Geo-spatial Approach for Assessing the Impact of Land-Use and Land-Cover Change on Groundwater Recharge: A Case Study in Akaki Catchment, Central Ethiopia

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This is to certify that the thesis prepared by **Mearg Belay**, entitled: **Geo-spatial approach for assessing the Impact of Land-use/land-cover change on Groundwater Recharge: a case study in Akaki catchment, Central Ethiopia,** and submitted In Partial fulfillment of the Requirement for the degree of Masters of Science in Remote sensing and Geographic Information System (GIS) Complies with the regulations of the university and meets the accepted standards with respect to originality and quality.

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Abstract

Land-Use and Land-cover changes are the major factors influencing catchment hydrology and ground water resource. Thus, understanding the potential impact of land–use change on ground water resource particularly recharge is important for making carful management of water resources. The present study area is located in the central Ethiopian highlands at the western margin of the Main Ethiopian Rift .The main objective of this study was to determine the LU/LC change of Akaki catchment between the year1986−2015 G.C and to evaluate the impact of these land–use and land–cover changes on ground water recharge using a geospatial approach. To analyze the changes in area over the time, a set of satellite images was obtained for the years 1986 (TM), 2000 (ETM+) and 2015 (OLI-TIRS) and hydro meteorological data for 1986−2014 years was taken and used for the trend analysis of these factors. The methodology to evaluate land–use and land–cover and climate change effects on ground water recharge consists of three steps. In the first part land-cover maps of the year 1986, 2000 and 2015 were compiled by means of supervised classification method of Landsat images. Secondly, the relationship between hydro meteorological elements and ground water recharge have investigated by analyzing the temporal and spatial trend patterns of some of the hydro meteorological elements that have a great impact on groundwater recharge conditions. Trend analysis of these selected elements shows: the annual precipitation is slightly decreasing & however, it is insignificant to reduce ground water recharge. The trend of annual surface runoff and stream flow of the catchment is appreciably increasing and it causes recharge to decrease. Finally, a water balance modeling, WetSpass and GIS, was applied to estimate the past and present seasonal and annual ground water recharge. The model was run for the three different years land–use and land–cover maps keeping the other parameters constant hence; the result reflects impact of land–use and land–cover change on the ground water recharge. The simulated results of the model indicates that the mean annual ground water recharge was decreasing from 268.6 mm/y for land–use map of 1986 to 264.9 mm/y and 260 mm/y for land−use maps of 2000 and 2015, respectively. Study outputs indicated that ground water recharge in the catchment did not change significantly. However, land–use and land–cover had remarkable variation in the period between1986 to 2015. This result provides a better understanding of the spreading situation of Akaki catchment which would support decision making process to control the ground water conditions.

Keywords: GIS, RS, Akaki catchment, Ground water recharge, WetSpass, Surface Runoff

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LIST OF ABBREVIATIONS

3D	Three dimension
µm	Micro meter
AAWSA	Addis Ababa Water and Sewerage Authority
AVHRR	Advanced Very High Resolution Radiometer
B	Band
CAD	Computer Aided Design
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
ERDAS	Earth Resources Data Analysis System
FAO	Food and Agricultural Organization
FCC	False Color Composite
Fig	Figure
G.C	Gregorian Calendar
GeoTIFF	Geographic Tagged Image File Format
GIS	Geographic information system
GPS	Global Positioning System
GWD	Ground water Depth
ITCZ	Inter Tropical Convergence Zone
LU/LC	Land use and land cover
Max.	Maximum
MER	Main Ethiopian Rift
Min.	Minimum
MSS	Multi spectral scanner
MoWIE	Ministry of Water Irrigation and Energy
Mt.	Mountain
mm/y	Millimeter per year
N	North
NDVI	Normalized Difference Vegetation Index
NIR	Near Infra-Red
NMSA	National Meteorological Service Agency
NNE-SSW	North North East – South South West
OLI	Operational Land imagery

PCA	Principal Component Analysis
PET	Potential evapotranspiration
RH	Relative humidity
RGB	Red,Green,Blue
RS	Remote sensing
SPOT	System Pour l'Observation de la Terre
TIRS	Thermal Infra-Red Sensor
TM	Thematic Mapper
USDA	United States Department of Agriculture
USGS	United State Geological Survey
VIS	Vegetation Indices
WGS	World Geodetic System
WetSpass	Water and Energy Transfer between Soil, Plants and Atmosphere Under quasi-Steady State.
WTF	Water table fluctuation

CHAPTR ONE

INTRODUCTION

1.1 Background of the Study

Understanding impacts of land-use/land-cover (LU/LC) change on the hydrologic cycle is needed for optimal management of natural resources. Impacts of LU/LC change on atmospheric components of the hydrologic cycle (regional and global climate) are increasingly recognized (IPCC, 2007). Unlike surface water where, the impact of land-use and land-cover change on subsurface components of the hydrologic cycle, the saturated and unsaturated zone are less well recognized, in particularly groundwater recharge. However, the potential scale of subsurface impacts is large (Mishra *et al*., 2014). Changes in land-use and land-cover alter both runoff behavior and the water balance that exists between evaporation, evapotranspiration, ground water inflow and outflow, surface water inflow and outflow in certain water shades under a given period of time, with considerable consequence for all water users. The increase in imperviousness has a major impact on the groundwater, and is of major concern over the past years to those who are involved in groundwater studies (Mishra *et al*., 2014). The increase in urbanization results in reduction in infiltration, which affects the groundwater recharge. Thus, land use changes have to be evaluated properly using conventional and latest geospatial techniques like Remote Sensing (RS) and Geographical Information System (GIS). Proper planning and management for development of natural resources without jeopardizing the environment is a vital concern to be sorted out for the world community. Quality inputs on the rate and pattern of land use change is essential for proper planning and management. Land–use change pattern reflects the rate of change of groundwater recharge. It is necessary to detect the land–use change in the past and present existing land–use, and its spatial distribution and potential changes are essential prerequisites for planning and management. However, the quantity and quality of groundwater are changing due to human activities jeopardizing the suitability of the groundwater system as a source of drinking water and affecting natural reserves. Assessing the impact on the groundwater system and predicting the magnitude of change in the future is therefore a major challenge (Tang, 2005). It is also important to understand how LU/LC change impacts ground water recharge, especially in regions that are undergoing rapid urbanization. Therefore, this study focused on the analysis of hydrological processes and recharge ability of various land–use types in the Akaki catchment, central Ethiopia. Akaki catchment supply large quantity of ground water for domestic supply in Addis Ababa. The method applied in this study was geospatial approach specifically the interaction among ground water recharge, surface water and LU/LC change were analyzed through the utilization of GIS and RS imagery processing and wets pass modeling. The fast population growth, uncontrolled urbanization and industrialization causes serious quality degradation of surface and ground water in particular (AAWSA *et al*., 2000) in Addis Ababa. Understanding impacts of land-use/land-cover change on the ground water recharge is therefore needed for optimal integrated management of both surface and subsurface water resources. So far, impacts of LU/LC change on ground water resource particularly ground water recharges are less well recognized. Therefore, to estimate and understand the impact of LU/LC change on ground water recharge, it is also important to accurately assess the type and direction of changes occurring within the watershed. This can be accomplished through change detection analysis of multi-temporal remotely sensed imagery. Correlating historical LU/ LC practices with recharge can be used to assess the impact of changes on ground water recharge.

1.2 Problem statement and justification

Land–use change and climate change are frequently indicated to be the main human induced factors influencing ground water system. Akaki catchment is exposed to intensive development; significant part of the area is characterized by greater level of impervious surface such as road parking lots sidewalks and roof tops. At present, there are still large gaps in knowledge, skills and experiences for a proper assessment and sustainable development and management of groundwater, as well as the impact of land–use changes on the groundwater flow system, including a possible reduction in recharge and increase in demand. Addis Ababa experiences fast urbanization and industrialization with high population growth which in directly causes degradation of ground water quantity by affecting ground water recharge. Therefore, the need for scientific research on the impact of LU/LC change on ground water recharge in the catchment is unquestionable. Most of the previous researchers mainly focused on assessing impact of land-use/land-cover change on ground water quality and surface hydrology often neglecting effects on the ground water recharge condition. Ground water resource is highly dependent not only on the quality of the resource, but also the quantity. Understanding the ground water resource management and its effects a result of LU/LC is crucial for sustainable use of the resource. The focus of this study was understanding and estimating the potential impact of LU/LC change on ground water recharge, which helps for a better use, and management of the subsurface water resources in the catchment.

1.3 Objective of the study

1.3.1 General objective

The main objective of this research was to assess of the potential impact of land-use and land-cover changes on ground water quantity in Akaki catchment based on recharge estimation using a geospatial data sets like remote sensing and GIS.

1. 3.2 Specific objectives

- To assess the implication of development scenarios (especially urbanization) on the ground water recharge in Akaki catchment.
- To assess the general trend of land-use/land-cover change of the catchment and to produce a complete land–use map of the catchment for the past three decades.
- To assess the relation of ground water recharge with catchment factors (climate , land-use and land-cover)
- To quantitatively estimate ground water recharge at different periods
- To develop a conceptual model and ground water recharge map of the study area.

1.4 Research questions

1. How does the trend of LU/LC changes for the past 29 years?
2. How does LU/LC change impact recharge?
3. What will be the implication of urbanization, population development and ground water demand on the hydrologic cycle?
4. What will be the best land–use practice to protect ground water availability?
5. How well can WetSpass model simulate effect of LU/LC change on hydrologic cycle especially ground water recharge in the watershed?

1.5 Significance of the study

The land-use and land-cover changes have significantly affects natural resources, socioeconomic and environmental systems all over the world. However, to assess the effects of land-use and land-cover change on ground water recharge, it is important to have an understanding of the land-use and land-cover patterns and the hydrological processes of the watershed. Understanding the types and impacts of land-use and land-cover changes an essential indicator for resource base analysis and development of effective and appropriate response, strategies for sustainable management of natural resources in the country in general and in the study area in particular.

Moreover, the study presents a method to quantify land-use and land-cover change and their impacts on hydrological regime, particularly ground water recharge. The relationship between the land-use /land-cover change and groundwater resources has been represented by RS-GIS methods and it will be helpful to assist policy analysis and decision making related to the sustainable development and management of ground water resource. Especially, outputs from this study provides a sound technical support for the management of water resources, which indicates that geospatial approach like integrated RS-GIS and hydrological model are desirable in studying land-use /land-cover and its relationship with water resources and socioeconomic developments. This has been achieved using the GIS based WetSpass modeling for estimating ground water recharge, GIS and remote sensing techniques to analysis the land–use and land–cover change.

1.6 Organization of the thesis

The thesis is organized into six chapters: chapter one is the introduction section where the background, statement of the problem, objectives of the study, research questions and significance of the study are discussed. In chapter two, review of related literatures where the definition and concepts of land-use and land-cover changes, land-use and-land cover changes in Ethiopia, Application of Remote sensing on land-use and land-cover changes and other fields, basic concept in image analysis, common operations in digital image processing of satellite images including accuracy of image classification, estimation techniques for groundwater recharge and other environmental factors that affect groundwater resources are reviewed. Chapter three provides necessary background information about the study area in terms of location, climate, topography, hydrology, geology and hydrogeology. Also this chapter elaborates the source of the materials used and methodologies applied to achieve the desired objectives as well as the methods of imput data preparation and analysis. The fourth chapter assesses the spatio-temporal characteristics of the hydro-meteorological data of Akaki catchment. The analysis includes the rainfall, temperature, and evapotranspiration and flow data across the river. The fifth section describes interpretation and discussion of the result of the research works from land-use and land-cover analysis, WetSpass modeling and NDVI calculation. Finally, in section six, conclusion, recommendations and suggestions for further research work of the study area are provided.

1.7 Limitation of the study

This study has faced many limitations and the following main obstacle:

- The research study is limited on using high resolution remote sensing imageries for preparing a more realistic land-use and land–cover maps of the past years.

- In this study, geospatial technologies like remote sensing, GIS and GIS based water balance model (the WetSpass modeling) were used to estimate ground water recharge of a catchment under different land-use and land-cover scenarios. However, this methodology is limited to make field data check and measurement for validation of the model results and some of the model input parameters due to the time bound set for the thesis work coupled with field constraint (transport and instrument).

- This research study is also limited to data like time series and seasonal measurement of ground water depth data.

- Ground water recharge along geological structures was not considered and is a big limitation of WetSpass model.

CHAPTER TWO

LITERATURE REVIEW

This chapter briefly introduces concepts and surveys relevant literature on the definition and concepts of land-use and land-cover change, land-use and land-cover change studies in Ethiopia, mapping and change detection of land-use and land-cover, application of remote sensing on land-use and land-cover change and other fields, basic concept in image analysis, common operations in digital image processing of satellite images including accuracy of image classification, estimation techniques for groundwater recharge, other environmental factors that affect groundwater resources and introduction to the WetSpass modeling.

