	1252	2694	1.152	8.86%	4854	8007	64.92%	4.99%
7	599	1263	1.1076	8.52%	2556	4183	63.60%	4.89%
8	1013	2327	1.2984	9.98%	4042	8292	105.12%	8.09%
9	1402	2484	0.768	5.90%	5465	9138	67.20%	5.17%
Total	9317	19725	1.116	8.58%	38711	65231	68.88%	5.30%

According to the 1994 and 2007 housing and census report of Central Statistics Agency of Ethiopia, there were 9317 housing units in October 1994 and 19725 housing units in May 2007(Table 5.12) in Debre Birhan town. Between 1994 and 2007, the town's housing stock increased by 10408 units, or 111.60%. This percentage increase is greater than the population percentage change of 68.88% for the same year.

According to the statistics (Figure 5.6), the number of housing development and provision has not been proportionate with the rate of population growth in Debre Birhan town. Factors such as the lack of available finances, limited access to land and overall poor planning for the provision and distribution of housing has resulted in this disproportional distribution of housing development.

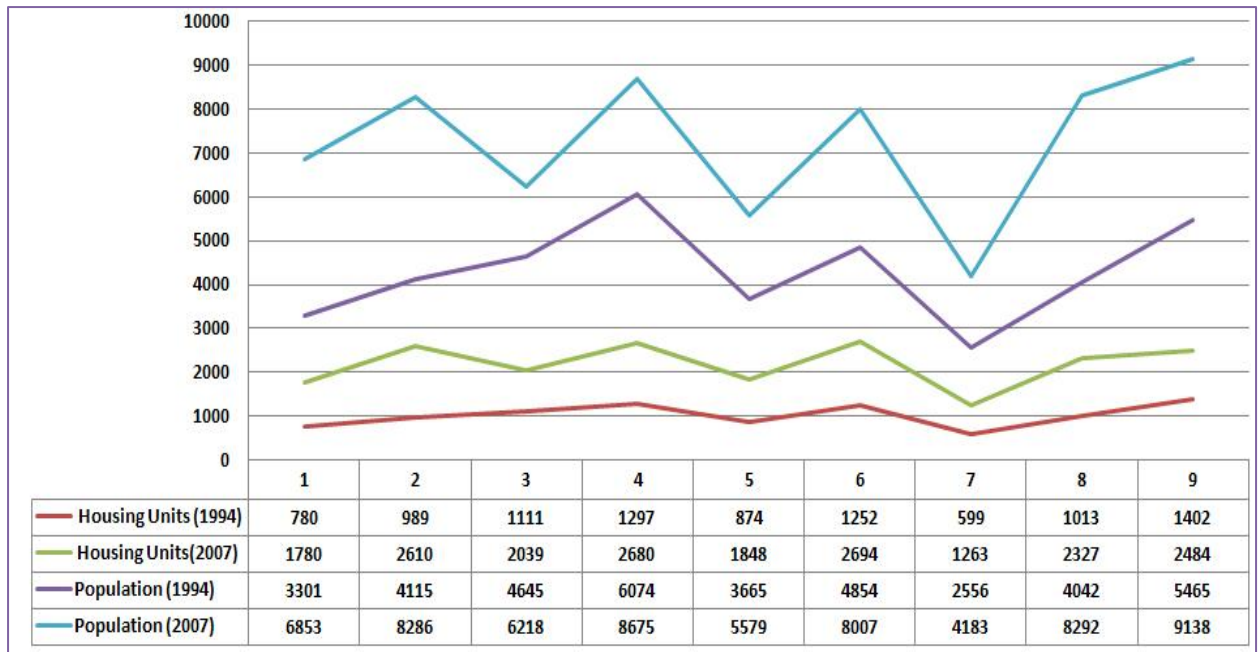


Figure 5. 8: Population distribution and housing stock by Kebele(1984-2007)

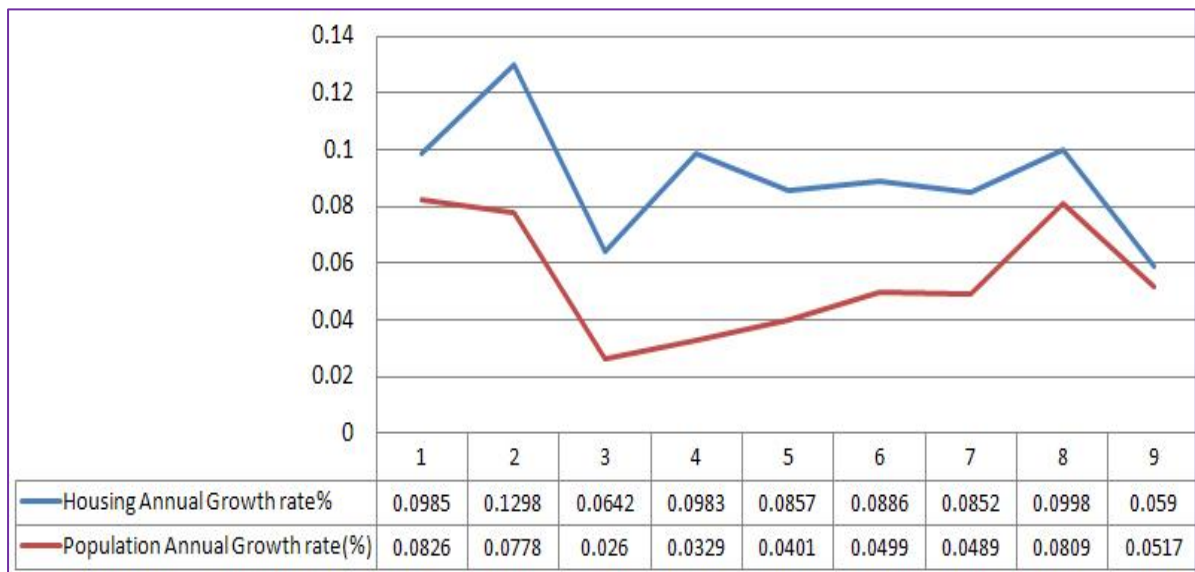


Figure 5. 9: Annual growth changes in Housing Units against annual growth changes in Population

Figure 5.9 shows the annual growth rate in housing units compared to the population growth rate. The rate of housing growth shows faster than town's population growth rate.

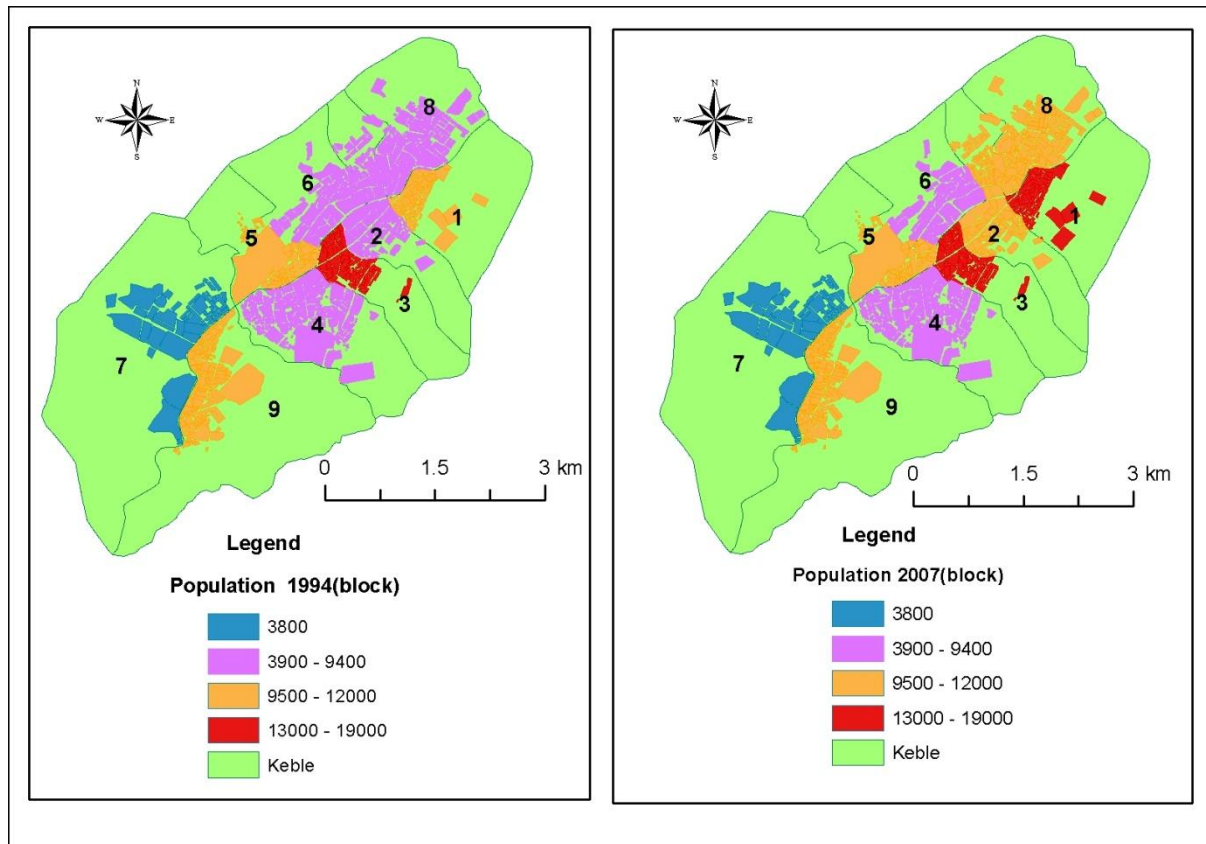


Figure 5. 10: population distribution by street blocks (1994 and 2007)

The population data of 1994 and 2007 were used to calculate the population density for each block using ArcGIS 10 software. Figure 5.10 shows the population size the town by block. In 1994 blocks in Kebele 3 had the highest population size and blocks in Kebele 7 had the lowest population size. In 2007, blocks in Kebele 3 and Kebele 1 had the highest population size and Kebele 7 had the lowest population size.

B. Population and housing density by Kebele and block

The population density of any region is found by dividing its population by its area: Population density is measured in people per square kilometer.

Due to the absence of census block map, I used Kebele boundary and street block map to examine population density of the study area. Density per administrative unit area is

normally calculated by taking all land area such as open spaces, water body, etc to density calculation. A better technique is calculating population density excluding opens spaces.

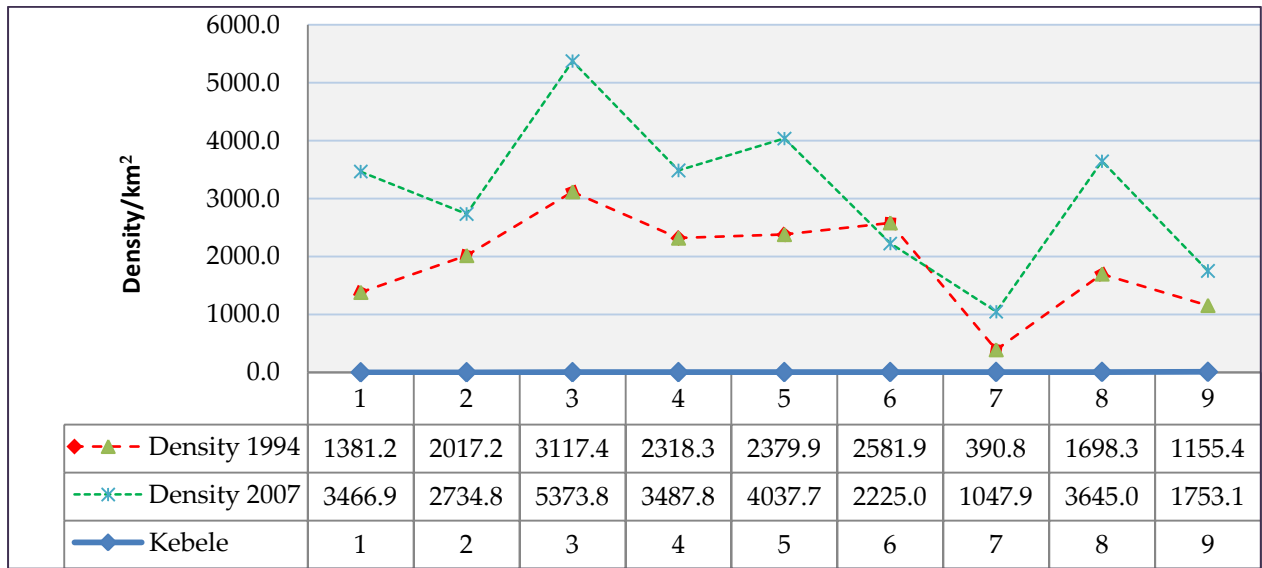


Figure 5. 11: Population density By Kebele

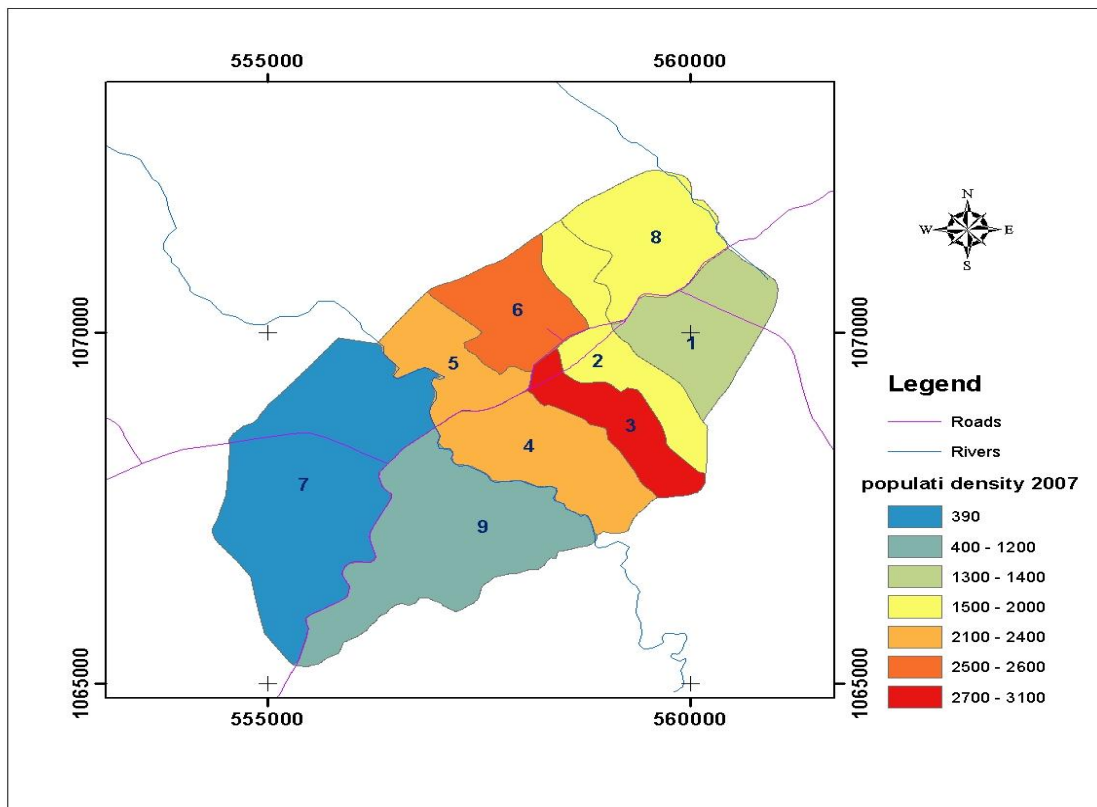


Figure 5. 12: Population Density by Kebele(2007)

Figure 5.11 and Figure 5.12 shows that the highest population density was exhibited in Kebele 3 for both 1994 and 2007 and relatively the lowest population density has been seen in Kebele 7 and Kebele 9.

There are a wide variety of density measures. All density measures fall in to: **gross density** and **net density**. Gross density indicates that the entire land area is used as the basis for calculation and net densities exclude certain land uses or features such as regional open space (Forsyth, 2003). Therefore, the density of population by Kebele can be considered as gross density but by excluding some open space from the Kebele, the block density has been calculated using a census data of 1994 and 2007.

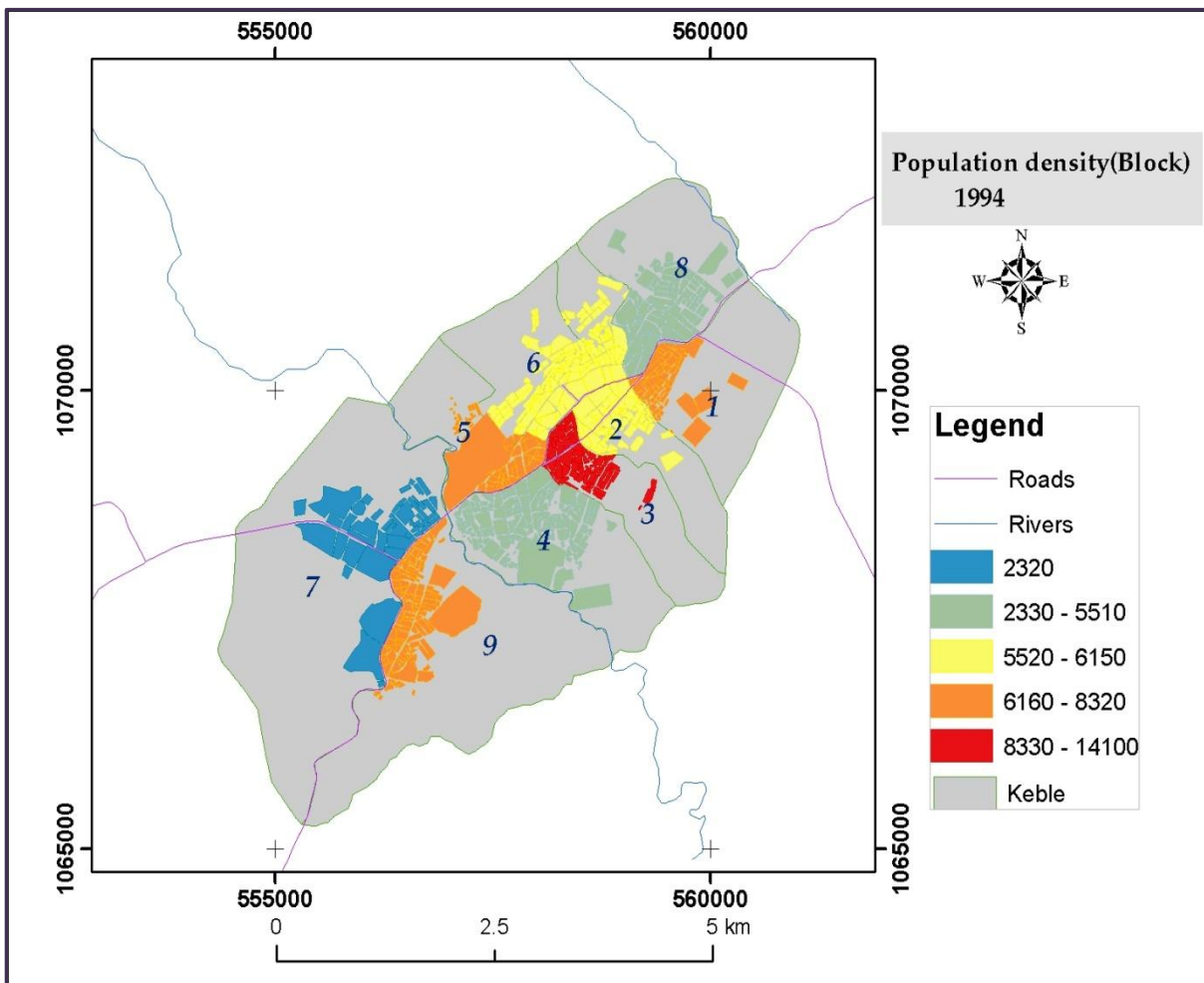


Figure 5. 13: Population density by block boundary (1994) in km²

The map in Figure 5.13 shows the population density per block area (km²) in each Kebele. This calculation was performed by dividing the total population of the Kebele by total area of block within the Kebele.

The difference of this population density from the Kebele population density of this map shows the population density based on the land areas that contain housing units and excluding all agricultural land and other open spaces.

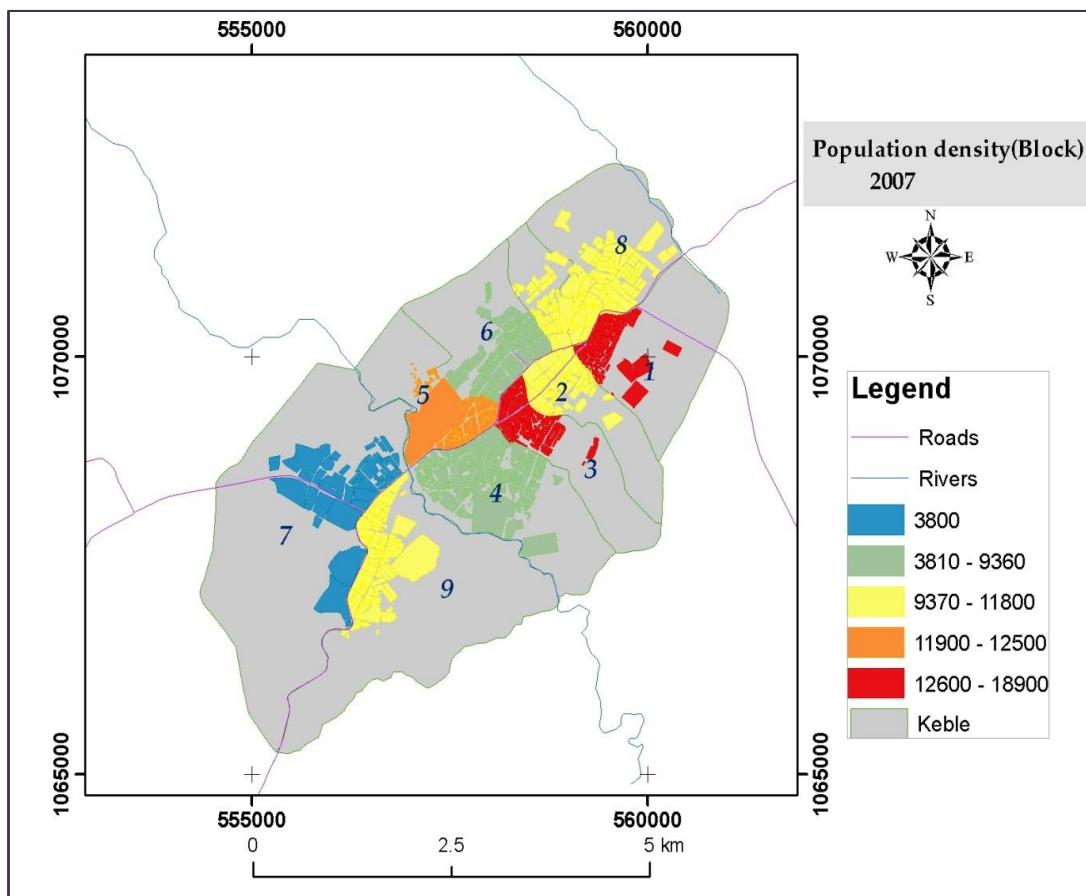


Figure 5. 14: Population density by block boundary (2007) in km²

The block density map of 1994 and 2007 (Figure 5.14) indicated that the highest population density occurred in Kebele 3 which was the same as population density by Kebele in Figure 5.14. The most striking difference of population density by Kebele and street block was that the block density had a higher density. The reason for this was that the total base

area used for block density calculation was lower than the base area used in each Kebele. Kebele 7 and Kebele 9 had a large potential land for residential house development between the study year of 1995 and 2007. These Kebeles had the lowest population density than other Kebeles. In general, the north east and central part of the town had a higher population density than the west part of the town.

5.2.2. Physical urban growth Analysis

Debre Birhan town shows a fast growth within the last seven years of time (2000- 2008). The growth of the Debre Birhan town area in the last study years (2000-2008) has occurred through the linking of a number of smaller urban settlements spread along the main roads to northeast and west direction from its center. The central part of the town is characterized by relatively high rise buildings and the peripheral part of the town is dominated by low density houses with scatter development (sprawl).



Plate 5.1: Horizontal expansion (left) and vertical growth (right) of built-up area

Debre Birhan town's main urban structure is composed of nine KeBELs (Equivalent to Wards). Geographic Information System and Remote Sensing data and technique was used to study the physical extent of urban growth and the spatial pattern of dwelling units' growth.

5.2.2.1. Urban growth analysis from land-use/land-cover map

A. Growth Rate of Built-up area

Data from Landsat image helps us to map urban growth change results a change in landscape from historical perspective.

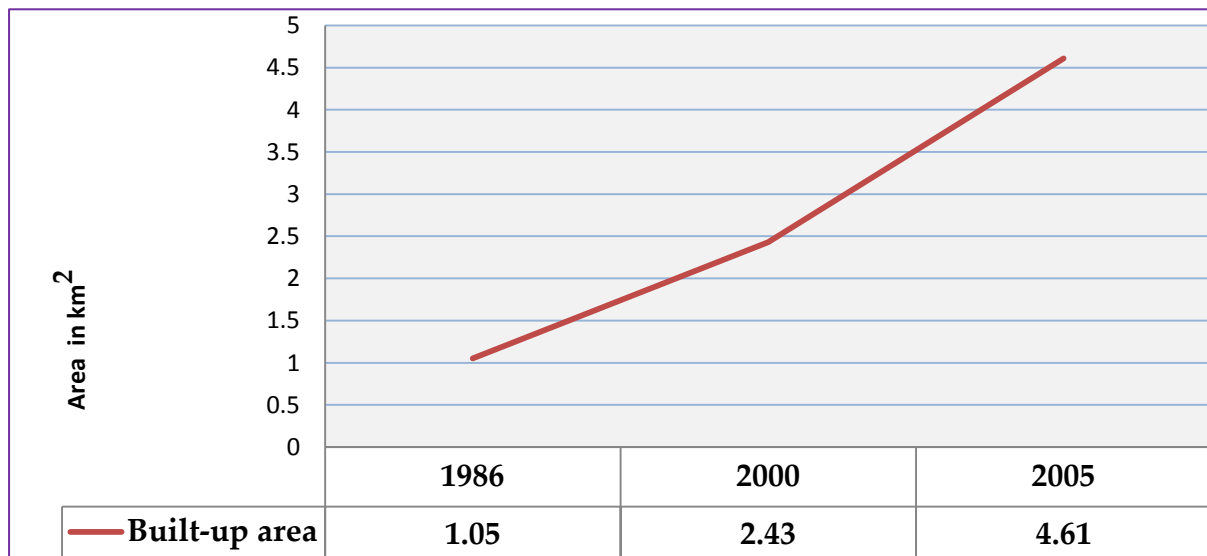


Figure 5. 15: Area (km²) and Growth rate of built-up area (1986-2005).

Between 1986 and 2000 the urban development in Debre Birhan town was very small compared to the development between 2000 and 2005. From the classified images, the urbanization growth was mainly on bare soil and agricultural land. The graph of the town population obviously indicated that there was a massive increase of population between 2000 and 2005.

B. Urban growth speed

The percentage change per year of the urban land uses/ land cover has been calculated and presented in Table 5.13. The rate of change of land use/land cover per year in the periods 1986-2000 and 2000-2005 was 9.38% and 17%, respectively.

Table 5. 5: Built-up area absolute growth and annual rate of growth rate%.

Year	1986	2000	2005
Built-up area (km ²)	1.05	2.43	4.61
	1986-2000		2000-2005
Absolute growth (Area)	1.38	2.18	
Percentage change (%)	131.43	89.7	
Annual growth rate (%)	9.38	17.00%	

To calculate the urban growth speed, one approach is to use observed population growth rate as the basis for assuming the rate of increase in the urban land uses. The effect of the (exponential) growth rate can be calculated using the following formula:

$$A_f = A_b (1 + \%/100)^{(f-b)} \dots \dots \dots 3$$

Where: "A" is area; "f" is the future year, "b" base year. And % is rate of change per year. Applying this formula for 2000 and 2005 urban growth on the study area, using the annual growth rate of 17%,

$$A_{2015} = A_{2005} * (1 + 17/100)^{(2015-2005)}$$

$$A_{2015} = A_{2000} * (1.17)^{(10)}$$

$$A_{2015} = 4.61 * (1.17)^{(10)}$$

$$A_{2015} = 4.61 * 4.81$$

$$A_{2015} = 53.93 \text{ km}^2$$

At current growth rate, the urban area of Debre Birhan town will be 53.93 km² after 10 year (2015). The estimation is using a linear growth rate annually disregarding rules and regulations that may be practical by the town administration. This prediction may occur if there is no any regulation mechanism on the growth rate of population and urban sprawl on the study area.

5.2.2.2. Urban growth analysis with building footprint data

Population increases, so does the need for new housing, schools, and transportation networks. Especially in developing country where population growth is high, the urban area is expanding without sufficient infrastructure provision. The growth of physical urban area associated with population growth creates a significant change on urban landscape. Therefore, the urban area is characterized by very low density, leapfrog and fragmented pattern of land development which commonly called as sprawl.

Due to the heterogeneous nature of most of the urban environment, data from high resolution imagery and topographic map helps to understand the pattern and sprawl nature of urban area better than low resolution Landsat image.

Although there is a no a standard method or techniques to measure urban sprawl, there are some indicators which are commonly used by researchers in urban sprawl assessment. Some of the sprawl metrics as has been mentioned on the literature of this thesis includes density, compactness, proximity, concentration, nuclearity and centrality (Galster and Cutsinger, 2007).

In this work, high resolution Ikonos satellite image (2008) and data from topographic map (1995) was used to study the urban growth and sprawl of the town. To identify housing sprawl, a GIS based map was prepared and tried to show where sprawl occurred on the study area. In order to analysis the pattern of residential houses on the study area:

- A GIS map was used to asses visually where scatter (sprawl) development occurred on the study area in two time frames (1995 and 2005).
- Housing density from polygon centroid of each housing units was used to identify low and high housing development(1995-2008)
- One of the core functions of ArcGIS the spatial statistics was used to analyze the clusters and desperation development of housing units(2008)

Visual inspection of these points reveals some clusters of high housing units, but additional analysis is needed to produce statistically sound results

1. Mapping and Visual assessment of urban growth

By visually displaying land based resource including potential environmental and cultural resource impacts and economic implications, GIS can help planners, public officials, and citizens better manage urban growth (EPA, 2002).

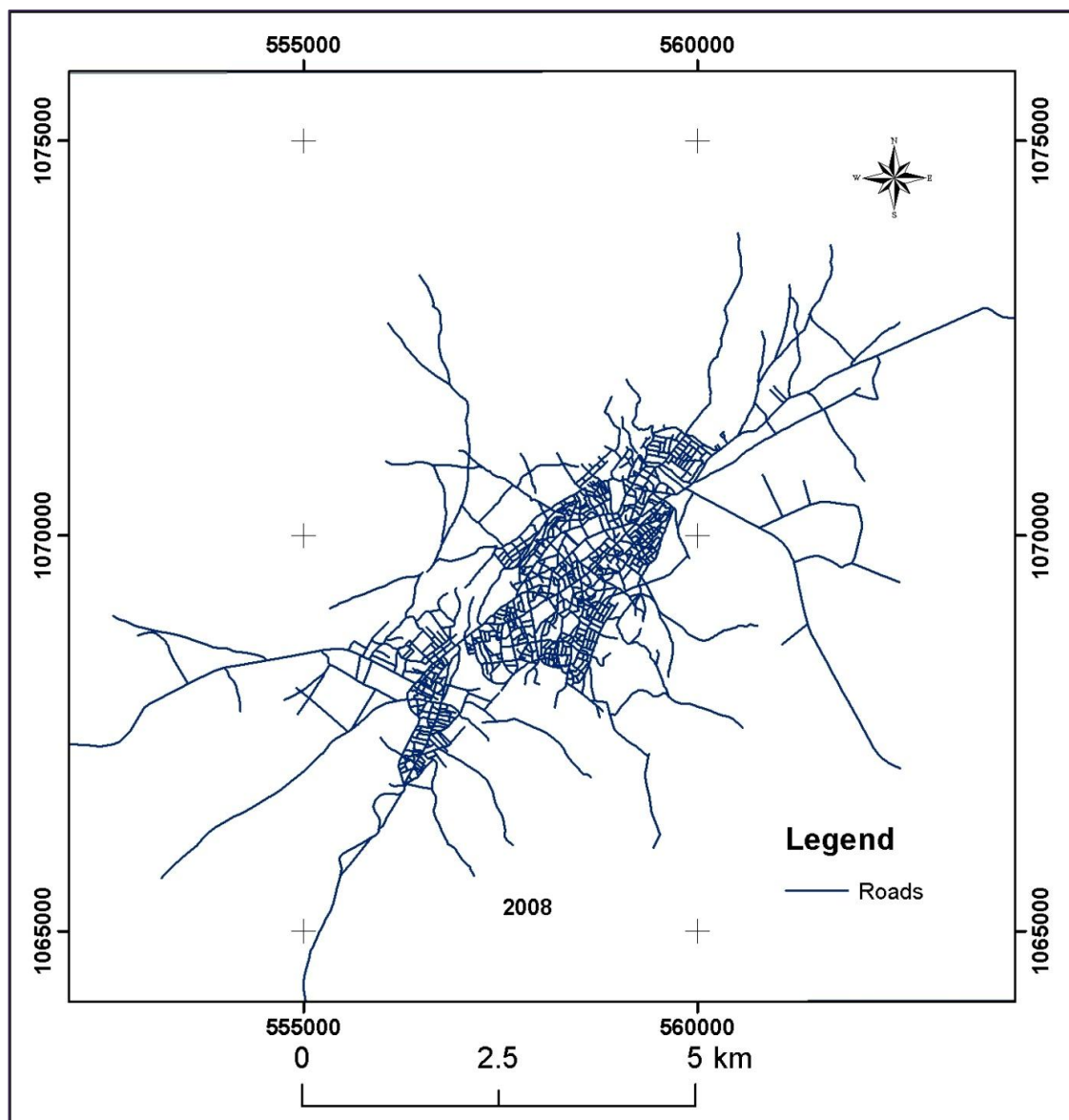


Figure 5. 16: Road networks (2008).