2.1 Land–use and land cover–change: definitions and concepts

Land-use and land-cover (LULC) changes have great effects for the environmental and socio-economic sustainability of communities. When one type of use replaces another, the effects tend to be superimposed and cumulative. During the process of urbanization, when rural and forest areas are converted to urban land-uses, hydrological cycle and rates of soil erosion will change accordingly (Yuan, 2008). Meanwhile, when agricultural land is decreasing, the dependence on the use of fertilizers and pesticides to increase the productivity is rising. As a consequence, unused nutrients, mainly nitrogen and phosphorus, near the soil surface could be transported by surface runoff to water bodies, thereby reducing water quality. The amount of urban impervious surfaces has emerged as an important indicator of environmental quality. It influences the non-point source pollution and water quality by directly affecting the amount of runoff to water bodies.

Human's production demands cannot be fulfilled without modification and/or conversion of land covers. In the past two centuries, the impact of human activities on land has grown enormously because of population increase, technological developments and the requirements thereafter, altering entire landscapes, and ultimately impacting the biodiversity, nutrient and hydrological cycles as well as climate (de Sherbinin, 2002), especially in the developing world. According to de Sherbinin (2002), land–use is the term that is used to describe human uses of land, or immediate actions modifying or converting land cover. On the other hand, land cover refers to the observed physical cover on earth's surface. Thus, land use often influences land cover. In the same source change defined as an alteration in the surface component of the landscape and is only considered occur if the surface has a different appearance when viewed on at least two successive occasions. Changes like clearing of forest or plantation area for urban expansion can be detected using remotely sensed data.

In a time of rapid and often unrecorded land use and land cover change, observations from space provide objective information of human utilization of the landscape. In the past, data from Earth sensing satellites have become important in mapping the Earth's features and infrastructure, managing natural resources and studying environmental change.

Generally, knowing of the impacts of land–use and land–cover changes on the natural resources like water resources depends on an understanding of the past land–use practices, current land–use and land–cover patterns, and projection of future land–use and land–cover, as affected by population size and distribution, economic development, technology, and other factors. The land-use and land-cover change assessment is an important step in planning sustainable land management that can help to minimize agro-biodiversity losses and land degradation, especially in developing countries like Ethiopia (Kiros Meles, 2008).

2.2 Land–use and land–cover change studies in Ethiopia

Most of the land in Ethiopia is being used by smallholders who farm for subsistence. With the rapid population growth and in the absence of agricultural intensification, smallholders require more land to grow crops and earn a living which results in deforestation and land use conversions from other types of land cover to croplands (Asmamaw Adamu, 2013). Most of these studies indicated that croplands have expanded at the expanse of natural vegetation including forests and shrub lands. Most of the empirical evidences indicated that land-use and land-cover changes and socioeconomic dynamics have a strong relationship; as population increases the need for cultivated land, grazing land, fuel wood; settlement areas also increases to meet the growing demand for food and energy, and livestock population. Thus, population pressure, lack of awareness and weak management are considered as major causes for the deforestation and degradation of natural resources in Ethiopia. These environmental consequences in turn lead to other problems. For instance, vegetation destruction increases surface runoff by doing that it affects the ground water recharge.

2.3 Mapping and change detection of land–use and land–cover patterns

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times. Essentially, it involves the ability to quantify temporal effects using multitemporal data sets. In a time of rapid and often unrecorded land-use and land-cover change, observations from space provide objective information of human utilization of the landscape. According to Ashbindu (2010) one of the major applications of remotely-sensed data obtained from earth-orbiting satellites is change detection because of repetitive coverage at short intervals and consistent image quality. Land–use and land–cover change have become a central component for managing natural resources and monitoring environmental change.

The basic premise in using remote sensing data for change detection is that changes in land–cover must result in changes in radiance values and changes in radiance due to land–cover change must be large with respect to radiance changes caused by other factors (Ashbindu, 2010). Such as differences in atmospheric conditions, differences in Sun angle and differences in soil moisture. Impacts of these factors may be partially reduced by selecting the appropriate data. For example, Landsat data belonging to the same time of the year may reduce problems from Sun angle differences and vegetation changes.

Land-use and-land cover change has become a central component in current strategies for managing natural resources and monitoring environmental change. The environmental consequences of uncontrolled population growth are obvious such as forest destruction, pressure on land and other natural resources, unsustainable pattern of land–use for agriculture, degradation of land and depletion of resources (EPA, 1997). These environmental consequences in turn lead to other problems. For instance, vegetation destruction increases surface runoff by doing that it affects the ground water recharge.

2.4 Remote sensing and GIS techniques in land–uses / land–cover mapping and change detection studies

The remote nature of remote sensing technology allows us to make observations, take measurements (i.e. measuring the reflected and/or emitted electromagnetic energy from the earths features), and produce images of phenomena that are beyond the limits of our own senses and capabilities. Satellite remote sensing provides a large amount of data at different spatial, spectral, and temporal resolutions by using appropriate combination of bands to bring out natural and man-made features that are most pertinent to a certain project for detecting changes. Planners and resource managers need a reliable mechanism to assess the consequence of the changes resulted by the stress imposed natural resource by detecting, monitoring and analyzing land–use changes quickly and efficiently. The conventional method of environmental data collection and analysis are not efficient in delivering the necessary information in a timely and cost effectively fashion. Hence, viewing the Earth from space has become essential to comprehend the cumulative influence of human activities on its natural resource base. Remote sensing technology, however, can play a vital role in providing accurate and reliable information with cost effective and lesser time compared to other methods.

The data obtained from satellites imagery used for a wide array of change related application areas such as vegetation and ecosystem dynamics, hazard monitoring, hydrology, land–use and land cover–change. Satellite image data enable direct observation of the land surface at repetitive intervals and therefore allow mapping of the extent and monitoring and assessment. Remote sensing at various scales play a major role in spatio-temporal earth surface monitoring (Neteler *et al.*, 2004). Some of the application of remote sensing technology in mapping and studding LU/ LC dynamics are: map and classify vegetation (forest), assess the spatial arrangement of land cover and vegetation types, provide information for extrapolating field observations, allow analysis of time-series images used to analyze landscape's history, report and analyze results of inventories including inputs to Geographical Information System (GIS), and provide a basis for model building.

The most useful characteristic of Remote Sensing in land-use and land-cover change detection is the multi–spectral and temporal resolution of the data. That is, images are obtained in different portions of the electromagnetic spectrum and the same area is imaged with a specified periodic time interval. The advantage of using remote sensing in land–use/land–cover is that information from the same area could be easily obtained at different times, and this is important in change detection applications. Furthermore, remote sensing can provide the required data in short time with a reasonable accuracy and has an important contribution to make in documenting the actual change in land–use/land–cover on regional and global scales.

Remote sensing and Geographic Information Systems (GIS) are providing new tools for advanced ecosystem management. The collection of remotely sensed data facilitates the synoptic analyses of earth-system function, pattern and change at local, regional and global scales over time. Such data also provide a vital link between intensive, localized ecological research and the regional, national, and international conservation and management of environment. Geographic Information Systems (GIS) is a technology, which enables the analysis of data related to entities that have geographic distribution. Georeferenced data, land-use/land-cover, crop type, or soils, can be incorporated in a GIS to produce map layers or "coverages". A map layer, generally composed of only one type of data, and thus considered to have a "theme". Many of these themes that have a similar spatial extent can be combined to form a full GIS database. As a result, the GIS serve as a tool for analyzing interactions among and within the various spatially referenced data themes.

Development of Remote Sensing and Geographic Information System (GIS) technologies have led to the advancement of mapping and interpretation techniques as a means of understanding and effectively managing the natural resource in a sustainable manner. Analysis mechanisms of land–use pattern changes play an important role not only forecasting changes but also formulating local development strategies. At present, remote Sensing in combination with GIS have given rise to the advent of more precise and geographically referenced data on land use and land cover, which in turn have created opportunities for improved assessments and analysis issues related with the land use/land cover dynamics (Codjoe, 2007).

2.5 Application of remote sensing for different fields

The utility of different remote sensing data from different satellites have been demonstrated in many fields such as agriculture, cartography, civil engineering, environmental monitoring, forestry, geography, water resources management, land resources analysis and land use planning**.** The use of satellite images in any of the fields mentioned above, demand the knowledge of the different bands that each sensor system onboard satellites use to take the imagery and how these bands of the electromagnetic spectrum interact with land surface features and with that of the atmosphere. As there are many satellites in the space providing remote sensing data, their application will vary with their way of data acquisition.

2.6 Basic concept in image analysis

Remotely sensed data includes a variety of data source that are defined from the range of spectrum of electromagnetic radiations. Aerial photography is used to capture reflective signal from the visible and near infrared portion of the spectrum. Most digital scanners operate in similar portion of the spectrum. Thermal and radar sensor systems are sensitive to the different portion of the energy spectrum.

Remotely sensed data provides an operational GIS with timely and synoptic data. Image analysis techniques are commonly utilized to perform regional vegetation mapping and to update existing vegetation maps. According to Jensen (1996) the utility of a sensor system for the detection of surface phenomena must be assessed along four dimensions: spatial resolutions (area or size of features that can be identified), spectral resolution (number and width of electromagnetic bands for which data are collected), radiometric resolution (detector sensitivity to various level of incoming energy) and temporal resolution (frequency of satellite overlaps).

Airborne and satellite digital sensor collect and store data values for discrete units of the surface of the earth. A scene is composed of large matrix of these cells. Each cell is referred to as a picture element or pixel and may correspond to a square meter, hectare or square kilometer, depending on the sensor. The spatial resolution of the sensor is usually expressed as the length of one side of the cell.

2.7 Common operations in digital image processing of satellite images

Digital Image Processing refers to the manipulation and interpretation of digital images, by a computer system, to prepare an image for display and interpretation and/or to extract useful information from the image. The possible forms of digital image manipulation are literally infinite (Lillesand *et al*., 2000). Digital Image Processing is largely concerned with four basic operations: image rectification and restoration, image transformation, image enhancement, and image classification.

A) Pre-processing

According to Lillesand (2000) the term pre-processing is understood as the correction of geometric and radiometric deficiencies and the removal of data errors. It seems natural that errors within the data are removed, if possible, before image interpretations start. The choice of methods to do so is always purpose dependent. If, for instance, a check of a certain land–cover or object with satellite image is the purpose, visual interpretation might be sufficient and even geometric correction not necessary (Jensen, 1996). The operator should define precisely the demands on the data and chose the necessary processing steps to achieve his specific task. The importance of pre-processing methods becomes obvious in change detection or monitoring applications, where the operator must be able to distinguish data noise, pre-processing and data handling errors from real changes.

B) Image enhancement

Image enhancement is used to increase the detail ness of the image by assigning the image maximum and minimum brightness values to maximum and minimum display values, and it is done on pixel values, and this makes visual interpretation easier by increasing the visual discrimination between features in a scene and assists the human analyst. False color composite (FCC) and Spatial resampling are among the techniques mostly used to enhance remote sensing imageries.

C) Image transformation

Image transformation refers to the derivation of new imagery as a result of some mathematical treatment of the raw image bands. Image transformation involves processes that are similar in concept to those processes in image enhancement, but unlike image enhancement these process are normally applied on multi-channel (band) images. Principal Components Analyses (PCA) and Vegetation Indices (VIs) are among image transformation processes.

D) Image classification

According to Bakker *et al.* (2000) in the application context the important thing in image classification is the thematic characteristics of an area (pixel) rather than its reflectance value. Thematic characteristics such as land–cover, land–use and soil type can be used for further analysis and input to models. In addition, image classification can also be considered as data reduction: a number of multispectral bands resulted in a single value raster file. Image classification is the process of creating thematic maps from satellite imagery. A thematic map is an informational representation of an image that shows the spatial distribution of a particular theme. This normally involves the analysis of multispectral image data and the application of statistically based decision rules for determining the land cover of each pixel in an image.

The computerized interpretation of images from remote sensors is known as a quantitative analysis due to its ability to identify pixels based on the numerical properties. Classification is a method that assigns categories to different pixel groups according with the spectral character. There are two main spectrally oriented classification procedures for land–cover mapping: unsupervised and supervised classifications.