A map provides the visual aspect from which studies on urban sprawl can begin in relation to urban growth. Mapping urban phenomena helps to identify where urban sprawl occurs and where compact form of development can be identified. A Geographic Information System is useful for mapping the spatial pattern, direction and distribution of urban areas.

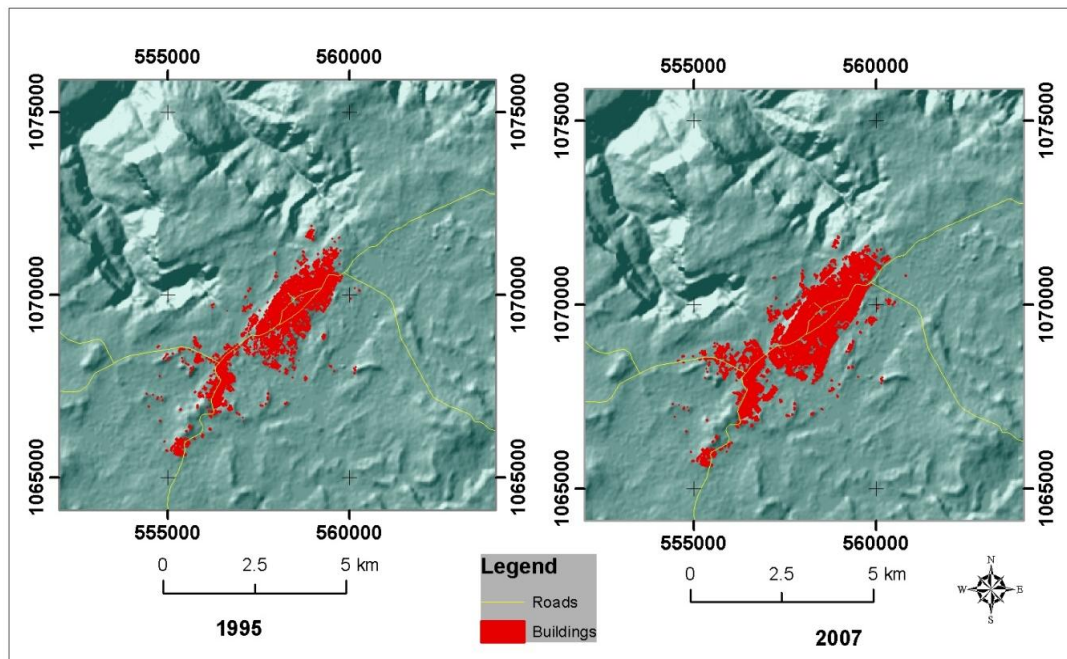


Figure 5.17: Built-up area (1995 and 2008)

The distribution and pattern of housing in Debre Birhan town from 1995 through 2008 can be directly examined through direct visual observation from a GIS map presented in Figure 5.17. From the map of housing spatial distribution, it has been shown that the development of houses in 2008 were mostly towards the north east and west peripheral part of town. The remaining houses development distribution shows development inside the central part of the town and along the major roads.

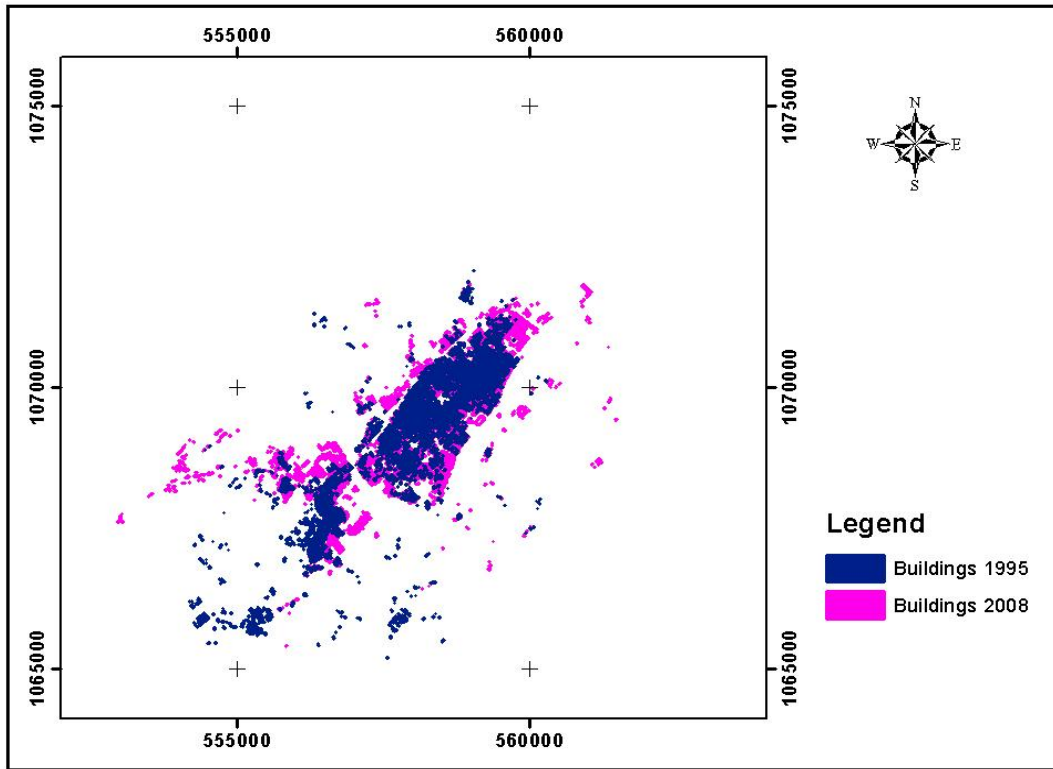


Figure 5. 18: Built up expansion of Debre Birhan town, 1995-2008

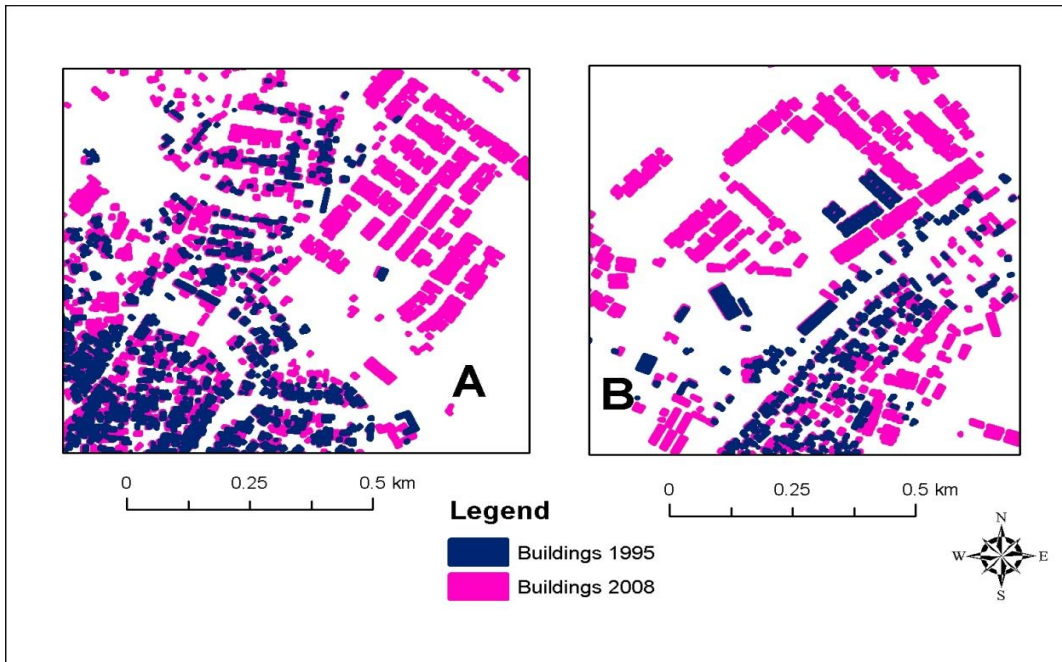


Figure 5. 19: Building footprint (1995 and 2008), North east part of the town

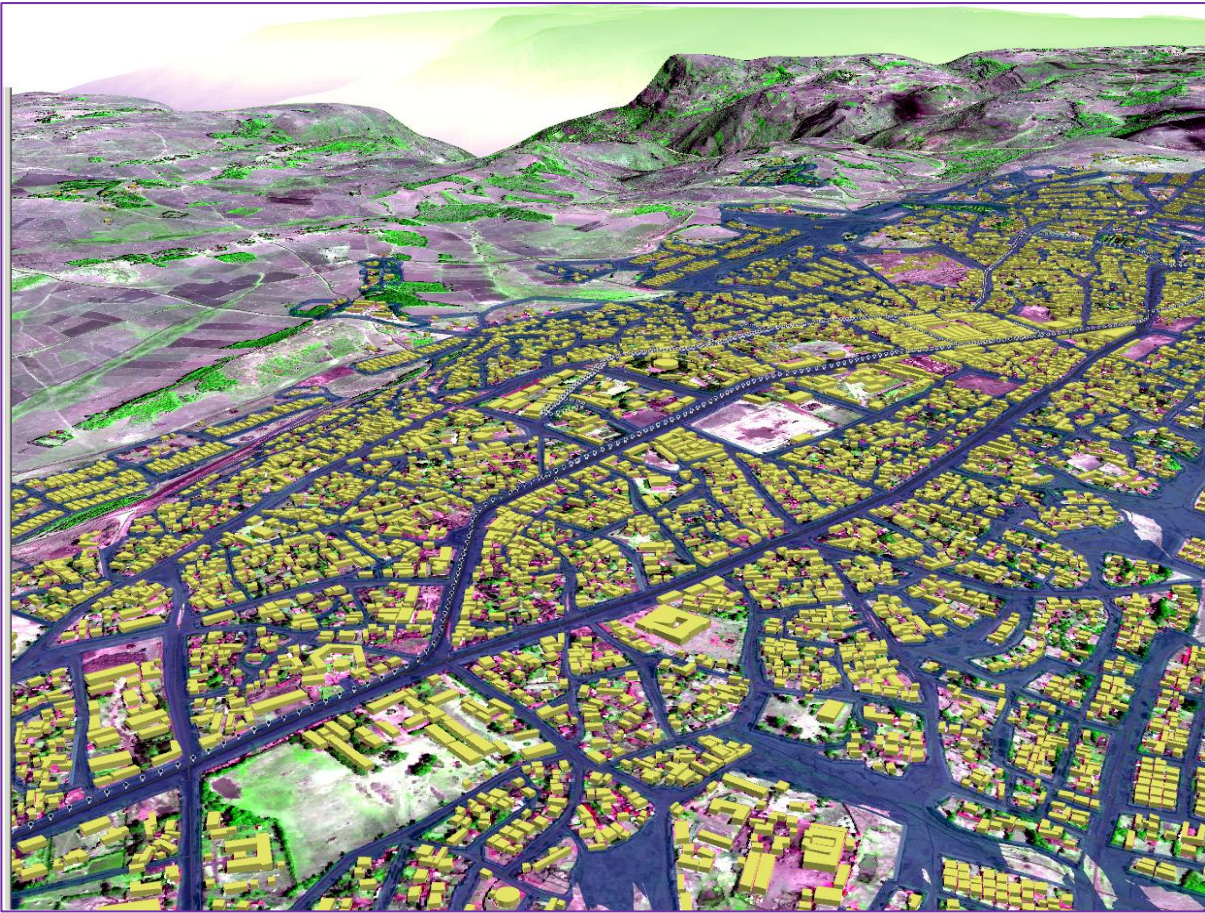


Figure 5. 20: Building footprint (2008) overlaid on Ikonos image and draped on DEM (Central part of the town).

The expansion of the town needs an in-fill process which can reduce the sprawl of housing development on agricultural land. The sprawling pattern is the results of a fast- growth and, absence of tight control of developers according to a defined plan. If there is a town belt that restricts further informal housing development, sprawling growth begins to slow down and the growth of the urbanized area expands into filling up the vacant lands left behind by urban sprawl.

A recent field photograph with digital camera (January 2011) of Figure 5.21 shows an expansion of the built-up are to agricultural land (2008, Ikonos image draped on DEM).

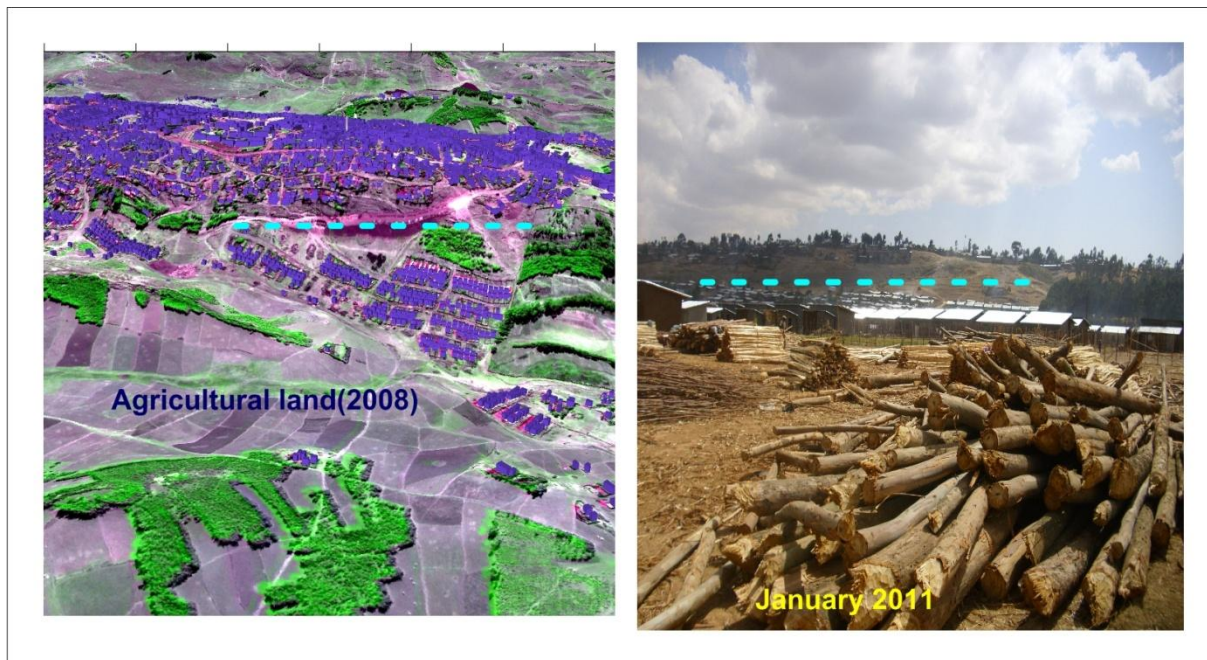


Figure 5. 21: built-up area expansion to agricultural land (field photograph of 2011)

The sprawling of houses was not limited to the town's administrative boundary. Figure 5.22 shows the development of housing beyond the Kebele boundary(1995& 2008).