The unsupervised classification is computer-automated and it enables user to specify some parameters that the computer uses to uncover statistical patterns that are inherent in the

data. These patterns are simply clusters of pixels with similar spectral characteristics. In some cases, it may be more important to identify group of pixels with similar spectral characteristics than it is to sort pixels into recognizable categories. On the other hand, in supervised classification the image analyst supervises the pixel categorization processes by specifying, to the computer algorithm, numerical descriptors of the various land cover types present in a scene (Lillesand, 2000). To do this, representative sample sites of known cover type, called training areas are used to create the parametric signatures of each class.
According to Jensen (1996) each pixel in the data set is then compared numerically to each category in the interpretation key and labeled with the name of the category. There are different algorithms under this classification type in which minimum distance, variance and covariance of the classes are considered during classification. Of these algorithms the best is maximum likelihood classifier. It quantitatively evaluates both the variance and covariance of the category spectral response patterns when classifying an unknown pixel. It is hoped that at the more generalized first and second levels, accuracy in interpretation can be attained that will make the land-use/land-cover data comparable in quality to those obtained in other ways. For land-use/land-cover data needed for planning and management purposes, the accuracy of interpretation at the generalized first and second levels is satisfactory when the interpreter makes the correct interpretation 85 to 90 % of the time.

An important assumption in supervised classification usually adopted in remote sensing is that each spectral class can be described by probability distributions in multispectral space which will be a multivariable distribution with as many variables as dimensions of the space. Such distribution describes the chance of finding a pixel belonging to that class as any given location in many multispectral spaces. This is not unreasonable as it would be imagined that most pixels in distinct cluster or spectral class would lie towards the center and would decrease in density positions away from the class center, there by resembling a probability distribution. The distribution found to be most valuable is the normal distribution. It gives rise to tractable mathematical descriptions of the supervised classification process and robust in the sense that classification accuracy is not overly sensitive to violations of the assumptions that the classes are normal.

2.7.1 Accuracy of image classification

The accuracy is essentially a measure of how many ground truth pixels were classified correctly. When looking at the land cover map, it is important to remember that no map is a perfect representation of reality. There are always errors in maps and we need to keep in mind how accurate they are, and whether that level of accuracy is sufficient for the ways we want to use the map information (Awotwi, 2009). To perform quantitative classification accuracy assessment, it is necessary to compare two sources of information: first, the remote sensing derived classification data and second, the reference test information data obtained from field observation. The relationship between these two sets of information is summarized in a Cell array. The Cell array is a list of class values for the pixels in the classified image and the corresponding reference image (Leica Geosystems, 2003) where the class values for the reference are based on ground truth data and the Cell array data is retrieved from the image file. From the cell array assessment, two reports are derived: the error matrix comparing reference points to classified points, and the accuracy report. The result of an accuracy assessment provides us with an overall accuracy of the map based on an average of the accuracies for each class in the map. The error matrix is a square array of numbers laid out in rows and columns that express the number of sample units assigned to a particular category relative to the actual category as verified in the field. The columns usually represent the reference data, while the rows indicate the classification generated from the remotely sensed data. Once accuracy data are collected and summarized in the error matrices, they are subjected to detailed interpretation and further statistical analysis. Kappa is used to measure the agreement or accuracy between the remote sensing derived classification map and the reference data as indicated by the major diagonals and the chance agreement, which is indicated by the row and column totals (Jensen, 2003). It is a discrete multivariate technique that is used in accuracy assessments. Kappa analysis yields a Khat statistics (an estimation of Kappa) which measures the difference between actual agreement in the error matrix (i.e., the agreement between the remotely sensed classification and the reference data), and the chance agreement between the reference data and a random classifier (Lillesand et al., 2008).

$$\text{Over all accuracy} = \frac{\text{Total Number of pixels correctly classified}}{\text{Total number of pixels(cells)}} \qquad \text{Eq (2. 1)}$$

Producer’s accuracy is the total number of correct pixels in a category divided by the total number of pixels of that category as derived from the reference data (column total). This statistics indicates the probability of a reference pixel being correctly classified and is a measure of omission error.

The Kappa factor is given by the formula:

$$\text{Kappa} = \frac{p_0 + p_e}{1 - p_e} \qquad \text{Eq (2.2)}$$

Where: Po = is the proportion of correctly classified cases

Pe = is the proportion of correctly classified cases expected by chance.

Such formula statistic serves as an indicator of the extent to which the percentage correct values of an error matrix are due to true agreement versus the chance agreement. As the true agreement or the observed agreement approaches 1 and chance agreement approaches 0, Kappa approaches 1 which is considered the ideal case. In actual classification, usually kappa ranges between 0 and 1. A Kappa of 0 indicates that a given classification is no better than random classification or assignment of pixels while if Kappa takes negative values, then it is an indication of very poor classification. According to Jensen (2003) it is worth mentioning that there are two other error measurements derived from the error matrix. The first is the omission error or producer accuracy which indicates how well a certain area can be classified and is estimated by dividing the total number of correct pixels in a category by the total number of pixels of that category. The other is called the commission error or users error and it indicates the probability that a pixel is classified on the image actually represent that category on the ground.

2.8 Impact of land-use and land-cover change on hydrological cycle

The hydrologic cycle is a conceptual model that describes the storage and movement of water between the biosphere, atmosphere, lithosphere, and the hydrosphere. Land-cover change, and urban expansion in particular, can have many harmful environmental and ecological effects. Regarding hydrology, land cover change can have local, regional and even global consequences. It can also influence several surface and near surface hydrological processes that affect storm runoff, stream flow and flood regimes. These processes include evapotranspiration, interception, litter storage, root zone storage, infiltration-excess overland flow, surface and subsurface runoff and surface retention (Liu et al., 2006). According to Liu (2006) most of the impacts of LU/LC changes on a global scale can be expected from large-scale removal or planting of forests, which may have an impact on potential and actual evapotranspiration and on precipitation patterns and amounts. The increasing area of impervious surfaces related to urban expansion can cause local decreases in infiltration, percolation and soil moisture storage, reduction in natural interception and depression storage and increases in surface runoff.

Modelling approaches that describe hydrological processes and their controlling factors have become increasingly popular as a tool to understand the hydrological system and to simulate the impact of possible environmental change. For this research the WetSpass modeling was applied to assess the potential impact of Land-use and land-cover change on the water balance of a catchment. The impact of different climate change scenarios is also evaluated in order to assess the combined effect of both environmental changes on ground water recharge.

2.9 Groundwater recharge estimation

Groundwater recharge is the process in which surface water reaches the water-table in the aquifer's phreatic zone (Martinez, 2010). Groundwater recharge can occur in a variety of ways. The two most common vehicles for recharge are deep seepage recharge occurring between aquifer units and by infiltration recharge from precipitation.

Recharge is an integral part of the water budget for a shallow, freshwater aquifer. For the sustainable management of groundwater resources, the amount of recharge received by an aquifer is by far the most important figure required. Yet this figure is usually the least well-known quantity in hydrogeology, especially in arid and semi-arid environments (Kinzelbach *et al*., 2002). Unfortunately, it cannot be measured directly on any reasonable spatial scale. That so many years of effort have failed to find a single, reliable method for measuring groundwater recharge is due to the complexity of this phenomenon and the large variety of situations encountered. However, estimation of groundwater recharge is of great importance in water resources management, especially for areas in which groundwater is vital for the local water supply. Exact estimation of regional groundwater recharge requires a good understanding of the hydrological processes in the area, which could be greatly altered by global change and human activities (Nolan *et al*., 2007). Thus, the effects of land use change on groundwater recharge should be thoroughly investigated, especially in the regions subject to rapid urbanization and limited surface water. The key to the successful estimation of groundwater recharge lies in the utilization of a variety of independent methods. Because every method has its strengths and weaknesses, but combined they become much stronger.

Groundwater recharge can usually be estimated using experimental methods such as isotope tracers and numerical methods like water balance simulation. By bringing together environmental tracers, modern measurement techniques, automatic monitoring equipment, DGPS and remote sensing in a comprehensive groundwater model, the study of the hydrology of arid and semi-arid environments can enter a new era (Kinzelbach *et al*., 2002). Szilagyi *et al*. (2005) estimated naturally occurring long-term mean annual recharge to groundwater in Nebraska by a novel water-balance approach. This approach uses GIS layers of land cover, elevation of land and groundwater surfaces, base recharge, and the recharge potential in combination with monthly climatic data.

As groundwater is essential for both humans and the ecosystem, understanding groundwater recharge is critical for sustainable management of water resources under changing environmental conditions. A specific modeling tool to estimate recharge that should be mentioned in depth, as it was used in this research project, is the WetSpass modeling. The WetSpass model calculates the water balance of a grid cell while considering the fractions of vegetation, bare soil, open water and impervious area; therefore, it provides a good choice for estimation of long-term average spatial patterns of groundwater recharge (Batelaan and DeSmedt, 2001; 2007). For this study the WetSpass model is to be applied with a focus on how hydrological processes respond to land use change, and what effect various land uses have on groundwater recharge.

2.10 Introduction to WetSpass model

WetSpass is an acronym for Water and Energy Transfer between Soil, Plants and Atmosphere under quasi-Steady State and it was built as a physically based methodology for estimation of the long-term average, spatially varying, water balance components: surface runoff, actual evapotranspiration and groundwater recharge. It is especially suited for studying long-term effects of land use changes on the water regime in a watershed. The model is completely integrated with GIS ArcView (3.x) as a raster model coded in Avenue, the programming language of ArcView. Parameters such as land use and soil types are connected to the model as attribute tables of land use and soil raster maps, which allow new definitions of climatic as well as land use and soil types (Batelaan et al., 2003).

WetSpass requires spatially-distributed input data for land cover, soil texture, topography, precipitation, wind speed, groundwater depth and potential evapotranspiration at any meters resolution. However, precipitation and soil inputs are the drivers. In this study, the different land cover maps were resampled to a spatial resolution of 30x30 meters. In addition, the model needs a series of model parameters that describe the model’s behaviour. WetSpass gives various hydrologic outputs on a yearly and seasonal (summer and winter) basis. Even though the model was originally developed to compute the long-term spatially distributed recharge of a basin, it also simulates runoff, evapotranspiration, interception, transpiration, soil evaporation and errors in water balance. This model has been used in many instances to estimate groundwater recharge. For example, Teklebrhan Arefaine etal (2012) used it to estimate ground water recharge, evapotranspiration and surface runoff in Illala Catchment, Northern Ethiopia.

2.11 Additional factors affecting ground water recharges

While increased demand due to increasing population and pumping rates can cause large stresses on an aquifer, there are other confounding factors that can affect the quality and quantity of groundwater resources. In addition to land–cover change other environmental changes, such as global and regional climate change, groundwater use, water retention in reservoirs and river management, can have a large impact on the catchment hydrology. Climate change includes scenarios such as changing precipitation patterns, increase in hurricanes and other large storm events, and sea level rise. Studies have been done that have illustrated the significant effects of land–use on groundwater recharge. As there is often an obvious relationship between land–use and recharge, scientists have attempted to estimate recharge using–land cover data. Cherkauer and Ansari (2005) outlined a method to estimate recharge which uses ground-surface information instead of long-term groundwater monitoring data. They used the topography, hydrogeology, and land cover of the site to estimate recharge. The method obtained a conservative approximation for recharge, but recommended that the estimate should be refined with other methods. Similarly, Ranjan *et al*. (2006) estimated recharge based on land-use and climatic factors.
Researchers have not only studied the effect of land-use/land-cover on groundwater resources, but they have also studied the effect of land-use/land-cover change on aquifer systems. Scanlon et al. (2005) completed a study on the Southwestern United States to test their hypothesis that the LU/LC change of a natural rangeland into an agricultural ecosystem will affect the groundwater recharge and chloride mass balance. By examining three types of LU/LC, they were able to detect significant differences in mean chloride concentrations. Information gained from this study and similar studies suggest that groundwater resources can be somewhat managed through modification of LU/LC.

Another factor that has the potential to significantly affect groundwater resources is climate change. Since the mid-twentieth century, carbon dioxide levels in the atmosphere have been steadily rising. If this phenomenon continues, many researchers believe that the global and local climate characteristics will be significantly altered in the caming decads (Ranjan *et al*., 2006). This trend has been termed climate change, and would likely have large effects on the hydrologic cycle around the world. Increased atmospheric carbon dioxide levels would lead to an increased “greenhouse effect,” in which solar radiation is trapped by the increased gases. This results in increased temperatures, which in turn affects evapotranspiration, precipitation, and soil moisture.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Study Area

The Akaki catchment is located in the central Ethiopian highlands at the western margin of the Main Ethiopian Rift (MER). It is bounded to the north by the Entoto ridge system, to the west by Mt Menagesha and the Wechecha volcanic range, to the southwest by Mt Furi, to the south by Mt Bilbilo and Mt Guji, to the southeast by the Gara Bushu hills and to the east by the Mt Yerer volcanic centre. The catchment is situated at the northwestern Awash River basin between latitude 8°45′30″–9°13′20″N and longitude 38°36′20″–39°1′40″E covering a total area of the catchment about 1466.56 km^2 (Fig 3.1). Addis Ababa is located at the center of the catchment. Surface water reservoirs located within the study area include Legedadi, Gefersa, Dire and Abasamuel. The big Legedadi dam provides sustained flow to the rivers. Dire and Gefersa are relatively small reservoirs. The large Aba Samuel reservoir was used for water supply and hydropower generation. Now, it is a non-functional swamp area.