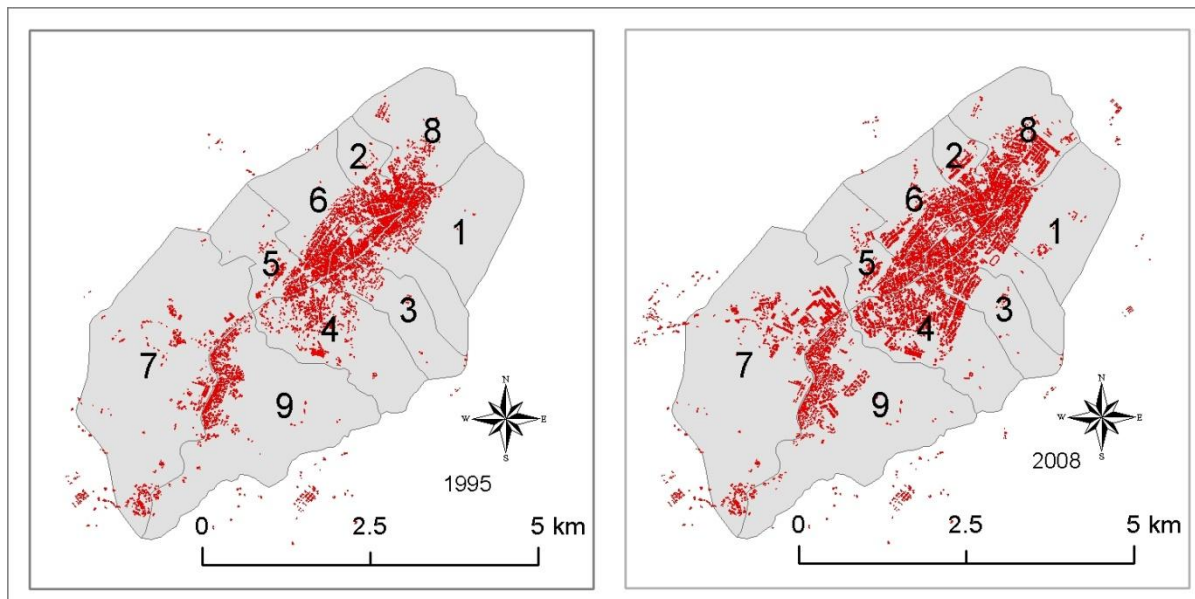


Figure 5. 22: Scattering of houses beyond the Kebele boundary (1995 & 2008)

2. Spatial assessment of urban building population

Spatial analysis based on building population is very rare or absent in GIS. Spatial analysis based on building population data is a key benefit in disaster management to provide humanitarian assistance, for customer's physical distribution is one of the key factors in market management and business site selection (Lwin, 2010).

However, there is always a problem to get building population data to use in GIS analyses since building population data is not available at polygon level for public use. Therefore, building footprints digitized from high resolution Ikonos image and automatically extracted from scanned topographic map were used to investigate spatial distribution of houses. This is important to understand clustering or dispersion of housing units on the study area in order to plan the sustainable growth of the town.

Visual assessment of the residential house which contains the results from the digitized polygon of residential houses from Ikonos image and the automatically extracted polygon of residential houses from topographic map showed success in distinguishing between different distributions of residential development.

A. Housing Density

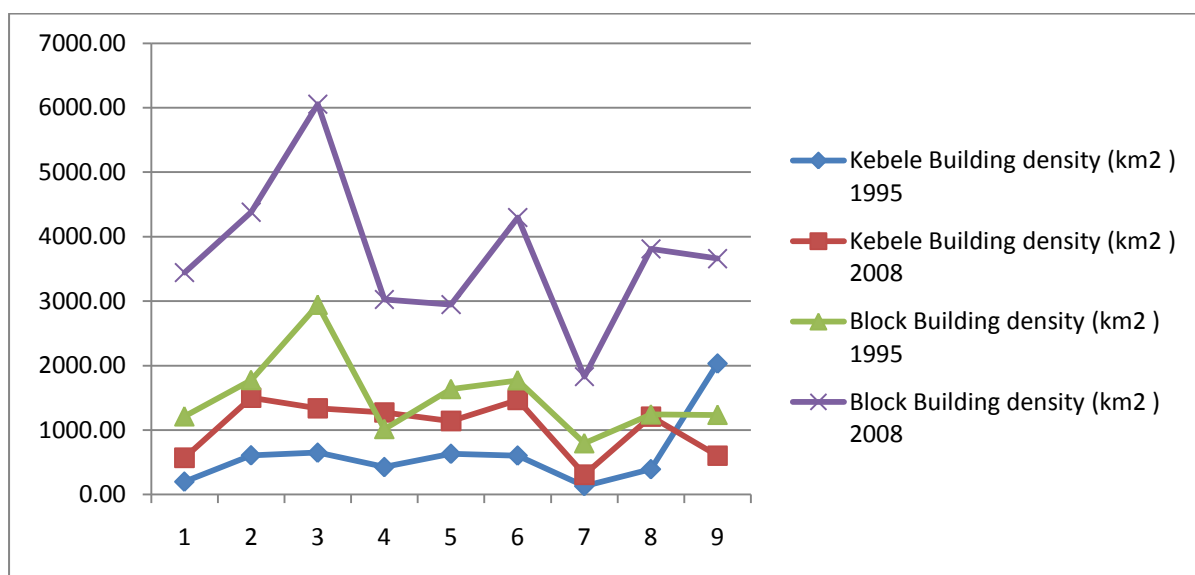
Density has been one of the most employed variables to look at the spatial structure of cities. Probably because of that, it has also been one of the phenomena to which more attention has been paid in order to measure sprawl, and several ways have been proposed to capture it, with different levels of complexity and different interests.

Block Density can be calculated as dwelling unit divided by block area measured to the curb if the boundaries of the street block are clear. This is relatively easy to measure from aerial photos and census data (Forsyth, 2003).

We have data such as blocks and buildings, for the areas under study, based on which we can compute the density of buildings per square kilometer. As shown in Table 5.14, there is a strong relation between the density of buildings per square kilometer at block level and at Kebele level for the 1995 and 2008 years of data.

Table 5. 6: Building density/km² at block and Kebele level

Kebele	Area km ²	Block Area(km ²)	Buildings 1995	Buildings 2007	Kebele		Block	
					Building density (km ²) 1995	Building density (km ²) 2008	Building density (km ²) 1995	Building density (km ²) 2008
1	2.39	0.396777	481	1366	201.26	571.55	1212.27	3442.74
2	2.04	0.699911	1243	3065	609.31	1502.45	1775.94	4379.13
3	1.49	0.329168	969	1993	650.34	1337.58	2943.79	6054.66
4	2.62	1.102837	1120	3337	427.48	1273.66	1015.56	3025.83
5	1.54	0.596104	975	1757	633.12	1140.91	1635.62	2947.47
6	1.88	0.642195	1138	2760	605.32	1468.09	1772.05	4297.76
7	6.54	1.100492	875	2012	133.79	307.65	795.10	1828.27
8	2.38	0.755699	939	2880	394.54	1210.08	1242.56	3811.04
9	4.73	0.777518	961	2845	2031.92	601.48	1235.98	3659.08

Figure 5. 23: Building density per km² by Kebele By block and Kebele(1995- 2008)

The comparison of density of buildings per km² at block level and Kebele shows that there higher density of buildings in 2008 at block level. In 1995, the density magnitude was nearly similar to the density of housing units by Kebele at 2008. This means that in 1995,

there was large open space within the block that was not occupied by buildings because we used a fixed size of block area for both study years.

Figure 5.24, 25, 26 and 27 shows the spatial distribution of building footprint at block and Kebele

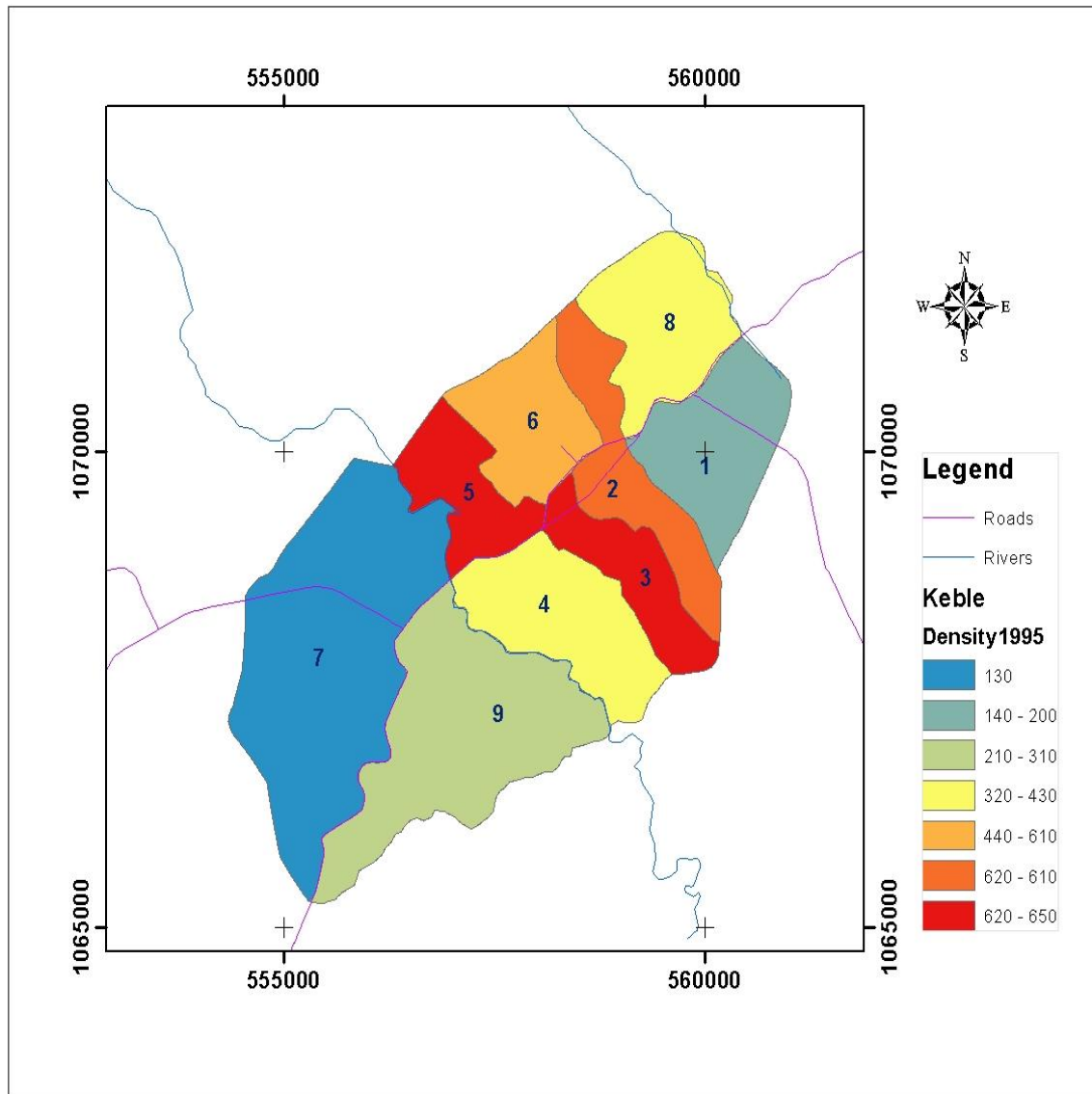


Figure 5. 24: Building footprint density 1995 by Kebele (in km²)

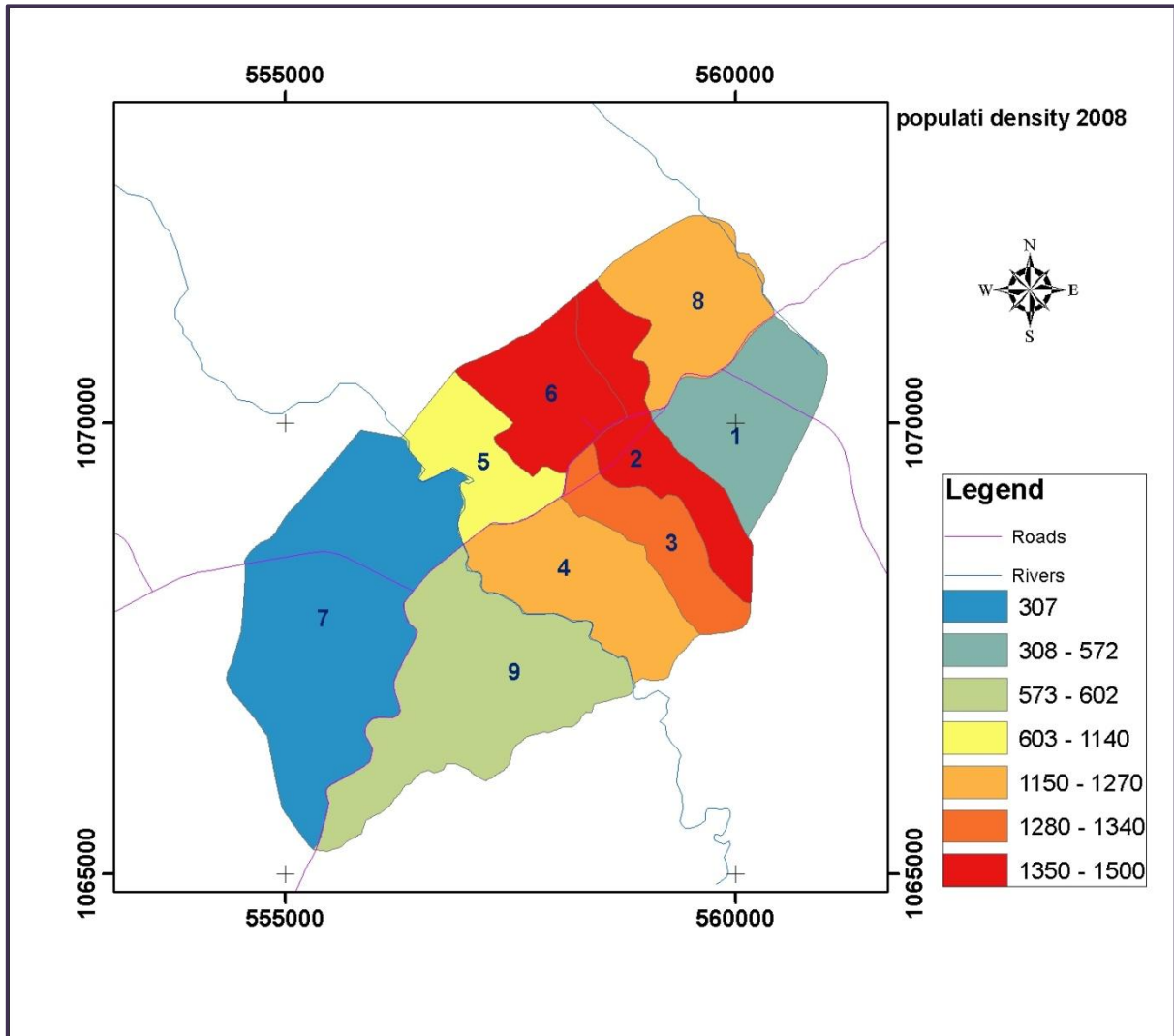


Figure 5. 25: Building footprint density 2008 by Kebele (in km²)

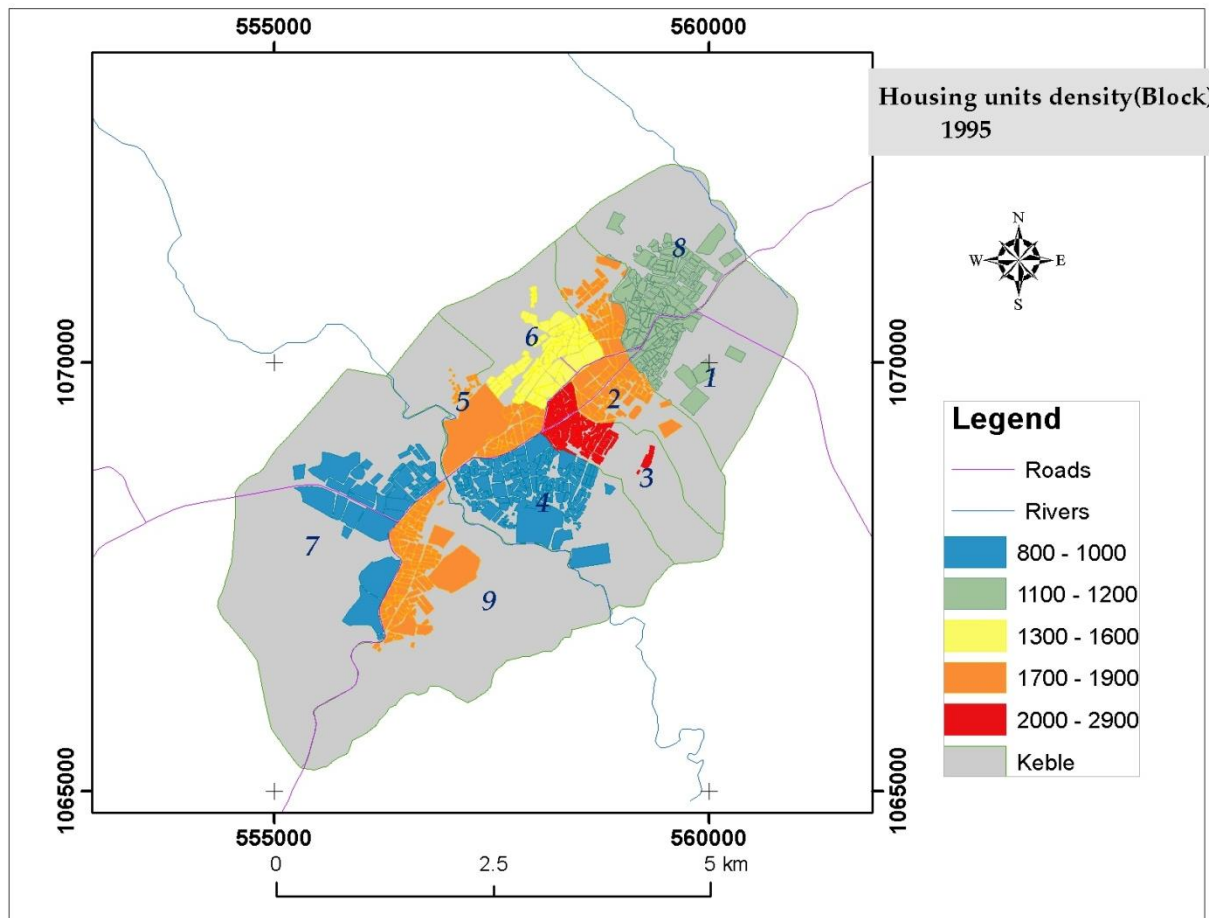


Figure 5. 26: Building footprint density of 1995 by block (in km²)

The density of housing units was calculated by dividing the total housing units by total area of Kebele boundary. The highest density of houses were exhibited in Kebele 5 and Kebele 3 in 1995 (Figure 5.24) and Kebele 6 and Kebele 2 in 2008 (Figure 5.25). The density of housing units more accurately was calculated using street blocks. The comparison of housing density by Kebele area in km² and block area showed remarkable difference. The highest density of housing units were calculated in Kebele 5 and 3 for the 1995 and Kebele 6 and Kebele 2 for 2008. The highest housing density at block level exhibited in Kebele 3 with maximum density of 2900 housing units per km² (1995) and with maximum of 6100 housing unit density per km² in 2008 (Figure 5.26 and Figure 5.27).

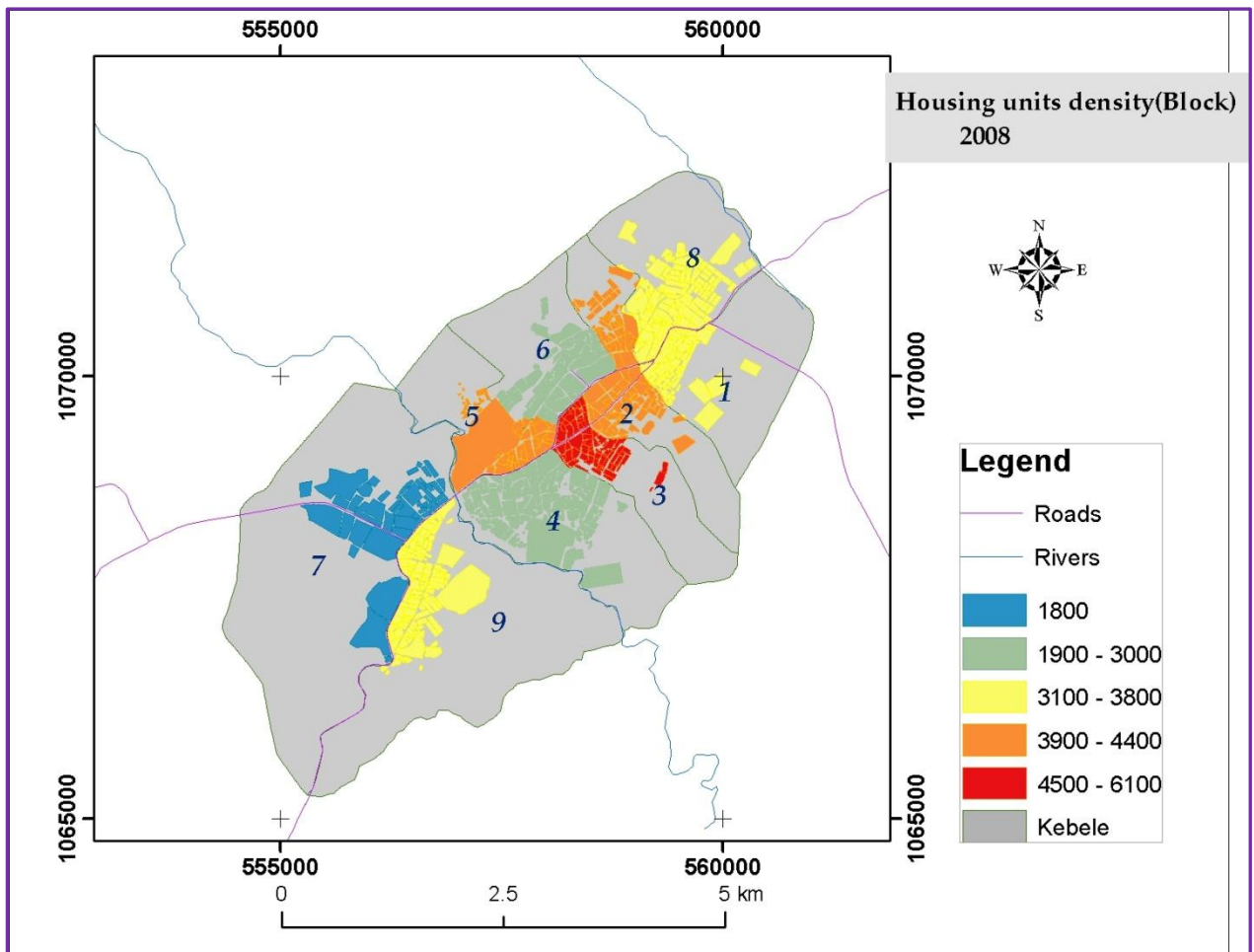


Figure 5. 27: Building footprint density of 2008 by block (in km²)

B. Cluster Analysis of Housing Units

Spatial statistics helps to identify where spatial clustering occurs, and where spatial outliers are located. The importance of housing to both the ecological and social sciences has focused increasing attention on the spatial patterns of housing growth. Furthermore, because housing growth is not a spatially random process, understanding its patterns requires a spatial explicit view (Lepczyk et al., 2006).

The following question can be used to guide to understand the spatial pattern of housing units in this work.

- What is the pattern of points in terms of their nearest distances from each other?
Or how spread is the housing units across the total urban area? The point data from polygon centroid was used because point data are the straight forward for this analysis.
- Is the pattern random, dispersed, or clustered?

Local Getis ord G^*

To identify housing growth and spatial pattern, local Getis-Ord G^* statistic was used to determine where housing growth hotspots exist in the study area. The Spatial Analyzing Patterns tool set in ArcGIS was used to identify the spatial patterns of residential housing units. The patterns with more clustering of housing units that contain hot spots and cold spots with above mentioned local indicators were mapped.

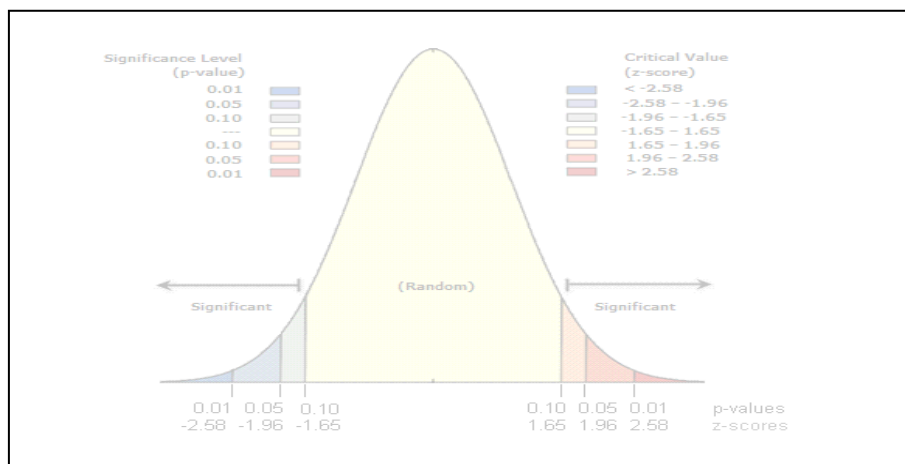


Figure 5. 28: Region of Hot spot and Cold spots in a normal distribution graph

(Zscore below -1.96 is the locations of cold spots and Zscore above 1.96 is the location of hotspots)

From the analysis, local Getis- Ord G^* hotspot and cold spot map indicated that there was a clear spatial pattern of clustering of housing units on the north east part of the town. The hotspot of housing unit location indicated by cyan color clustered polygon centroids and the cold spots of the housing unit analysis shown with blue color polygon centroids (Figure 5.29). According to this statistics, we can say that point patterns between G zscore >-2 and < 2 are randomly distributed, point values on the normal distribution with G zscore < -2 and >2 can be clustered which shows a compact development.

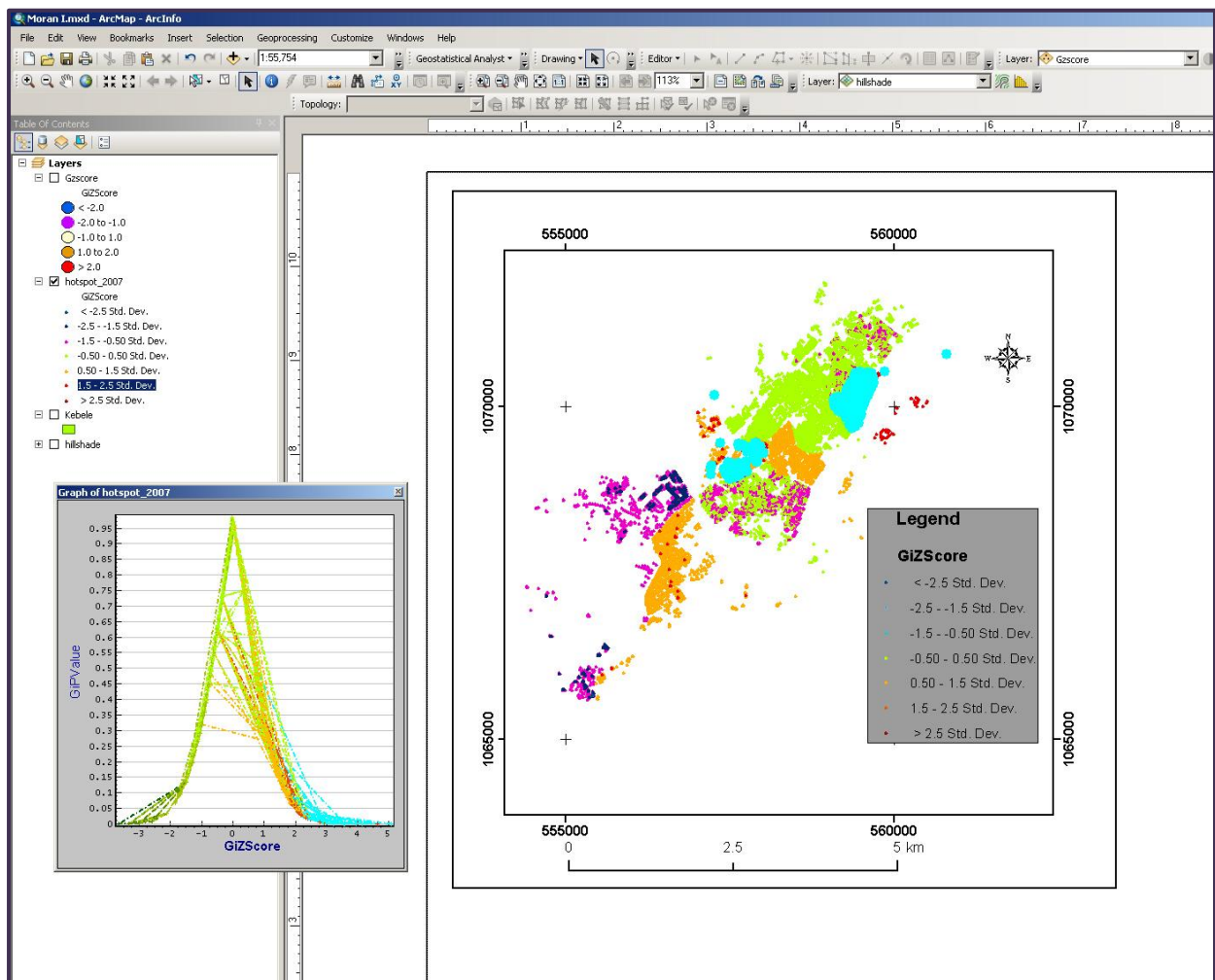


Figure 5. 29: Map shows Hot spot and Cold spots of housing units

From Fig 5.30, considering the Getis- OrdG* map, high Z-score value >2 , shows high values are clustered together in the Northeastern part and low z-scores value <-2 indicate low values are generally clustered in the west parts of the town. The Z-score value between -2 and 2 are generally a random pattern of housing units. That mean the development was none clustered.