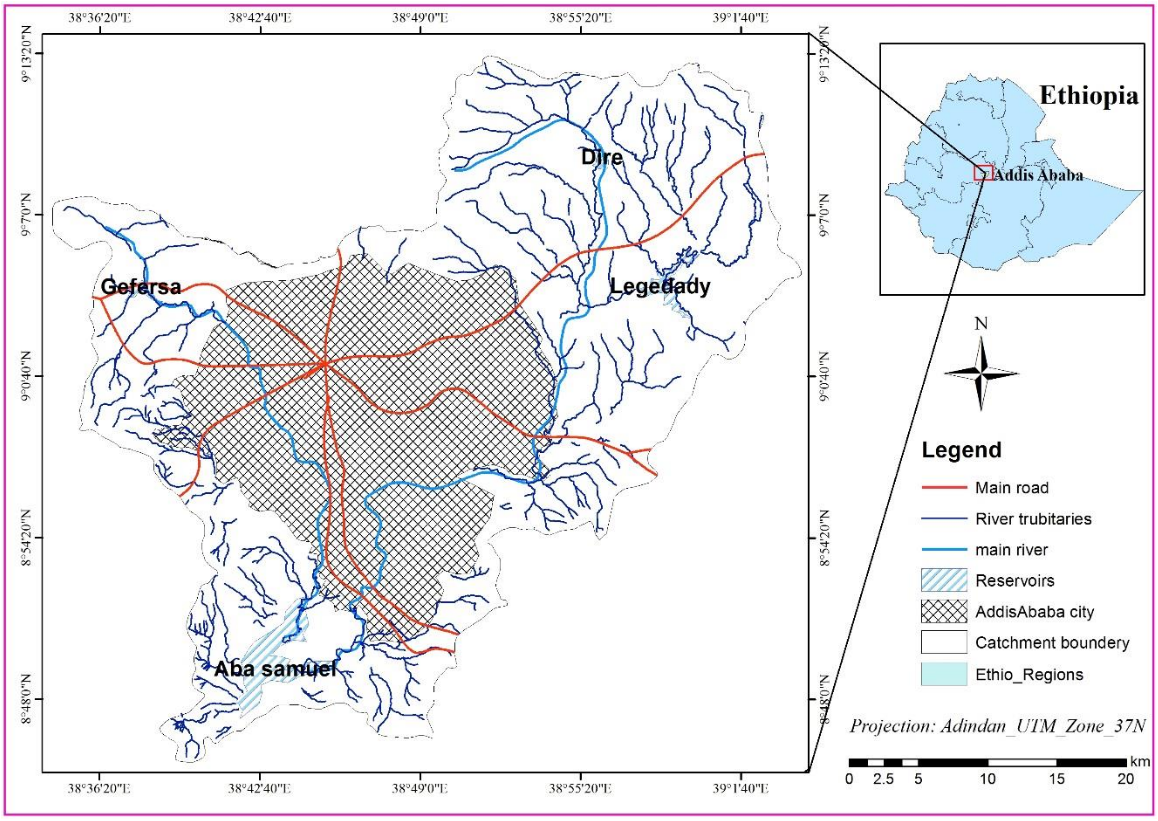

Fig 3.1 Location map of the study area

3.1.2 Physiography of the study area

Ethiopia can be divided into four major physiographic regions widely known as the Western plateau, Southern plateau, the Main Ethiopian Rift and Afar Depression (Mengesha Tefera *et al*., 1996). The watershed boundary of the study area is characterized by large central volcanoes and a well-developed morphology. It is surrounded by high rising mountain systems in all directions and the center of the catchment lies on an undulating topography with some flat land areas. The urban area of the catchment is deeply dissected by numerous valleys formed by the river systems crossing the city from north to east.

Entoto mountain ridge forms the northern boundary of the city following the East-West trending Ambo - Kassam major fault system. The elevation of this ridge ranges from 2600 to 3200 m asl forming the main recharge area. The volcanic mountains, Mt. Wechecha in the west, Mt. Furi in the south–west , and Mt. Yerer in the south–east are the high massive volcanic centers (Fig 3.2).

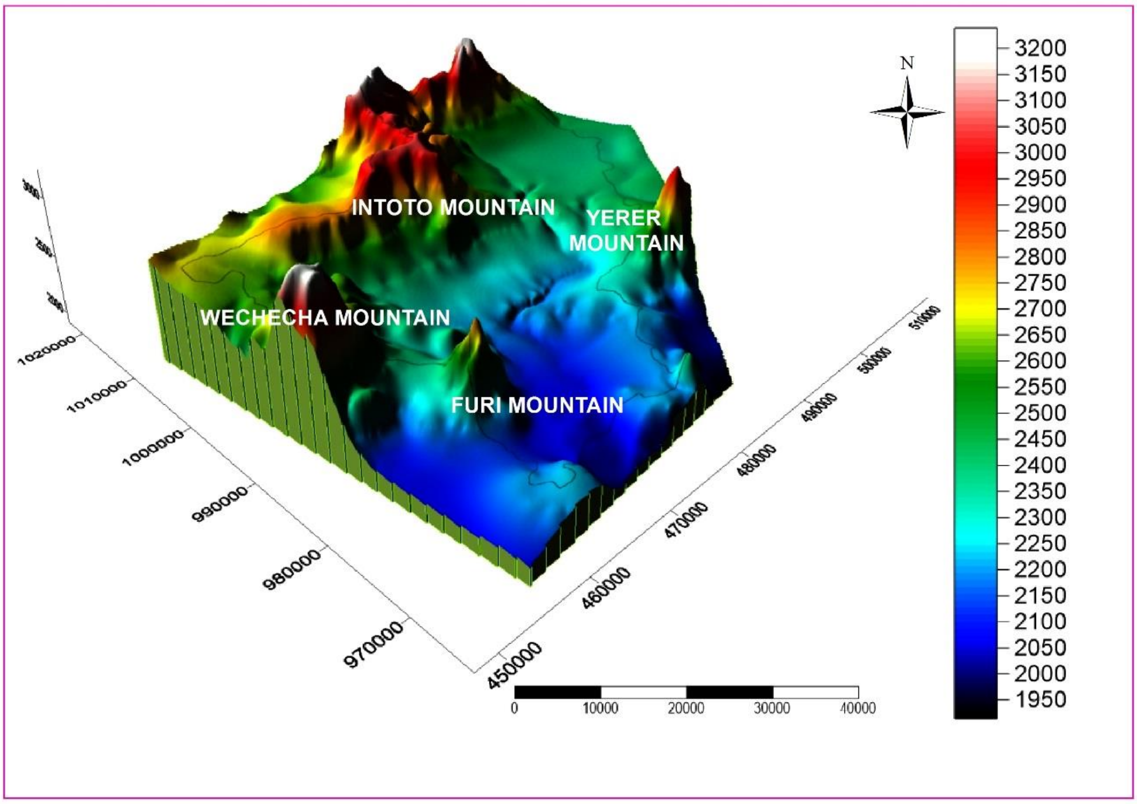

Fig 3.2 Physiographic map of Akaki catchment

In this study, profiles were drawn along distinct landforms (Fig 3.3), from the north east to the south–west (A-B) and form west to east(C-D) part of the DEM, to visualize topographic shape and structure of the study area.

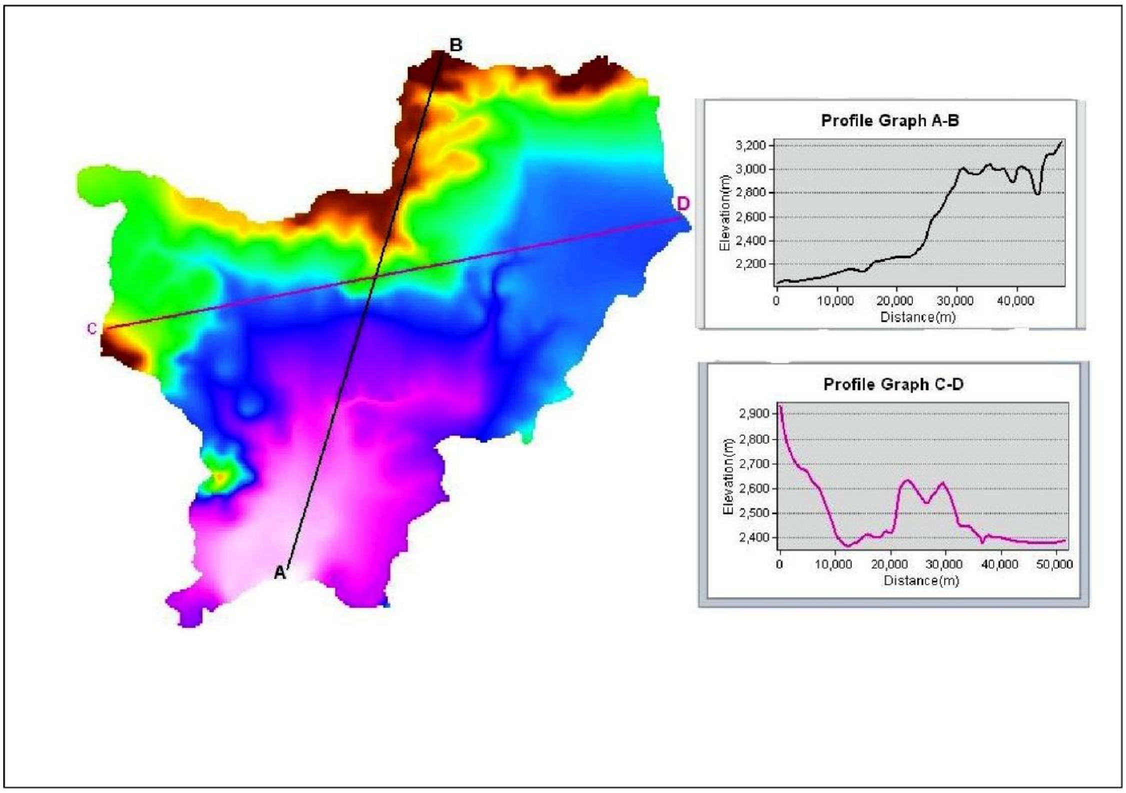

Fig 3.3 Elevation profile graph drawn along distinct relief areas

It is clearly shown From figure 3.3, the top left is the grid topographic map of the study region showing two path profile lines on the surface (A_B and C_D). Profile graph (A-B) shows the catchment is highly elevated to the north while the lowland area is to the south part of the study area.

3.1.3 Climate

In order to understand the environment and the possible impact of human activity on it, a basic knowledge of weather and climate is required. The former is the physical condition of the atmosphere at a specific time and place with regard to wind, temperature, cloud cover, fog, and precipitation. The climate of Ethiopia can be classified in different ways including the traditional, throthwaite's, rainfall regimes, and agro-climatic zone classification systems. The most commonly used classification systems are the traditional and the agro-ecological zones.

According to the traditional classification system which mainly relies on altitude and temperature, there are five climatic zones viz: Wurch (cold climate at more than 3000 m altitude), Dega (temperate like climate-highlands with 2500-3000 m altitude), Woina Dega (warm at 1500-2500 m altitude), Kola (hot and arid type, less than 1500 m in altitude), and

Berha (hot and hyper-arid type) climate (NMSA, 2001). Despite its proximity to the equator, the study area experiences a warm temperate climate. Ethiopia is located in the region where June through September is the main rainy season.

3.1.3.1 Rainfall

The climate of the study area is typically characterized by two distinct seasonal weather patterns: the wet season, which extends from June to September, contributing for about 73.7% of the annual rainfall, and the dry season which covers the period from October to May, with intermittent rainfall in the rest of the months. This seasonal variation of rainfall distribution within the study area is due to the annual migration of the inter-tropical convergence zone, a low-pressure zone marking the convergence of dry tropical easterlies and moist equatorial westerlies across the catchment (Ebasa Oljira, 2006). The study area receives rainfall from Atlantic Equatorial Westerly during the main rainy season and from Gulf of Aden and Indian Ocean during March and April months. There is low to negligible amount of rainfall in the other months. According to Leta Guddisa (2007) classification of Ethiopian rainfall region, Addis Ababa is located in the region where the rainy months are closely distributed weathering. In this region, there are seven rainy months from March to September and the small rains occur from March to May. The big rains are from June to September with high concentrations of rainfall occurs in July and very high concentrations in August.

The range of mean annual rainfall for the stations in the period 1986─2013 G.C lies between 1024.6 to 1283.99 mm and the mean monthly rainfall between June and September is above 100 mm, with monthly maximum rainfall recorded 337 mm in August. While November and December showed the lowest mean monthly rainfall (Fig 3. 4).

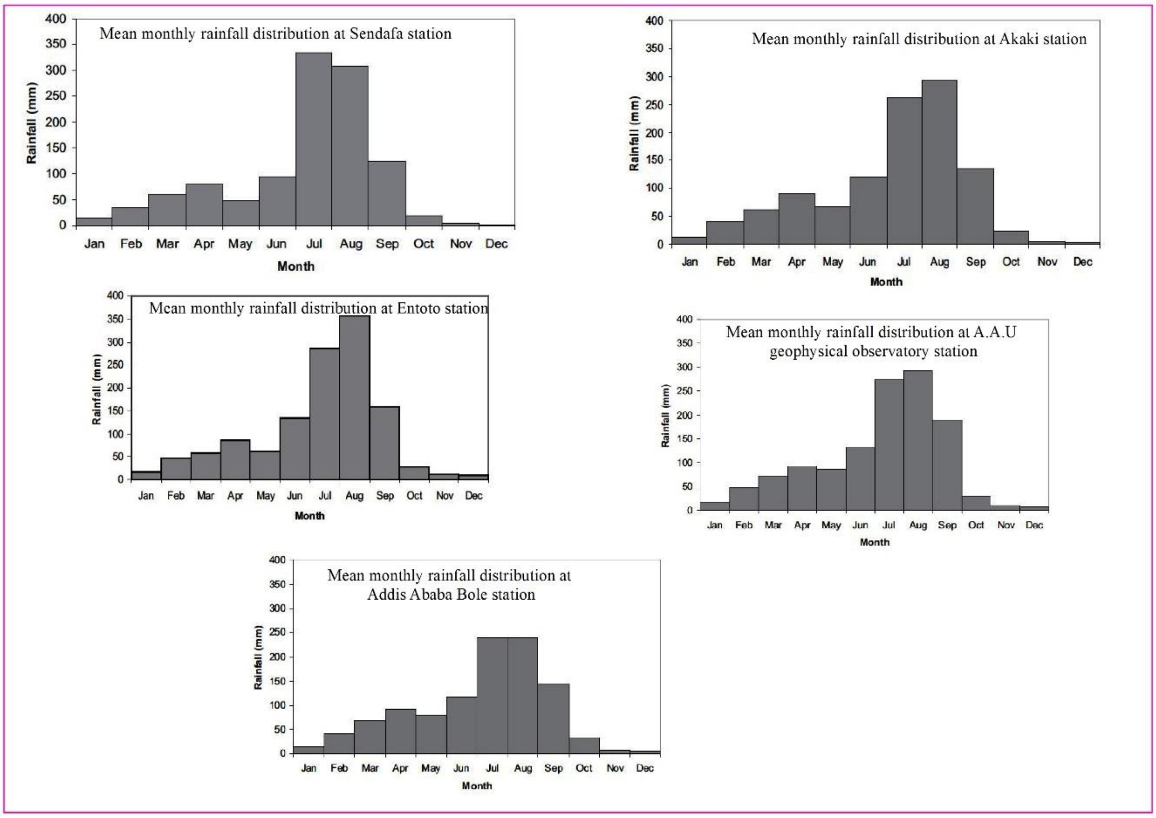

Fig 3. 4 Mean monthly rainfall distribution for the periods 1986─2013
(Source: Ethiopian Meteorological Agency)

Trend line was drawn to relate elevation with annual rain fall of the catchment. As shown in the trend line, the annual rainfall value is observed to increase with elevation (Table 3.1 and Fig 3.5).

Table 3.1 Elevation *vs* mean annual rainfall of Akaki catchment station

Name of the station	Easting	Northing	Elevation (m)	Mean annual Rainfall (mm)
Akaki	476486	979917	2057	1024.58
Addis Ababa Bole	476413	9992272	2354	1134.046
Addis Ababa Observatory	471986	997321	2457	1270.325
Sendafa	502257	1011809	2569	1275.88
Entoto	474400	1004200	2903	1283.99

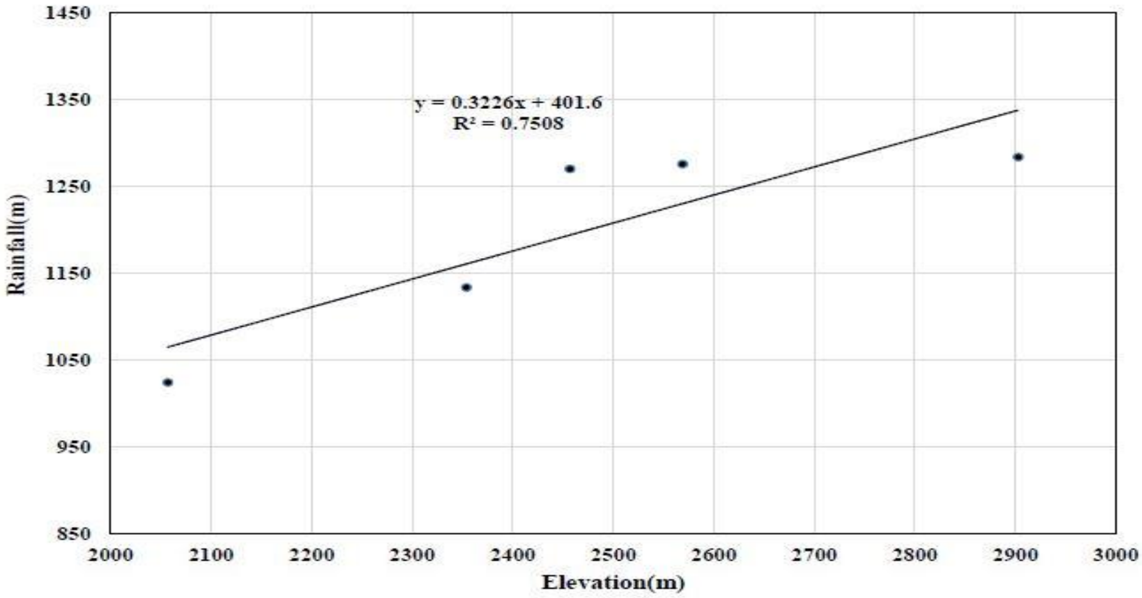

Fig 3.5 Variation of annual rainfall with elevation in Akaki catchment

3.1.3.2 Temperature

The maximum mean monthly temperature of Akaki catchment ranges between 21.1^{o}C (wet season) to 29^{o}C (dry season), while the minimum falls between 7^{o}C–12^{o}C (Table 3.2 and Fig 3.6). Unlike precipitation, the temperature of the study area decreases with increasing elevations (Fig 3.7). The mean monthly temperature of the catchment ranges between the lowest 14.9^{o}C in December to the highest 20.5 ^{o}C in May. While the mean annual temperature is 17^{o}C (Table 3.2).

Table 3.2 maximum and minimum average Temperature of Akaki catchment (1986–2013)

Temp.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nev	Dec	Ann. Ave.
Max.	23.3	24.3	26.8	28	29	23	22	22.1	21.1	22.4	22.6	22.8	23.95
Min.	8.2	9.5	10.9	11.5	12	10.8	10.8	10.8	10.5	9.2	7.9	7	9.925
Ave.	15.8	16.9	18.9	19.8	20.5	16.9	16.4	16.5	15.8	15.8	15.2	14.9	16.9

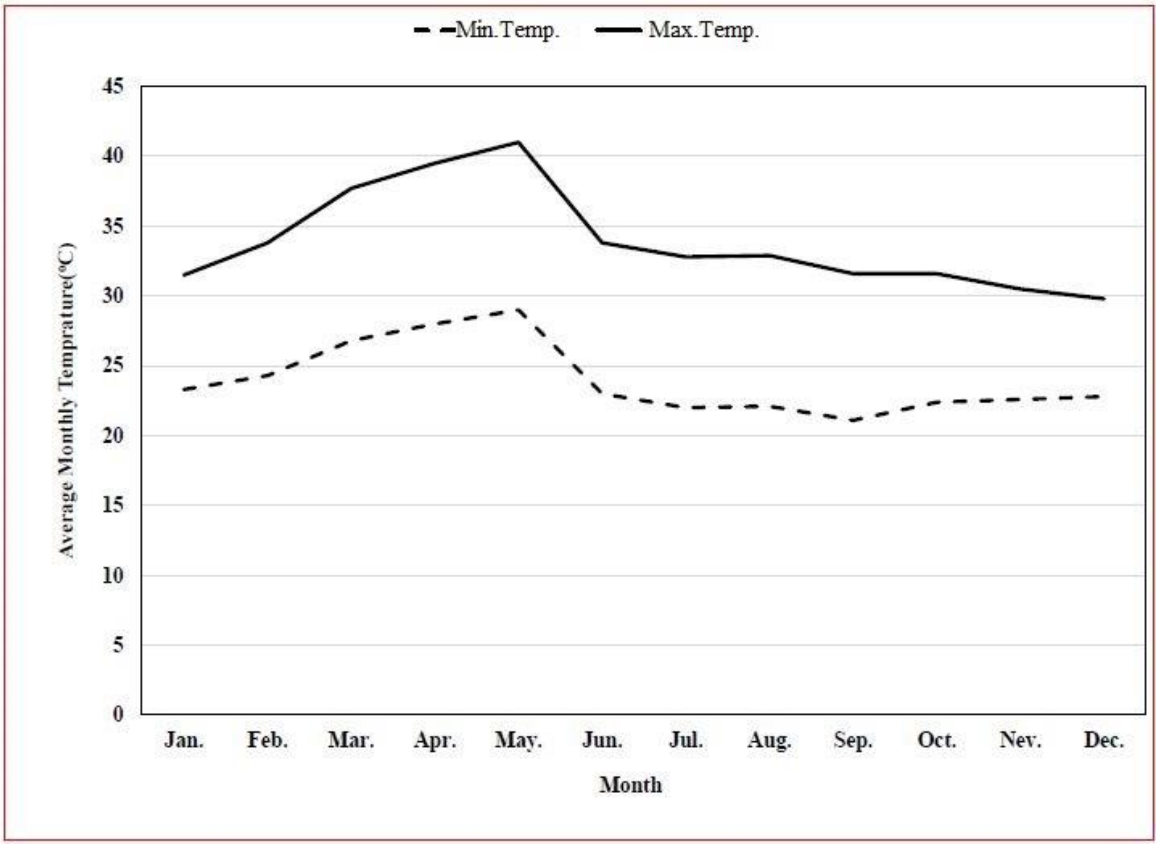

Fig 3.6 Average monthly minimum and maximum temperature of the study area from 1986–2013 (Source: Ethiopian Meteorological Agency)

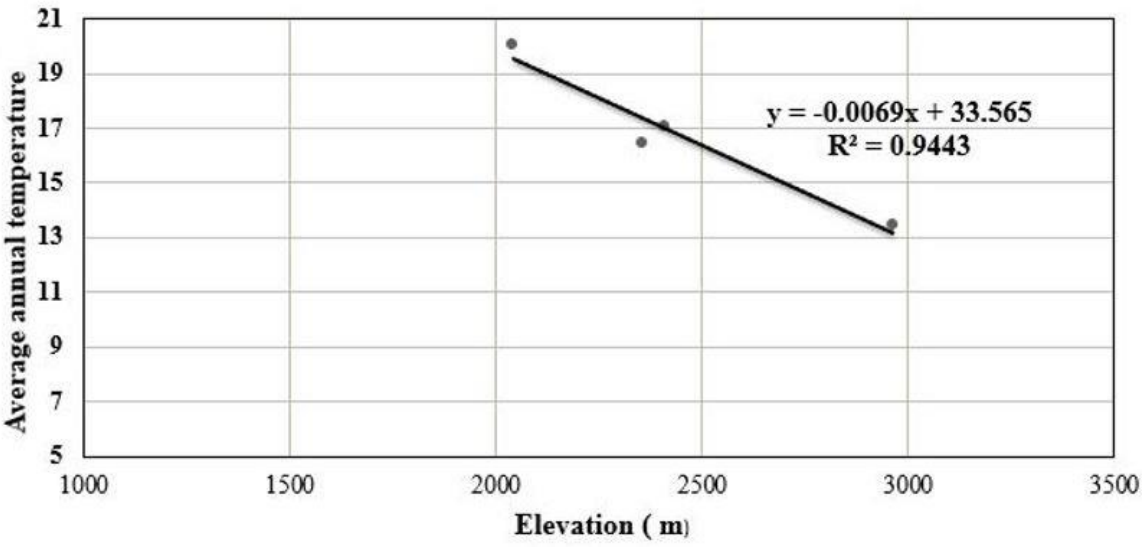

Fig 3.7 Variation of average annual temperature (°C) with elevation in Akaki catchment

3.1.3.3. Wind speed, sunshine hours and relative humidity

The wind flow pattern is influenced by the seasonal variation of the Inter Tropical Convergence Zone (ITCZ). The predominant wind direction during June to September is south to southwest. The wind speed pattern is distinctly bimodal in the region with peaks occurring in March and September and minimum speeds being recorded in August. The mean annual wind speed is 0.68 m/s. Sunshine hours vary from a daily mean of 9.66 hours in December to 2.18 hours in July. The monthly variation closely follows the rainfall pattern as would be expected with more sunshine hours in the dry months than in the wet months. At a station in Akaki catchment relative humidity has been measured four times a day, since 2013. The Relative humidity records show the average annual relative humidity value of 51.2% with average minimum monthly of 39.8% in December and reaches maximum 72%in August (Table 3.3 and Fig 3.8).