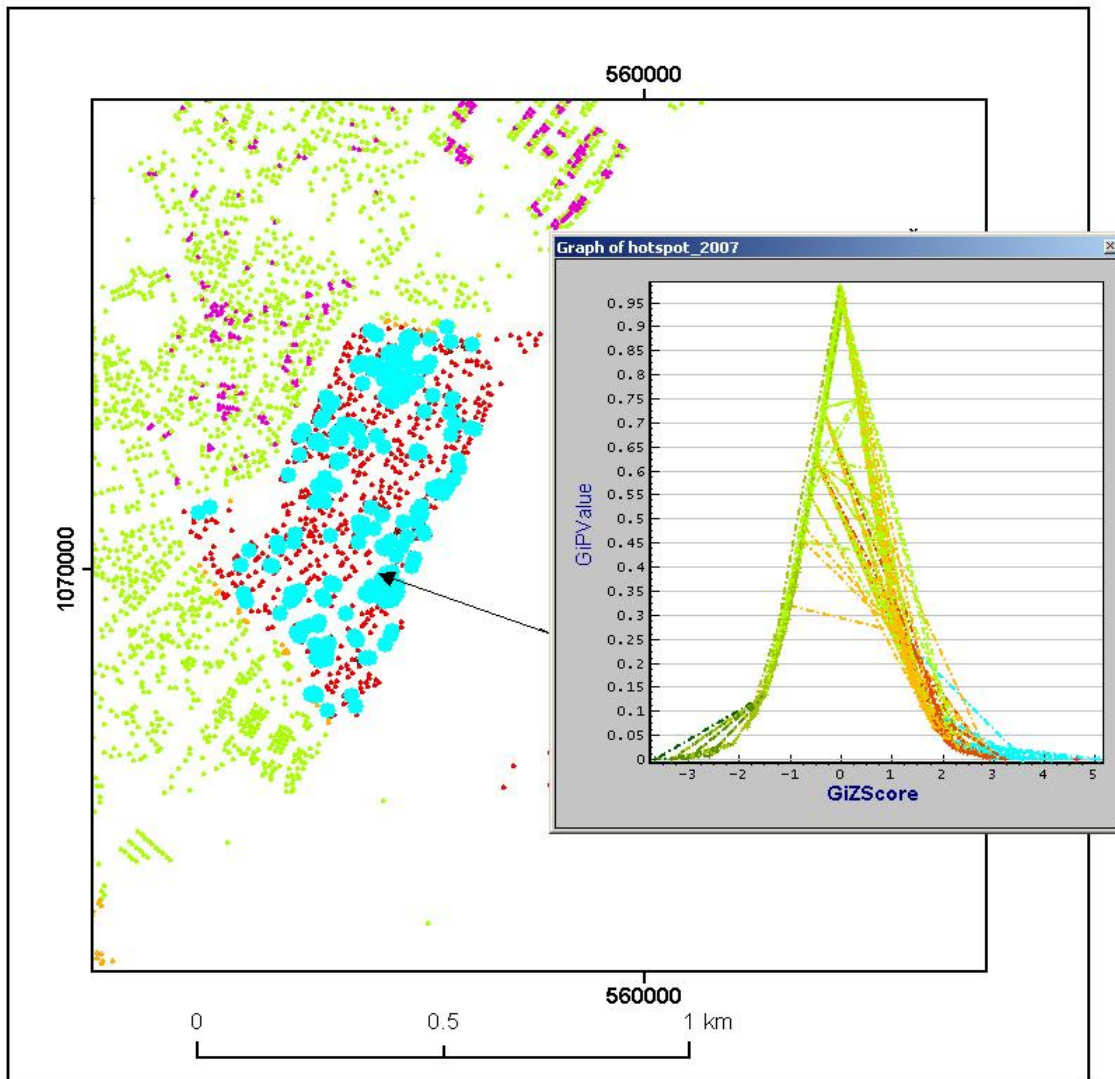


Figure 5. 30: Housing unit hotspots, Z score > 2

Generally, the higher (or lower) the z-score, the more intense the clustering is . A z-score near zero indicates no apparent spatial clustering. The spatial statics of housing unit distribution analysis indicated that the majority of the housing distribution didn't show a cluster pattern. The spatial relationship of the point features therefore indicates a random pattern or non compact development.

MODELING LAND REQUIREMENTS FOR URBAN EXPANSION

6.1. Urban expansion suitability analysis and assumptions

Due to population growth, built-up area expansion and industrialization, rapid urbanization is undergoing with the mixture of activities and fragmented land-use that can result in sprawl development.

Land suitability evaluation defines suitability of certain kinds of land use based on natural and socioeconomic attributes. It is the fundamental work and an important content of overall land use planning, which requires a scientific approach to guide development and avoid errors in decision-making for sustainable utilization of land resources.

Geographic Information System based Multi Criteria Evaluation (MCE) suitability analysis may be used to attain a specific goal from multiple alternatives where there is a need of land use suitability modeling for urban expansion. In this thesis, an evaluation model of multi-criteria urban expansion suitability using GIS platform was developed for the study area to point out where the future sprawl and urban expansion will occur. A number of factors, important in reality, will not be considered in this thesis. Some of the factors that are not included are: reserved land, some of the environmental constraints, municipal plans, ownership, political factors, socio-economic classes (affordability), etc.

This approach will define a suitability map for urban land cover based on the conditions that are associated with current urban land and areas of recent urban land cover change. Landscape variables, such as slope suitability, topographic constraints such as hills, valleys, drainages, land-use/land-cover and other factors such as distance from the center of the town, distance from the main road, will be used to define appropriate conditions for urban growth. Socio-economic variables, including lands that are protected such as woodlots, population density, will also be included.

Because the suitability model is focuses on urban landscape characteristics, and depend on only available data, it will have shortcomings to include, geological factors, soli

suitability, and socio economic conditions to map and to have a better representation of the landscape in terms of where development is more or less likely to occur.

The basic assumption of urban expansion suitability analysis is guided by the following ideas. All lands based on land use/land cover classification (2005) are available for urban expansion. The expansion model was, based on physical factors and constraints which are therefore, simplified and generalized.

Urban expansion is restricted by some natural constraints or facilitated by factors based on their influence land use suitability. Identifying the excluded area that restrict development, and mapping the suitable area for urban expansion by ranking those factors was one of the main focus of this study.

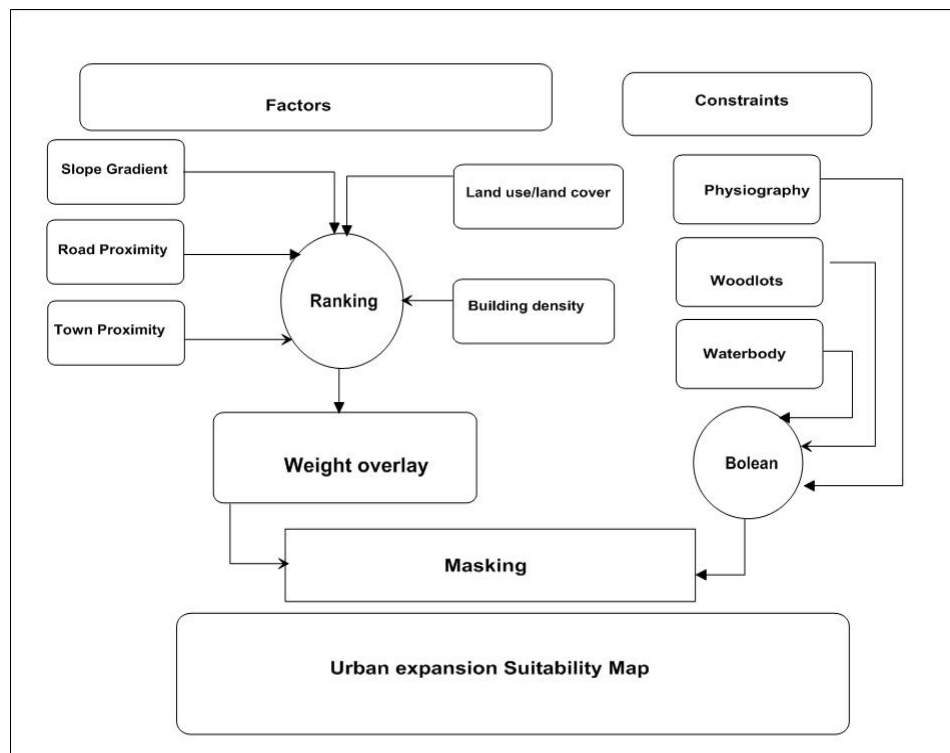


Figure 6. 1: Urban expansion suitability analysis flow chart

The first procedure as it is indicated in figure 6.1, was designing a suitability model to assess the amount of suitable area for urban expansion. The suitability factors were rated by combining them according to their rank. The final suitable map was produced as

highly suitable, moderately suitable, and unsuitable. There were also areas that cannot be used for any construction activity. These areas called constraints and were excluded from the suitability map by masking.

6.1.1. Constraints of urban expansion

Areas where development cannot occur because of either strict policy enforcement or physical barriers for development are called constraints. Thus constraints are physical factors or areas that require high costs and technology for development, areas that cannot be used by any means, areas that are restricted by human purposely.

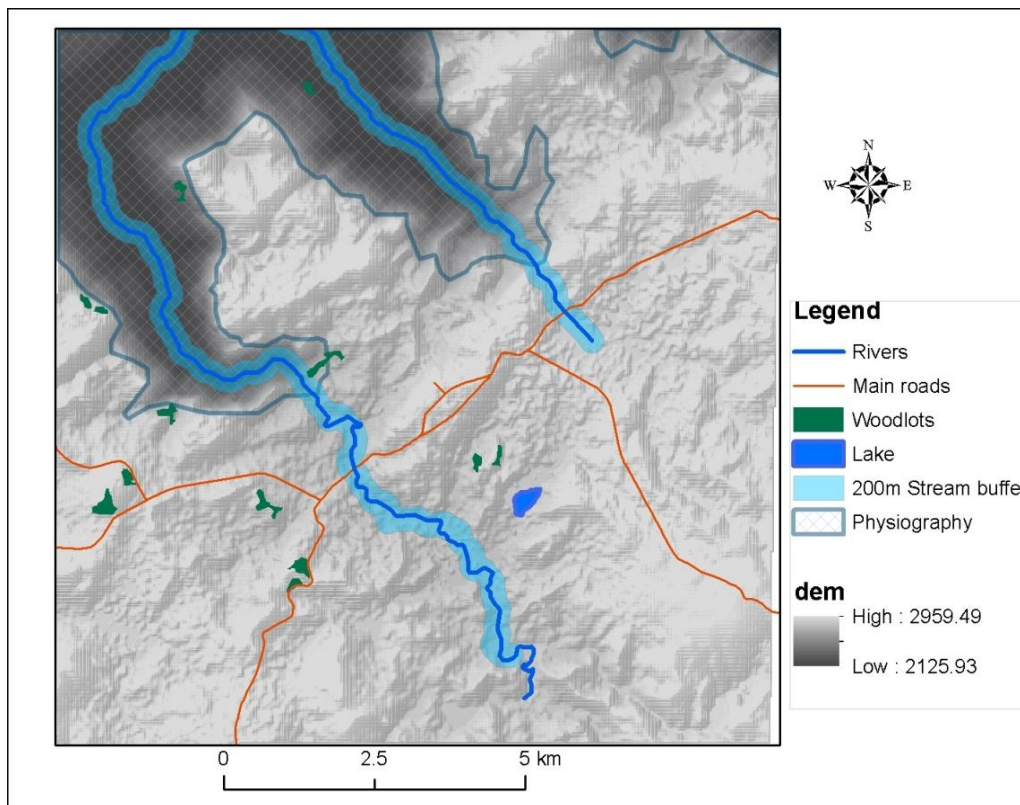


Figure 6. 2: Map shows constraints that restrict urban expansion

Constraints are the Boolean conditions which limit the alternatives under consideration (Eastman, 2006). Some of the constraint that restricts urban expansion on the study area includes open water body (rivers and lake) topographic conditions and woodlots. A 200

meter buffer on the two rivers that pass through the town, woodlots, and the valley and gorges found in the vicinity of the town, were excluded as constraints. The selection of 200m buffer for the rivers was based on the agreements from local experts in the study area.

6.1.1.1. Topography

Both topography and slope play an important part in determining urban development in a given site. While topography is the general configuration of the land surface which is measured by elevation and slope is the percentage change in the elevation over a certain distance.

Debre Birhan town lies on a plateau and surrounded by ridges oriented north-east, south-west situated between the two broad valleys found in the vicinity of the town (Figure 6.3). The general topography of the town is therefore includes plateau, undulating hills and valleys. These undulating hills and valleys considered as constituents for future expansion of the town.

6.1.1.2. Drainage

To avoid risks from river flood, runoff, and water pollution, generally, construction at some distance from open water body and rivers is chosen. Debre Birhan town has two rivers starts from the eastern part of the plateau and drained from southeast to northwest towards Jema River: River Beresa is a perennial river and Dalecha is an intermittent river. These rivers have therefore limitations for development because they must employ costly building and landscape measures to insure that destructive damage does not occur to structures and property during a flood event.

6.1.1.3. Densely vegetated area

From environmental condition perspective, it is restricted to use urban forest for residential and commercial housing expansion. Although there were not densely

vegetated urban forests in the study area, there are eucalyptus woodlots around the town. For the purpose of this study these areas were excluded from urban expansion suitability site selection.

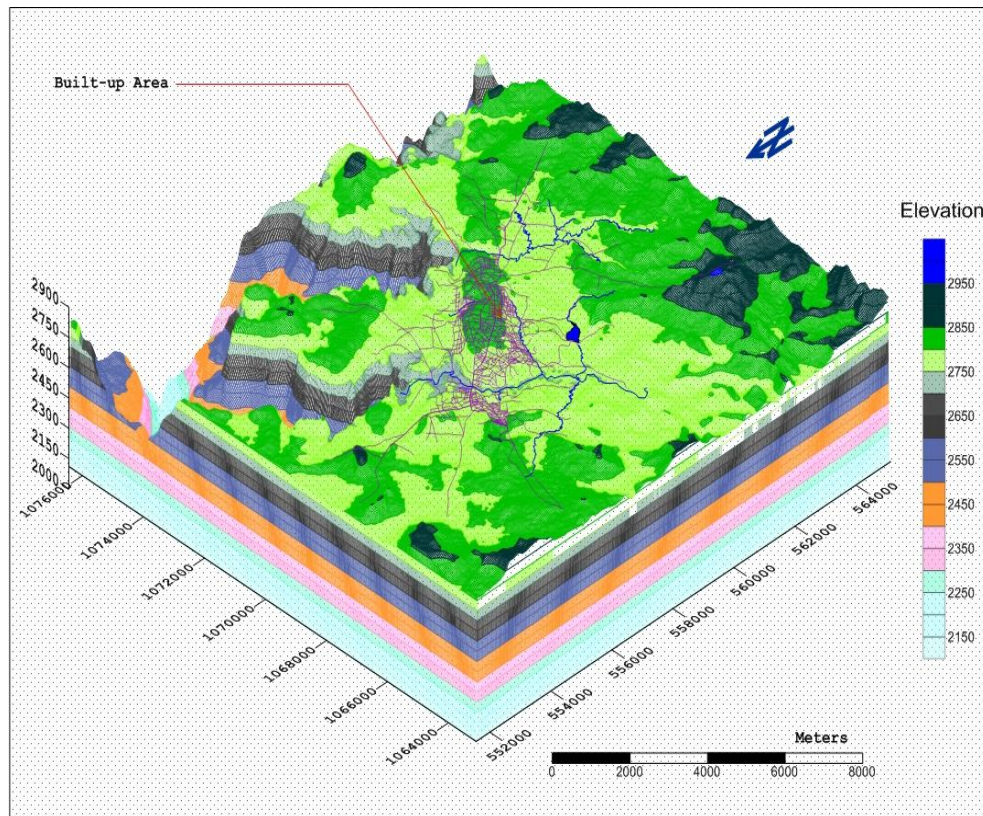


Figure 6. 3: Topography.

6.1.2. Selecting Factors for urban expansion suitability

Factor is a general category of information concerning the site being evaluated. The factors often considered in urban expansion suitability studies include natural environment factors (e.g. slope, geologic hazards, land cover, etc), built environment factors (e.g. existing land use, planned land use, accessibility to roads, availability of utilities, etc.), economic factors (e.g. land value, tax rate, etc.), and social factors (e.g. population present, jobs present, historical features present, etc).

In this study, economic and social factors, municipal land use restrictions, and factors such as soil suitability, water availability were not used due to lack of information.

6.1.2.1. Proximity Factors

A. Proximity to the center of the town

The central part of the town was considered as very suitable for urban development. Hence, the suitability will decrease from the center gradually. In general, areas closer to currently developed land are more suitable than areas farther from developed land because suitability decreases with distance.

B. Proximity to the main road

Distance from the main road not affect suitability very strongly although a large distance involves some extra cost and increase in travel time. But a new road might be constructed to change the accessibility. This factor, therefore, will have low weighting factor compared to others. The major road from Addis Ababa to Dessie crosses Debere Birhan town. Other main roads are road to to Ankober and Jiru. The residential roads are not included for suitability analysis. Like distance from the center, the suitability of urban growth also decreases gradually from the main road. Buffer distance from the main road 500m and reclassified to common measurement scale which is 10.

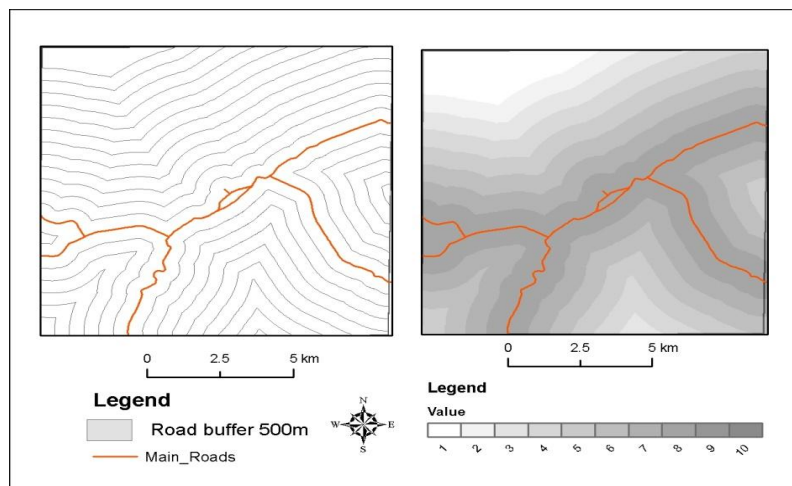


Figure 6. 4: Road proximity buffer with 500m

C. Slope factor

Low slopes make housing and road construction less expensive. A slope also will cause considerably higher construction costs, which strongly affects its suitability. Therefore, in most cases the slope $< 15\%$ are mostly taken as suitable for construction and slope $> 15\%$ are unsuitable.

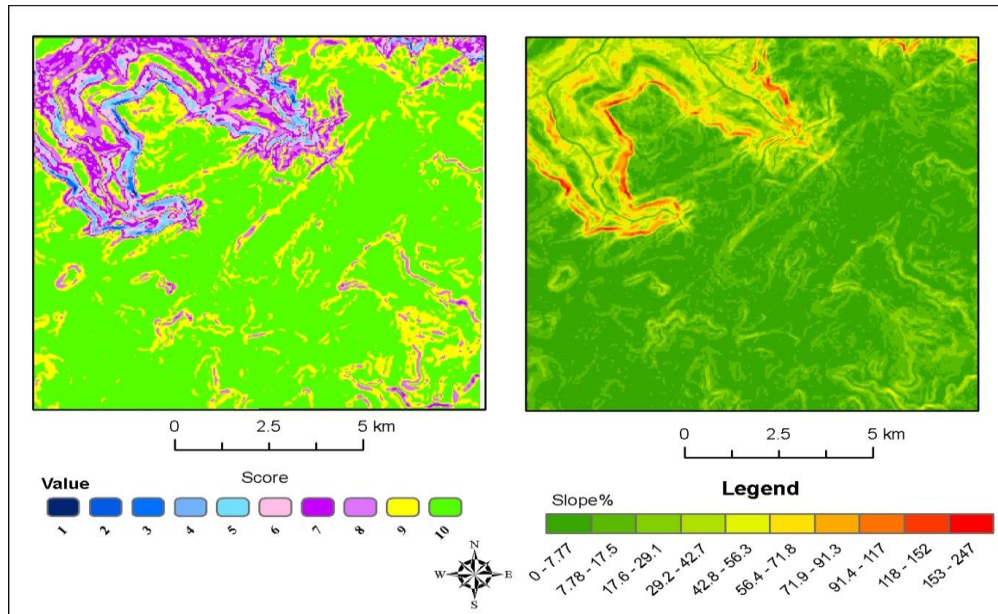


Figure 6. 5: Reclassified slope suitability (left).

D. Distance from built-up density

The more densely populated the urban area in population or built-up area, the lesser would be the future development than the sub-urban area. That means, replacing or renewing the densely built-up area requires, a larger cost for developers. Therefore, suitability from highly densely populated area increases gradually until certain distance limit. Sometimes densely populated area may attract developers due to market reasoning. This may facilitate urban growth on densely populated area. However, the assumption in this work is to know what factors should be considered for horizontal urban expansion. The point density of individual housing units was calculated and classified to standard score of 10 using ArcGIS spatial analysis tools.

E. Land-use/ land-cover

Agricultural and grass lands are being extensively used for urban expansion compared to other land cover land uses such as bush land and shrub.

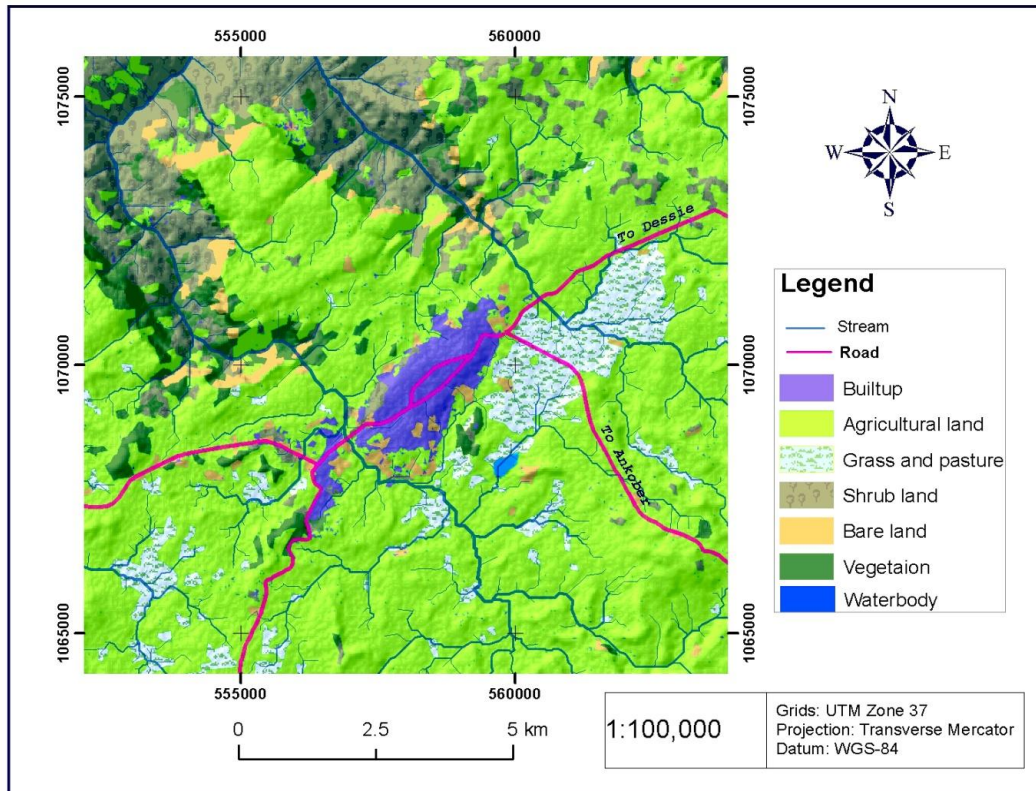


Figure 6. 6: Land use/Land cover map (2005).

6.2. Standardize the factors/criterion scores

A common standardization scale is used for the suitability value of each data set to make the comparison of each factor possible. The common measurement scale helps to determine how suitable a particular location is for urban expansion. Numeric scores from a total of ten (one as least and ten as most suitable) were assigned to each factor attribute class in spatial analysis of ArcGIS 10.0 platform. ArcGIS 10 (ESRI) with the Spatial Analyst Extension that includes the Model Builder tool is well suited for land suitability modeling in this study. The datasets were raster (grid) format with cells size of 30 meters.

6.3. Weighting and combining the data sets

All the criteria were aggregated with the most commonly used decision rule called Weighted Linear Combination. Therefore, the composite suitability score is given by a formula:

$$S = \sum W_i X_i \prod c_j \dots \dots \dots 4$$

Where:

S – Is the composite suitability score for urban suitability map

X_i – Factor scores (cells)

W_i – weights assigned to each factor

c_j – constraints (or Boolean factors)

Σ -- Sum of weighted factors

Π -- Product of constraints (1-suitable, 0-unsuitable)

Applying the formula on this study:

$$S = ((Town\ Proximity * 0.33) + (Road\ Proximity * 0.08) + (Slope\ gradient * 0.35) + (land-use/land-cover\ 0.07*) + (Building\ density*0.18) * Boolean.$$

The weighting of a suitability factor also depends on the intended land use: commercial activities have requirements different from those of residential activities, but this aspect is disregarded here.

In this study slope has been given higher weighting factor because it causes considerably higher construction costs, which strongly affects its suitability. The distance to a main road, on the other hand, may not affect suitability very strongly: a large distance involves some extra cost and increase in travel time. Moreover, a new road might be constructed to change

Table 6. 1: Pair wise comparison matrix of five factors to urban growth suitability

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	Very strongly	Strongly	Moderately	equally	Moderately	Strongly	Very strongly	Extremely
Less Important							Very important	
	Town proximity	Road Proximity	Slope Gradient	Land-use/land-cover	House density			
Town proximity	1							
Road Proximity	1/3	1						
Slope Gradient	1	4	1					
Land-use/land-cover	1/7	2	1/7	1				
House density	1/2	2	1/2	4	1			

The eigenvector weight of each factor is calculated using IDRISI 15.0 software. Based on the calculated weights, slope gradient is the first factor that influences urban expansion and therefore has been given the highest weight, town proximity has been given 33% weighting value. The next influencing factors include the densification of buildings on the existing built-up area and proximity to the main road which have weights 17 % and 8% respectively. The eigenvector of weight according to this calculation has a consistency ration of 0.06 which is acceptable for further analysis.

Table 6. 2: Eigenvector of the pairwise comparison matrix

ID	Factor	Weight	%
1	Town Proximity	0.33	33
2	Road Proximity	0.08	8
3	Slope Gradient	0.35	35
4	Land use/ land cover	0.07	7
5	Building Density	0.18	17

By multiplying all layers of factors and excluding those area which restrict future expansion the urban growth suitability was produced. According to the suitability analysis of urban expansion map (Figure 6.7), the most suitable location of land for urban expansion was agricultural land, grass and bare soil. The existing built-up area ranked as the next suitability area. There are also areas that were not suitable for urban growth inside the town because of the high density of the current built-up area.

The assessment of urban expansion suitability map indicated that the most suitable available land for urban expansion are agricultural and grass land. This indicated that for the next coming years, the rapid increase of urban sprawl will create a pressure on intensively cultivated agricultural land that found near and around the existing urban area. Suitability assessment of urban growth, using Geographic Information System based Multi- Criteria Evaluation (MCE) techniques used to identify the urban growth, sprawl and the environmental changes over time.

6.4. Validate the result before beginning the implementation

To assess the reliability of the output, ground truth verification should be necessary. But for this study, Ikonos image of 2008 was used. According to this suitability analysis result, all agricultural land and grass land were most suitable for urban growth. It is necessary to keep in mind here that this approach does not intend to model land suitability map for urban sprawl but aims at generating land suitability map for sustainable urban growth process.

Urban growth due to economic development and industrialization is a normal condition but urban sprawl is an informal scatter development which results loss of environmental resources and the expansion doesn't consider the level of economic development. Moreover, all parameters and their values used in this suitability analysis are subjective in reality because urban growth suitability map needs experts from different departments such as geology, hydrology, urban planning etc. But we assume that the contribution of

this work may be appreciated from GIS and remote sensing perspective since it provides the most valuable data sources and information for urban planners.

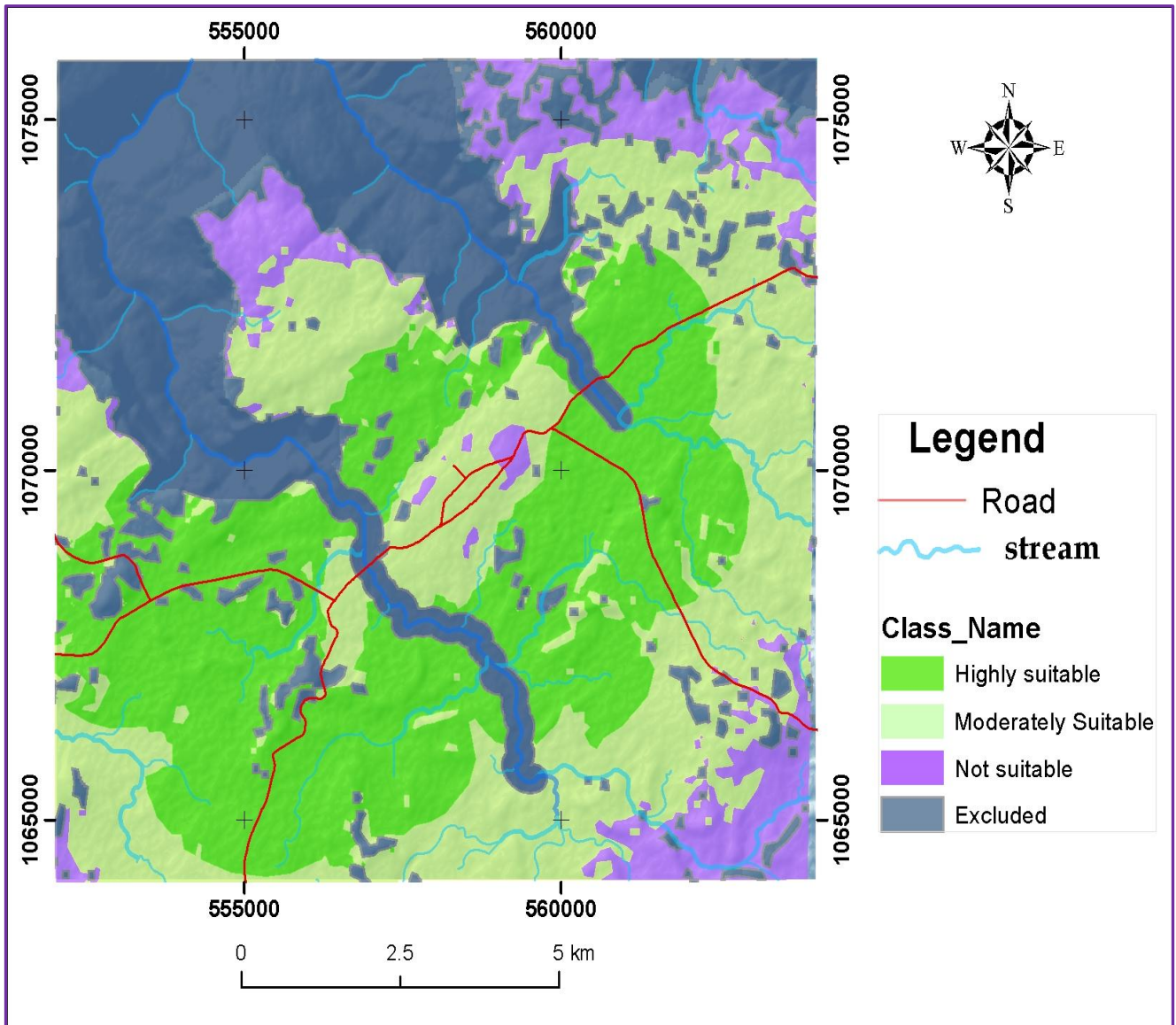


Figure 6. 7: Suitability map of urban growth from urban landscape perspective

CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

This study demonstrates the use of Remote sensing and Geographic Information System (GIS) to analyze the urban growth and sprawl mapping in the study area. Attempt was made to capture as accurate as possible seven land use-land cover-classes as they change through time. Satellite data are found to be useful in mapping and quantifying the historical land-use/land cover and the rate of urban growth in different time periods.

In order to give answers of the research questions framed in the present study, different experiments were carried out using multi-resolution satellite images and data from topographic map. From the classified land-use/land-cover classes, more emphasis has been given on built-up land as it affects all other class categories. The land-cover/land-use change statistics indicated that the growth rate of built up area occupied the largest share among other land-cover/land-use categories. The result of this work shows a rapid growth in built-up land between 2000 and 2005 while the periods between 1986 and 2000 witnessed relatively slow growth. The urban area development occurred mainly on bare land, grass land and agricultural land.

GIS based analysis of the pattern of urban expansion over the demographic change and landuse modifications has also indicated that urban growth has mainly taken place linearly along the major roads in the study area.

The vector data extracted from Ikonos imagery and topographic map of my findings were used to map whether housing development was sprawling or compact. Density of houses by Kebele and blocks was computed and mapped to identify the location of densely populated area with population and housing units. Residential house scattering and compactness has been measured with spatial statistics of hotspot analysis. The GIS map

shows that residential housing development has already sprawled during the study period.

The assessment of urban expansion suitability map indicated that the most suitable available land for urban expansion are agricultural and grass land. This indicated that for the next coming years, the rapid increase of urban sprawl will create a pressure on intensively cultivated agricultural land that found near and around the existing urban area. This may highlight some clues to decision makers and planners to understand the environmental change due to anthropogenic factors and to find solutions for sustainable urban development

7.2. Recommendations

There is a need to plan for balanced physical urban growth and population growth in our cities and towns. This can only be possible if there is an understanding of the nature of urban growth change, the urban demographic pressure, the level of service available to supply, the source and amount of resources to future growth of cities and towns.