Table 3.3 Average monthly Wind speed, Sunshine hours and Rh of Akaki catchment (1986–2013)

Average monthly	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nev.	Dec.
Wind speed (m/s)	0.54	0.79	0.95	0.74	0.62	0.57	0.6	0.5	0.54	0.85	0.8	0.73
Sunshine hours (hr)	8.78	8.5	6.7	6.34	5.6	4.25	2.18	2.24	5.03	6.89	7.95	9.66
Relative humidity (%)	42.4	40	43.9	47.6	46.2	60.6	70.9	72	64.5	45.5	41	39.8

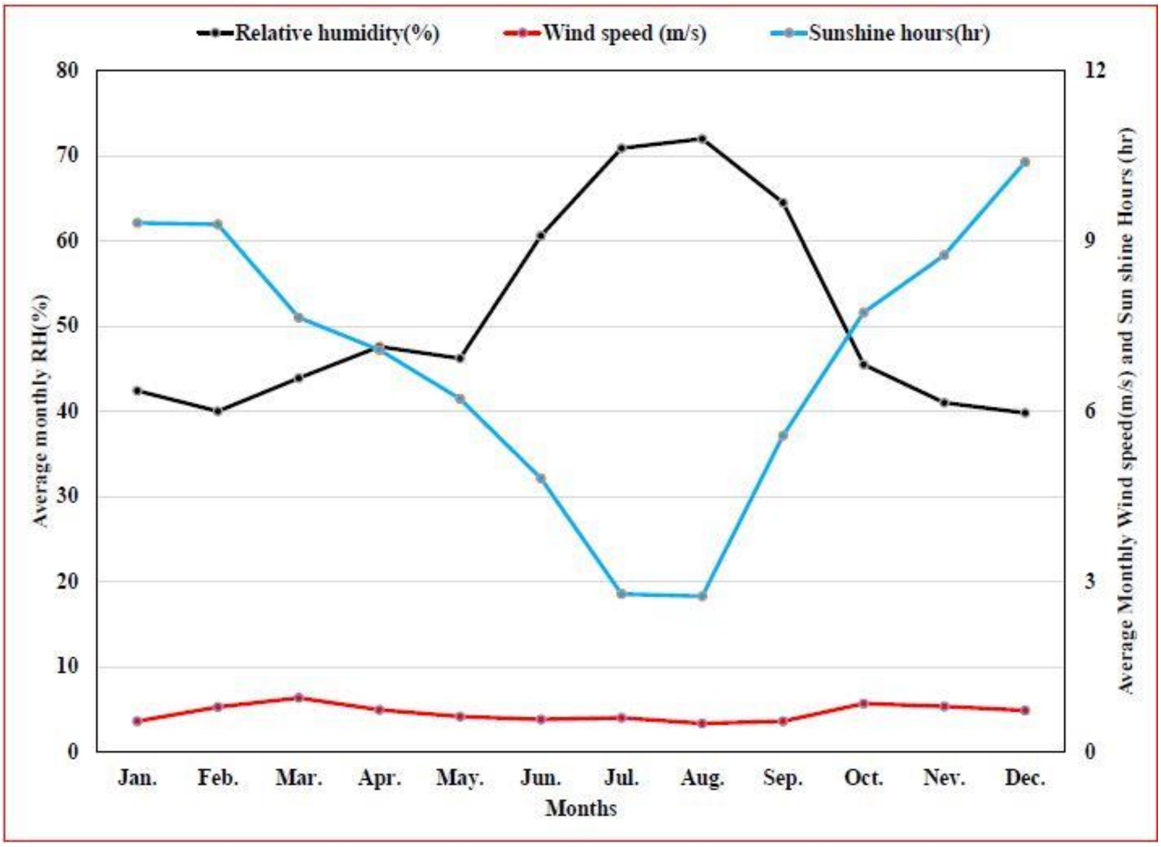

Fig 3.8 Average monthly wind speed, sunshine hours and Rh of the study area (1986–2013)

3.1.4 Geological setting

3.1.4.1 Regional geology

In Ethiopia, the present morphology, physiography and a geological setting is a result of two major post–Paleozoic tectonic phenomena, which were followed by important phases of volcanic activity (Mohr, 1967). The first tectonic event, which occurred in late Mesozoic- early Neogen period, produced the Afro Arabian Dome. The associated volcanic activity gave rise to the eruption of trap series succession (plateau volcanism), which is considered to be the immediate consequence of the up doming. The extrusion of the trap series fissure basalts during Eocene-Oligocene was the major and the largest volcanic episode of the whole Cenozoic. The second phase of tectonism resulted in rift development and related volcanic phenomenon during Neogen – quaternary period. The extensional tectonics which produced the Great Ethiopian Rift valley is genetically related to the Great Rift Valley of East Africa. The main Ethiopian rift runs NNE-SSW through the southern half of Ethiopia and widens out north wards in to the Afar region.

Extensive areas of the highlands of Ethiopia on both sides of the rift valley are covered by Neogen (Trap series) volcanic rocks which are mainly basalts with subordinate acidic rocks. Zanettin et al. (1978) divided the Neogen volcanics of central Ethiopians in three stages of volcanism and tectonism. These are transitional (thiolettic) flood basalt followed by alkali rhyolite and ending with alkali basalt. At the first stage the volcanism has occurred on a large elongated basin. During the volcanism stage strong extensive crustal movement occurred causing the renewal of volcanism which defines finally the escarpment. At the end the volcanism changed radically from fissural (Alajie rhyolite and Alajie basalt) to central type (Tarmaber-Megezez basalt). Rift related volcanic rocks were outpoured when fissural volcanism in the adjacent plateau had died out (Zanettin *et al*., 1980).

Nazret serious was given to a thick succession of welded ignimbrites with fiamme pumice ash and rhyolite flows and domes with rare intercalation of basalt flows which occur in the main Ethiopian rift (MER), rift margin and on the plateaus (Zanettin et al., 1980).

According to Zanettin et al. (1980) ignimbrite of the Nazret series is considered to be product of eruption mainly from marginal centers in the rift. In composition the ignimbrites are sub alkaline rhyolite and trachyte with rare per alkaline verities.

A group of early Pliocene shield volcanic complex which develop on both sides of the rift shoulders and margin of MER were named as the Chilalo formation (Kazmin and Berhe, 1978). Along the western margin centers such as yerer, Wechecha, Furi and Gash Magel represent the latest pulse of such felsic volcanism along the western escarpment. Pleistocene basalt flows associated with numerous well preserved scoria cones found on the escarpment of the MER south of Addis Ababa with a lower age limit 2 to 2.8 Ma were given the name Bishoftu basalt(Zanettin and Justin-Visentin , 1974).

Akaki catchment is located in the western margin of the Main Ethiopian Rift Valley. The margin is more recent, shows Mio-Pliocene volcanic and is characterized by normal faults down thrown towards the rift. The upper boundary of the margin is marked by the large fault running approximately east-west immediately north of the Addis Ababa-Ambo road. The lower boundary run north east to south west parallel to the principal systems of fissures of the rift-floor from Nazareth to awash Station (Zanettin *et al*., 1978).

3.1.4.2 Geology of the investigated area

Because of its physiographic position the geological history of the study area is an integral part of the evolution and the development of the Ethiopian plateau and the rift system. Many researchers have conducted the geological and stereo graphic sequences of the Akaki catchment. Morton et al. (1979) and Haile selassie Girmay and Getaneh Assefa (1989) are among the important geological studies conducted in the area. Based on field investigation, satellite image interpretation and previous geological studies a simplified geological map was established (Fig 3.9). Among the geological formations discussed above the Bishoftu formation, Alaji Formation, Chilalo formation, Tarmaber-Megezez formation and Addis Ababa basalt are the dominant. According to AAWSA (1991) the following lithostratigraphic units can be identified in the catchment younging to the south.

Alaji Formation

In this part of the escarpment, the Alaji group volcanic rocks (Alaji rhyolite and Intoto Silicics) were outpoured from the end of Oligocene until middle Miocene (Zanettin and Justin-Visentin, 1974). This unit is dominant in the northern part of the study area and it extends from the crest of Entoto (ridge bordering the northern parts of Addis Ababa) towards the north (Haileselassie Girmay and Getaneh Assefa, 1989).The main rock types in this unit includes rhyolites, trachytes, tuff, agglomerate, and aphianitic basalt. The Entoto Silicics represents massive Oligocene fissure-basalt, rhyolites, and trachytes with minor welded tuff and obsidian (Morton *et al.*, 1979).

Addis Ababa Basalts

Stratigraphically, this unit is underlain by the Entoto silicics and overlain by lower welded tuff of the Nazareth group. It is porphyritic in texture and mainly present in the central part of the city (Hailesellase Girmay and Getaneh Asefa, 1989) and covers the central and southern part of Addis Ababa. Olivine porphyritic basalts outcrop around Merkato, Teklehamanote and Sidest Kilo with a varying thickness. The Lower Welded tuff overlies Olivine porphyritic basalt near by the building college, the kolfe Police School, the KokebeTsebah School and Yeka Mariam church. On the other hand, only in the gorge of the Ketchene stream the olivine porphyritic basalt is overlain by the plagioclase porphyritic basalt (Varnier *et al*., 1985).

Younger Volcanics (Nazaret Group and Bishoftu Formations)

The units identified in the Nazaret group denoted as Lower Welded Tuff, Aphanitic basalt and Upper Welded Tuff. The Nazaret group is underlain by Addis Ababa basalt and overlain by Bofa basalts. Bofa Basalts outcrop south ward from Akaki River where they appear in the form of boulders reaching a thickness of 10 m. They are restricted and dominated in the south eastern part of the city. This rock is characterized by big vesicles that are filled by calcite. This basalt is underlain by the tuffs which cover the welded tuff. The rock outcrops mainly south of Filowha fault and extend towards Nazaret. They are composed of aphianitic basalts, welded tuffs, ignimbrites, trachytes, and rhyolites. The Bishoftu formation consists of olivine porphyritic basalt, scoria, vesicular and scoriaceous basalt, and locally trachy-basalt lava flows. They are localized in the south and are 20 to 40 m thick in the Akaki well field. Locally, it is overlain by scoria, tuff, sand, and gravel. This unit forms the major aquifer of the region (Tenalem Ayenew *et al*., 2008).

Recent Deposits

These include alluvial, residual, and lacustrine deposits. The thickness varies between 5m and 50 m near river banks in the south (AAWSA, 2000).It is often overlain by dark younger black cotton clayed soils. Alluvial deposits are found in some places along the little and Big Akaki rivers, particularly south and south west of Addis Ababa. Residual soils are located in the central, south east, northeast, and western flat plains.

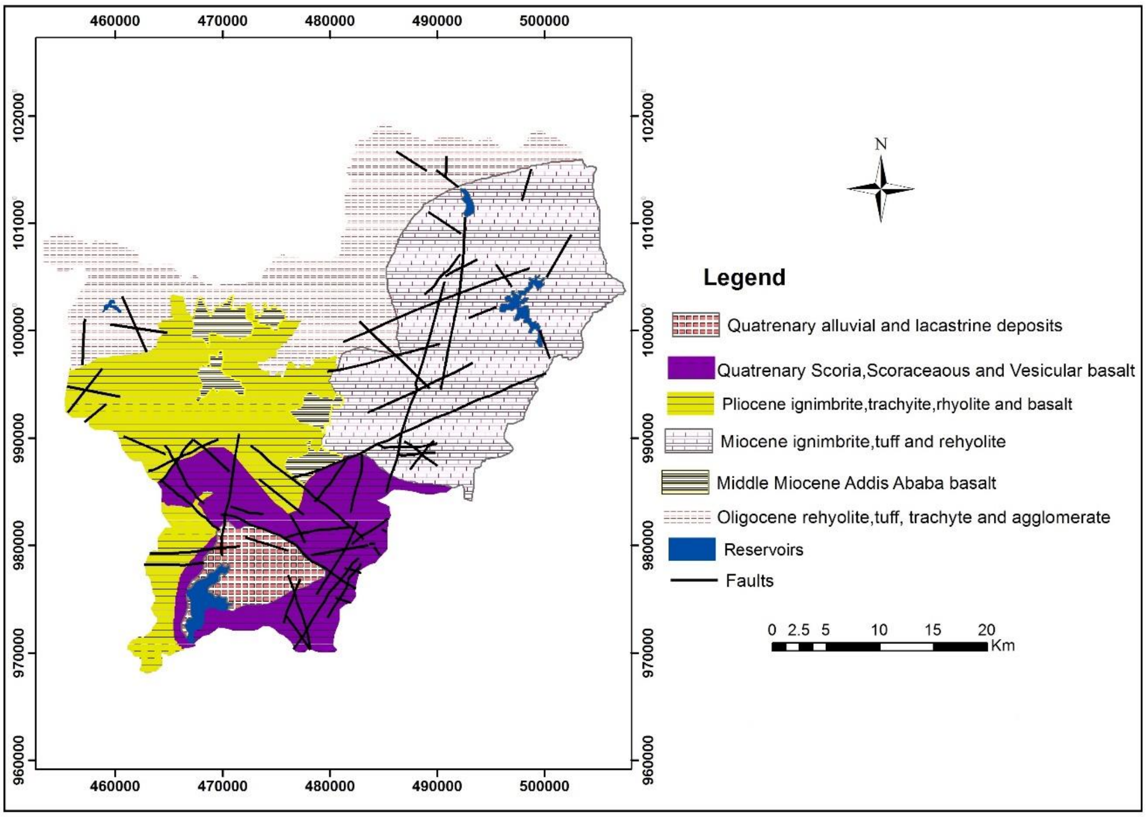

Fig 3.9 Geological map of the study area

3.1.4.3 Geologic structures of the study area

The lineament or "fracture trace" analysis, used in conjunction with groundwater investigations of fractured hard rock aquifers, are not credible without field verification. For regional scale studies, field checking of each lineament is impossible because of the significant cost and time involved. However, systematic checking is possible and is necessary to decipher the nature of lineaments.

The investigated study area is highly tectonized and is complex in structure because of its vicinity to the Main Ethiopian Rift. The occurrence of faults, joints and other structures with in different volcanic rocks of the study area were reported by different authors. The main diastrophic structures encountered are lineaments and faults whereas the non-diastrophic structures are bedding and volcanic layering shown in the false color composite (FCC) of the Landsat image (Fig 3.10).

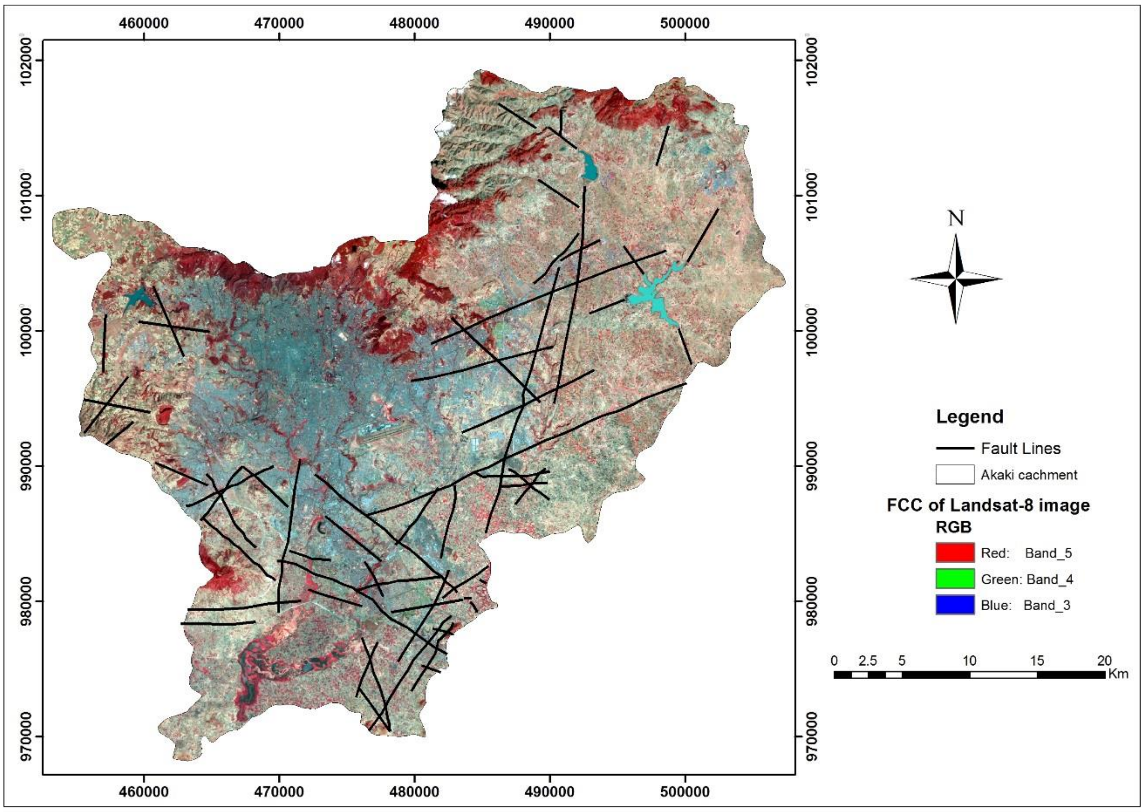

Fig 3.10 Structural map of the study area

3.1.5 Soil

The soil development in the study area is mostly due to the physical disintegration and chemical decomposition of volcanic rocks. The weathering products are either remain in places and form residual soils or transported and deposited in the low lying flat lands and depressions. The difference observed in the type and development of soils in the study area mostly depends on the topography, parent materials and the degree of weathering (Tamiru Alemayehu *et al*., 2006). The variation in the characteristics of soils makes them different in water infiltration and holding capacity. Climate, topography, parent materials, maturity and biological activities are the major controlling factors that facilitates soil formation.

Although there is significant difference in the degree of weathering on the slopes, mostly soils are highly eroded and result in thin soil cover. The type of parent material and the length of time to which the parent material was subjected to weathering, control the variation in the thickness of the soil. In the localities where the topography is plain to gentle (central and southern part) of the study area is covered by thick soil profile. In places where young basalt and welded tuffs occur, the thickness of the soil cover is reduced.

Most of the soil types of the catchment has compacted clayey nature. Clay soil has very low permeability with very low percolation rate. Alluvial deposits are the major soil type of the area found in middle reach of Akaki River. The dominant composition of this soil type is black cotton soil characterized by very low permeability. The other type of soil in this area is a Residual soil which lies in the Northern and North Eastern part of the catchment. There are also lacustrine sediments along the Akaki Rivers and lake areas at southern and south-eastern part.

The different soil types of the study area are presented in (Fig 3.11). The predominant soil types found in the catchment are clay, clay loam and silt loam. Fine sandy loam is found in the catchment to small extents. The clay soil type which is widely distributed along the east, north east, south and south east cover most part of the study area.

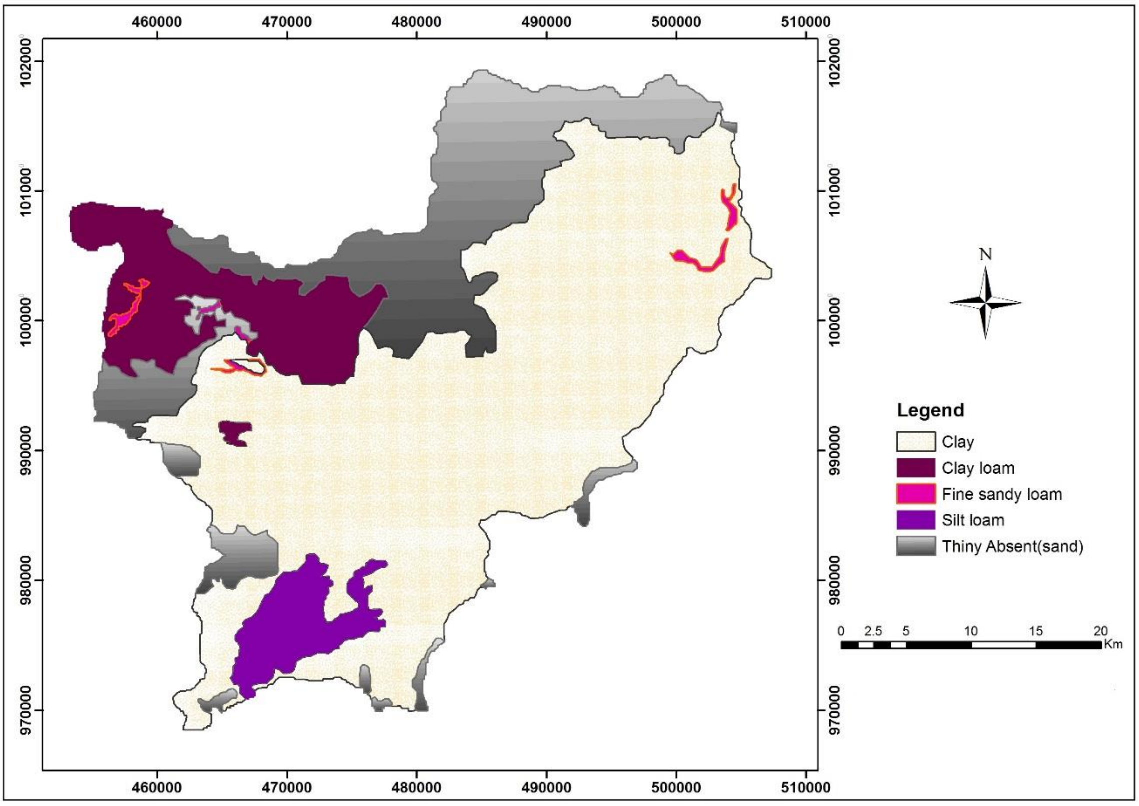

Fig 3.11 Soil map of the catchment (source:-Ministry of Water Resource, Irrigation and Energy)

3.1.6 Drainage pattern

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

Major perennial rivers start from the Intoto ridge and drain to the south. The main ones are the Big and Small Akaki rivers and the Kebena river draining through the center of the city of Addis Ababa. The big Legedadi dam provides sustained flow to the rivers. The drainage pattern is governed by the geology and physiographic set up of the area. Streams are dense with deep valleys on top of mountains such as Entoto ridge forming radial and dendritic drainage patterns (Fig 3.12). In the southern part of the catchment, the density of the streams is reduced and the main rivers show meandering type of flow. This is due to the decrease in the gradient of the valley floor. In general, streams are structurally, controlled which is characterized by plains, rolling terrains and river gorges.

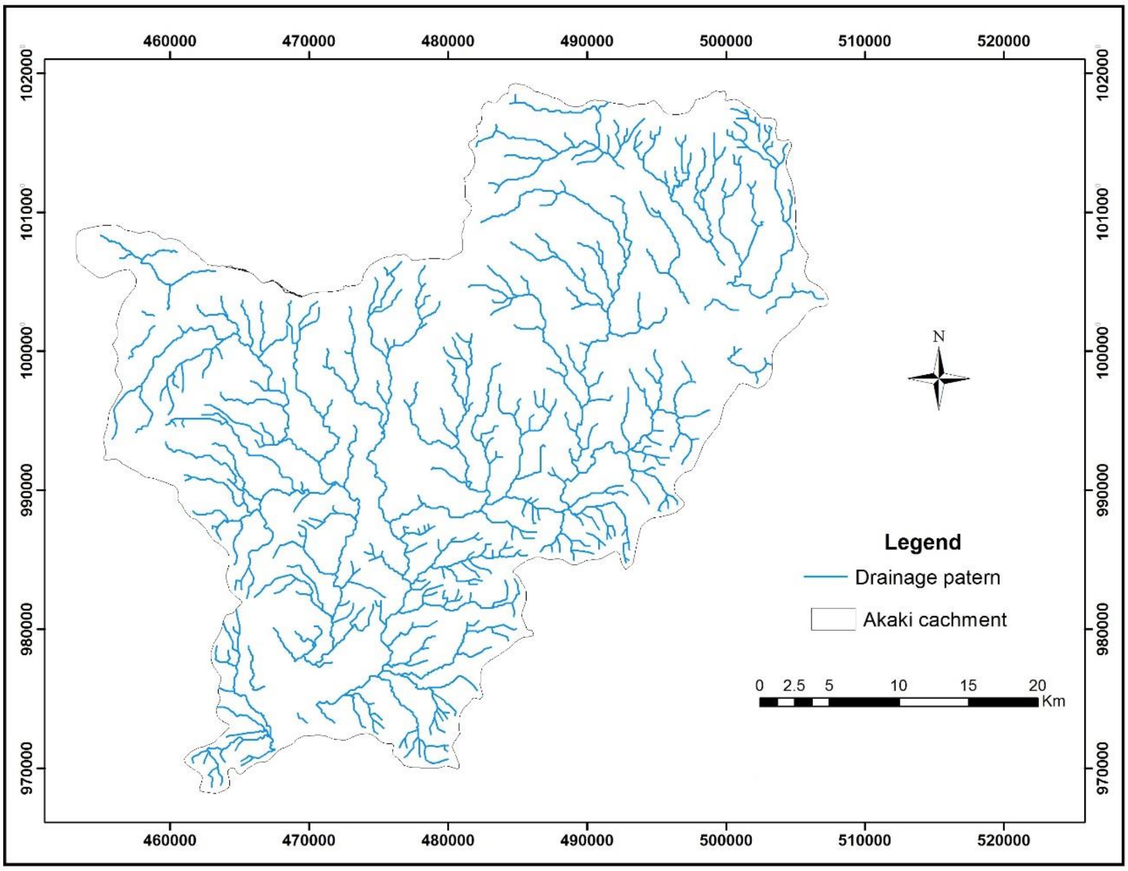

Fig 3.12 Drainage pattern map of Akaki catchment

3.1.7 Hydrogeology

The ground water distribution depend on the hydrogeological characteristics of the material more specifically hydraulic properties such as porosity, permeability. Similarly the origin, flow and chemical constitutes of ground water is controlled by the type of lithology, distribution, thickness and structure of hydrogeological units through which it moves. More over the stress due to tectonism and weathering govern the hydro geochemical characteristics of earth materials. Volcanic rocks mainly basalts, rhyolites, trachytes, scoria, trachy-basalts, welded and unwelded tuffs are the dominant rock outcrops in the area. Besides, unconsolidated materials of different origin also occur in the study area. These rocks are the major groundwater supply for large parts of Addis Ababa.