Urban planning authorities and town planners should think about the future growth of the town and should understand the consequence of unbalanced physical urban growth and, public service and infrastructure supply.

Urban planning authorities should have to depend on a GIS data base and information system to regulate their urban development in a sustainable way such that they will manage the supply of public services and infrastructures that will be needed as a result of future urban expansion.

Satellite remote sensing with repetitive and synoptic viewing capabilities, as well as multispectral capabilities, is a powerful tool for mapping and monitoring the ecological changes in the urban core and in the peripheral land-use planning. The use of remote

sensing needs to be introduced for monitoring the activities of developers. This will help in reducing unplanned urban sprawls and the associated loss of agricultural lands

The last section of this thesis looked towards mapping the land requirements for urban expansion. By using GIS based multicriteria evaluation method, the future suitable urban expansion land has been mapped which can be used as a visual guide for urban planners. This will help them to plan urban growth with effective design, not just architecturally, but also at the 'urban design' level which is crucial to understand that higher-density developments(not over crowded) can theoretically be made as attractive as the lower density urban sprawl which is agreed by many researchers.

Generally, the following core points are recommended

At current rate of population dynamic, land-use/land-cover change is certain to increase. Therefore, the following management strategies are recommended:

1. The use of GIS and remote sensing based urban land management and urban sprawl controlling
2. Encourage of new development or redevelopment in already built up area.
3. Sustainable use of land resources and avoiding agricultural land loss by uncontrolled horizontal urban expansion.

To reduce the impact of urban sprawl, the following four policy measures are suggested:

4. Controlling land use and residential development through land price regulations
5. Control of housing prices by local authorities.
6. Instead of new housing development on agricultural land, renewal of older buildings and infill development of high rise buildings to meet the demands and needs of the increasing number of population in the town

References

- Alberti, M. and Torrens, P. (2000). Measuring Sprawl. Working Paper Series No. 27, Center for Advanced Spatial Analysis. University College London.
- Anselin, L. (1995). Local Indicators of Spatial Association-LISA Geographical Analysis 27: 93-115.
- Anselin, L. (2003). GeoDa 0.9 User's Guide, Center for Spatially Integrated Social Science, Urbana-Champaign
- Barnes, K.B., Morgan III, J.M., Roberge M.C. and Lowe, S. (2001). Sprawl development: Its patterns, consequences, and measurement. Towson University: A white paper. Available at: [http://chesapeake.towson.edu/landscape/ ... _paper.pdf](http://chesapeake.towson.edu/landscape/..._paper.pdf)
- Bull, T.A. (1988). Agroecological assessment of Ethiopian Vertisols. In: Jutzi, S. C., Haque, I. Proceedings of a conference held at ILCA, Addis Ababa Ethiopia 31 August-4 September 1987. ILCA (International Livestock Centre for Africa), Addis Ababa Ethiopia, pp: 89-105.
- Campagna, M. (ed.) GIS for sustainable development. London: Taylor and Francis, 2006.
- Central Statistics Agency (CSA). The 1994 and the 2007 population and Housing Census of Ethiopia. Summary Report at Country and Regional Level.
- Central Statistical Authority (CSA), 1996. The 1994 Population and Housing Census of Ethiopia: Results for Amhara Region. Statistical Report on Population Size and Characteristics. Volume I: Part I. Ethiopia, Addis Ababa
- Central Statistical Authority (CSA), 2010. The 2007 Population and Housing Census of Ethiopia: Results for Amhara Region. Statistical Report on Population Size and Characteristics. Volume I: Part I. Ethiopia, Addis Ababa
- De Jong S.M., F.D. van der Meer & J.G.P.W. Clevers.(2004). Basics of Remote Sensing. In: De Jong S.M. & F.D. Van de Meer F.D. (Eds.), Remote Sensing

Image Analysis: Including the Spatial Domain. Kluwer Academic Publishers, Dordrecht. pp. 1-16.

Daniel Meshesha, Dejene Haile Mariam and Abrham Mamo, (2000). Geology of Debre Birhan Area, unpublished report. geoscience mapping core process, geological survey of ethiopia (GSE).

Doebele, W. (1984). The Evolution of Concepts of Urban Land Tenure in Developing Countries. Graduate School of Design, Harvard University, Cambridge. USA. 11(1): 7- 22, Printed in Great Britain.

Eastman, J. R. (2006). IDRISI Andes Tutorial. Clark Labs Clark University, 950 Main Street Worcester, MA 01610-1477 USA. Manual Version 15. Web: <http://www.clarklabs.org>

ESRI (2010). ArcGIS Desktop Help 10 – Spatial Autocorrelation (Moran’s I) (Spatial Statistics). Online Available: [http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=Spatial Autocorrelation](http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=Spatial%20Autocorrelation),

Ewing, R. (1997). “Is Los Angeles-Style sprawl desirable?” Journal of the American Planning Association, 63(1): 107-126.

Ewing, R., Pendall, R. and Chen, D. (2002). Measuring Sprawl and Its Impact. Smart Growth America. Washington, DC, USA.

FAO (Food and Agriculture Organization of the United Nations) (1997). The Digital Soil and terrain Database of East Africa (SEA). Notes on the Arc/Info files. Version 1.0 completed 3rd April 1997.

Forsyth, A. (2003). Measuring Density: Working Definitions for Residential Density and building Intensity, Design Centre for American Urban Landscape, University of Minnesota.

Galster, G. and Cutsinger, J. (2007). Racial settlement and metropolitan land-use patterns: Does sprawl abet Black–White segregation? Urban Geography, 28: 516–553.

- Getis A., Ord J.K. (1992). The analysis of spatial association by use of distance statistics, *Geographical Analysis*, 24: 189-206.
- Gibson, J. (2010). Operational Performance Measurement: The Case of Debre Birhan Water Supply and Sewerage Service in Ethiopia. Water Institute of Southern Africa (WISA) 2010, Biennial Conference and Exhibition ICC Durban, South Africa. :www.wisa.org.za www.ewisa.co.za.
- Griffith, D.A. (1984). Theory of Spatial Statistics. In: Gaile, G.L. and Willmott, C.J. (eds.) *Spatial Statistics and Models*. Dordrecht: D. Reidel Publishing Company
- Gou, Y.H. (2003). Using GIS to Examine Urban Growth Pattern in Alachua County, Florida. Master thesis in Urban Planning at Virginia, Polytechnic Institute and State University.
- Gulch, E. (2000). Digital Systems for automated cartographic feature extraction. *International Archives of Photogrammetry and Remote Sensing and Spatial Information Sciences*, Vol. XXXIII, Part B2, pp. 241-255.
- Haregewoin Bekele (2005). Urbanization and Urban Sprawl. Master of Science Thesis, Royal Institute of Technology Stockholm, Sweden.
- Hu, H. (2010). Urban Land-cover Mapping with High-resolution Spaceborne SAR Data. Master of Science Thesis, Royal Institute of Technology Stockholm, Sweden. Stockholm, Sweden.
- Irwin, E.G. and Bockstael, N., and Cho, H.J. (2006) Measuring and Modeling Urban Sprawl: Data, Scale and Spatial Dependencies, unpublished working paper.
- Konecny, G. (2003). *Geoinformation: remote sensing, photogrammetry and geographic information systems*. Taylor & Francis. London and New York.
- Lee, J. and Wong, D. (2005). *Statistical Analysis with ArcView GIS*. New York. Wiley, 2nd Edition.
- Lepczyk, C.A.; Lortie, C.J.; Anderson, L.J. (2008) . An ontology for landscapes. *Ecological Complexity* 5(3): 272-279

- Lillesand, T.M., and Kifer, R.W. (1994). *Remote Sensing and Image Interpretation*. (Third Edition). United States of America: John Wiley & sons, Inc.
- Longley, P. A., Goodchild, M. F., Maguire, D. J. and Rhind, D .W. (2005). *Geographic information systems and science*. 2nd Edition. Chichester: Wiley.
- Lu, D., and Weng, Q. (2006). Use of Impervious Surface in Urban Land-Use Classification. *Remote Sensing of Environment*. 102: 146-160.
- Lwin, K., (2010). *Online Micro-spatial Analysis Based on GIS Estimated Building Population: A Case of Tsukuba City*. Doctoral Program in Geoenvironmental Sciences. University of Tsukuba
- Mathema, A. S. (2001). *Housing and land markets in Kathmandu, Nepal*. Master Thesis. Department of Urban Studies and Planning Massachusetts Institute of Technology, Cambridge.
- Mohsen, A. (1999). *Environmental land use Change detection and assessment using with multitemporal satellite imagery*. Zanzan University.
- Myers, D., & Kitsuse, K. (1999). *The Debate over Future Density of Development: An Interpretive Review*. Working Paper. Washington, D.C.: Lincoln Institute of Land Policy.
- National Meteorological Agency (NMA). *Climate data for Debre Birhan Station (1999-2008)*, Central Statistical Agency, Addis Ababa, Ethiopia.
- Ord J.K., Getis A. (1995) Local spatial autocorrelation statistics: distributional issues and an application, *Geographical Analysis*, 27: 286-305.
- Rutledge, D. T., C. A. Lepczyk, J. L. Xie, and J. G. Liu. (2001). Spatiotemporal dynamics of endangered species hotspots in the United States. *Conservation Biology* 15(2):475-487
- Ryan J. H. (2002). *Measuring sprawl in Rhode Island: a Gis based analysis of land use change in the Pawcatuck river watershed*. Master thesis, University of Cornell.

- Schowengerdt, R.A. (2007). Remote sensing: models and methods for image processing. 3rd Edition. Amsterdam: Elsevier; Burlington: Academic Press.
- Singh, A. (1989). Digital change detection techniques using remotely sensed data. *International Journal of Remote Sensing* 10: 989–1003.
- Skidmore, A.K. (ed.), (2002). Taxonomy of environmental models in the spatial sciences. In: *Environmental modeling with GIS and remote sensing*. London: Taylor & Francis, 2002.
- Smith, R. B. (2006). Introduction to Remote Sensing of Environment (RSE) TNTmips. Microimages. [Online]: www.microimages.com
- Sudhira, H. S., Ramachandra, T.V. and Jagadish, K.S. (2004). Urban sprawl: metrics, dynamics and modeling using GIS. *International Journal of Applied Earth Observations and Geoinformation* 5(1): 29-39.
- Sun, H., Forsythe, W. and Waters, N. (2007). Modeling Urban Land Use Change and Urban Sprawl: Calgary, Alberta, Canada. *Networks and Spatial Economics*, 7(4): 353-376.
- Theobald, D. M. (2001). "Quantifying urban and rural sprawl using the sprawl index", Paper presented at the annual conference of the Association of American Geographers in New York, on March 2nd, 2001
- Tsai, Y.H. (2005). Quantifying Urban Form: Compactness versus Sprawl. Taylor & Francis. *Urban Studies* 42(1): 141-161.
- UN-Habitat (2008). *The State of African Cities. A Framework for Addressing Urban Challenges in Africa*, UN Habitat, Nairobi.
- UN-Habitat (2010). *State of the World Cities, Bridging the Urban Divide Report 2010/2011*. London: Earthscan.
- Yeh, A., and Li, X., (2001). Measurement and monitoring of urban sprawl in rapidly growing Region using entropy. *Photogrammetric Engineering & Remote Sensing*. 67(1):83-90.

Appendices

Appendix 1: Monthly temperatures data (1999-2008)

Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1999	Maximum	19.4	21.5	20.5	21.8	22.6	22.4	17.1	18.1	18.5	17.9	17.7	18.5
	Minimum	2.2	3.1	5.9	5.2	5.8	6.3	8.6	8.6	6.2	4.6	-1.2	1.8
2000	Maximum	19.7	20.5	21.5	20.8	21.8	22.7	18.3	17.7	18.5	18.4	18.5	19.4
	Minimum	1	3.4	4.8	7	7.1	5.7	8.6	8.1	6.8	3.3	1.7	1
2001	Maximum	19.9	20.8	19.2	21.2	22.2	21.5	17.9	17.6	19.6	19.9	19.6	19.3
	Minimum	1.5	4.5	8.3	6	8.2	8	9.2	9.2	6.4	3.3	2.9	4.6
2002	Maximum	19.5	21.2	20.7	21.4	23	22.8	21.5	17.5	18.6	19.6	19.8	19.3
	Minimum	5	6.3	8.4	7.6	7.7	7.6	9.1	9.1	7.5	3.1	2.8	7.2
2003	Maximum	20.3	21.4	21.2	20.8	21.8	22.5	18	18.3	19	19.4	18.5	19.4
	Minimum	5.3	6.9	7.9	9.5	7	8	9.4	9.6	8.1	3	2.7	1.6
2004	Maximum	20.7	20.4	21	20.4	23.1	21.2	18.7	18.7	19.1	18.6	19.5	19.6
	Minimum	5	4.4	5.6	8.9	6.7	8.1	9.2	9	7	3.3	2.7	5.2
2005	Maximum	20.1	22.1	22	21.3	20.4	21.6	18.3	18.9	19.3	19	18.8	18.9
	Minimum	5.3	7.3	8.3	9.2	9.2	7.8	9.2	9.2	8.3	3.9	2	1.7
2006	Maximum	20	21	20.5	20	21.9	22.6	19	18	18.6	19.6	18.3	19.1
	Minimum	5.9	8	7.5	8.5	7.4	8.2	9.8	9.8	7.4	5.4	2.8	4.7
2007	Maximum	19.9	20.6	21.8	20.8	22.7	21.2	18	18.2	18.7	19	18.6	20
	Minimum	6.6	7.5	7.7	8.5	8.1	9	9.6	9.2	7.5	3.4	3.9	1.5
2008	Maximum	19.4	20.2	22	20.8	21.3	21.2	18.9	19	19.4	19.2	18.4	19.1
	Minimum	5.4	5	5.5	7.7	8.6	8.5	8.6	9.2	7	4.2	4	4.6
Average		12.16	13.329	13.87	14.28	14.84	14.705	13.85	13.617	13.075	11.35	10.62	11.2914

Source: Source: National Meteorological Agency of Ethiopian

Appendix 1: Monthly rainfalls (1999-2008)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual Rainfall
1999	6.9	0	26.6	2.8	11	48.9	362.4	365.1	52.4	59.6	1.4	0	937.1
2000	0	0	25.9	47.3	37.1	45.8	352.4	317.5	105.2	28.5	18.8	6.8	985.3
2001	0	33.8	71.2	45	64.6	34.9	406.7	260.4	32.2	4.1	0	3.4	956.3
2002	18.1	28	60.6	46.1	18.4	29.1	214.4	294.8	109.1	3.1	0	8.4	830.1
2003	15.6	36.3	60.2	85.7	3.8	99.5	334.7	288.7	74.2	7.1	0	7.4	1013.2
2004	24.4	9.7	29.7	113.3	5.6	99.7	334.7	301.3	78.9	14.1	11.8	0	1023.2
2005	34.3	4.5	28.6	49.5	76.4	91.1	310.7	228.3	106.8	0.7	1.5	0	932.4
2006	17.3	24.4	61	38.3	19.8	35.2	432.6	224.2	59.8	8.6	4.5	26.3	952
2007	0.3	30.4	8.9	71.8	13.6	93.2	309.9	414.6	128.5	4.9	5.7	2	1083.8
2008	0.3	1.7	0	34.6	68.9	66.4	397.7	234.8	76.6	9.9	54.6	1.2	946.7

Source: National Meteorological Agency of Ethiopian

Appendix 3: FAO Soil classes of 1997(FAOCLASS1)

Code	Soil Unit	Vegetation		Geology		Landscape		Texture	
		Code	Description	Code	Description	Code	Description	Code	Description
CMv	Vertic Cambisols	C	Cultivated	B/P	Basic and ultrabasic rocks/Pyroclastic rocks	Y/L	Piedmont Plains/Plateau	4	Clay Loam
LPe	Eutric Leptosols	C	Cultivated	B/P	Basic and ultrabasic rocks/Pyroclastic rocks	H/V	Hills, Minor Scarps/ Valleys/Minor Valleys	4	Clay loam
						V	Valleys/Minor Valleys		
LPq	Lithic Leptosols	BG	Bush land, Grass land	B/P	Basic and ultrabasic rocks/Pyroclastic rocks	V	Valleys/Minor Valleys	5	Clay

Source: Food and Agriculture Organization of the United Nations (FAO, 1997).