The aquifer properties of the Akaki catchment are controlled by lithology, stratigraphy and the structure of the rock units. More specifically the hydraulic complexity of these volcanic rocks is caused by their complex spatial distribution, their different reciprocal stratigraphic relationships, their significant compositional, structural and textural variability, and their different levels of tectonization and weathering (Vernier, 1993). The study area is predominantly covered by volcanic rocks. Volcanic rocks exhibit greater variations in their water bearing properties. Basic volcanic rocks like basalts are generally rich in cavities (formed due to high mobility of lava flowing for more time and space before solidifying and thus escaping a lot of gases) and contraction cracks, and as such may became permeable and source of underground water (Garg, 1983). On the other hand, acidic igneous rocks may or may not contain ground water although generally they possess interstices. The reason is that the interstices may be filled up with ash and other minerals and hence uncertainty. The volcanic aquifers can be considered as a double porosity medium due to the fact that both the matrix and the fracture porosity contribute to the transmission and storage of subsurface water.

- Scoria, scoraceous basalt, and intra-formational gravel and sand layers constitute highly productive aquifers with primary porosity and permeability.
- Highly weathered and fractured basalts, fractured tuff, ignimbrite and other pyroclastics constitute highly productive aquifers of secondary porosity and permeability.
- Basalts with some fractured, vesicles and sparsely spaced joints, ignimbrites and agglomerates form moderately productive aquifers in the area (AAWSA, 2000).

Anteneh Girma (1994) have grouped these volcanic aquifer units in to an upper most shallow phreatic aquifers constituted by layers of alluvial sediments ,weathered and fractured volcanics and a confined and semi confined volcanic aquifer of widespread areal coverage. Furthermore, according to AAWSA (2000) it is observed that highly transmissive areas do not correspond to high storativity areas, because of different fracturing and weathering of the volcanic aquifers. From field observation and assessment of previous geological works a simplified hydrogeological map showing aquifer nature of the rock types of the study area was established (Fig 3.13).

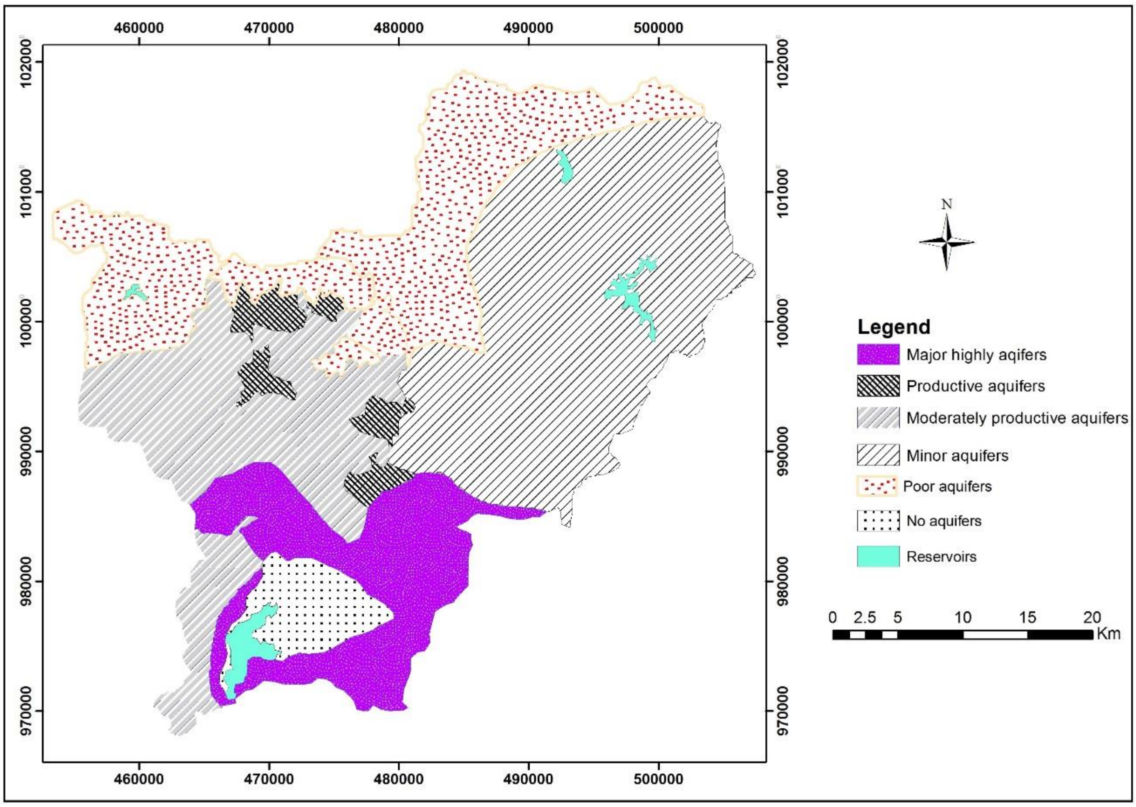

Fig 3.13 Hydrogeological map of the study area.

Relatively better hydrogeological informations are obtained in the central and southern part of the catchment where most of the wells are concentrated. Major contribution to the hydrogeology of the area come from studies related to the water supply of the city of Addis Ababa (AAWSA, 1991; AAWSA, 2000) and academic works (Anteneh Girma, 1994; Molla Demilie, 2006).These studies provided important information about the hydrogeological set up of the study are.

In general, according to previous studies the main aquifers in the Akaki catchment can be categorized in to three groups:

I. Shallow aquifer: those which are made of from weathered volcanic rocks and alluvial sediments along the river valleys.
II. Deep aquifers: those which are made of from fractured volcanic rocks at which boreholes are drilled for drinking water supply purpose.
III. Thermal aquifer: those which are located at depth greater than 300 m.

3.1.8 Demography of the study area

Understanding of the human population dynamics is extremely important when considering the impact of various human activities upon the water supply aquifers.

Central Statistical Agency of Ethiopia (CSA, 2007) reported that Addis Ababa has a total population of 2,738,248 of whom 1,305,387 are men and 1,434,164 women. This report also shows that population of the city grow at an average rate of 2.1% than that of 1994 Census (Table 3.4 and Fig 3.14). This change has occurred due not only to natural increase but continues attraction between 90,000 to 120,000 new residents every year. Based on the census report of 2007, the population of Addis Ababa is projected to be 3275348 by the year 2015 G.C.

Table 3.4 Average annual population and growth rate of Addis Ababa from 1961 to 2007

Year (G.C)	1961	1967	1978	1984	1994	2007	2010	2015(projected report)
Population	443,728	683,530	1,167,315	1,423,111	2,112,737	2739551	2914245	3275348
Growth rate		7.6%	4.99%	3.63%	3.57%	2.1%		

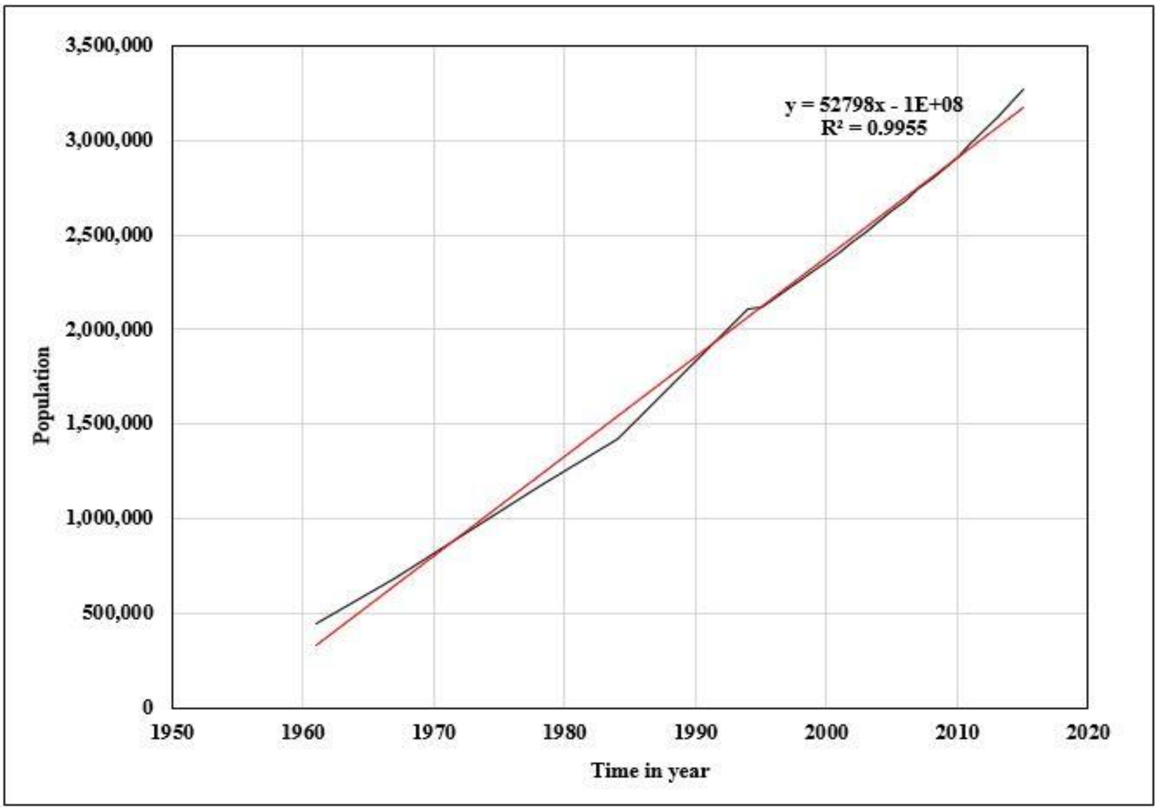

Fig 3.14 Average annual population growth of Addis Ababa (Source: CSA, 2007)

3.2 Materials and data used

The first step in every research is to identify the materials/data needed to solve the problem justified earlier. The data used in the study involve RS imagery and hydro meteorological data. The following spatial (image) data and historic time series of hydro meteorological data have been collected and used in this study for the assessment of the impact of land use land cover change on ground water recharge, using geospatial technologies like remote sensing, Geographical Information System (GIS) and GPS integrated with field survey:

Satellite image data and maps:

- Landsat Thematic Mapper image acquired in 1986 G. C (bands 4, 3 and 2).
- Landsat Enhanced Thematic Mapper plus (ETM+) image obtained in 2000 G.C (bands 4, 3 and 2).
- Landsat 8 Operational Land Imager (OLI) image acquired in 2015 G. C (bands 5, 4 and 3).
- Shuttle Radar Topographic Mission (SRTM) data of 30 m resolution acquired at the year 2014 G. C. was used for hydrologic modeling and to produce 3D map of the catchment.

Topographic maps having a scale of 1:50,000: were used during field survey, digitization of road network, drainage network reservoirs and contour.

- The Geology and Soil map of the area prepared by Geological survey of Ethiopia and FAO respectively were used as to show the geological and soil map of the study area.
- Hard copies of different color compositions of satellite images were used during field survey for ground verification.

Time series of hydro meteorological data:

The hydro meteorological information was derived from monitoring stations in the Akaki catchments and includes:

- Daily and Mean monthly flow and runoff data of Big Akaki and small Akaki sub catchments collected from the Ethiopian Ministry of Water Irrigation and Energy(MoWIE), has been used for calibration and validation of the model.
- Daily precipitation, relative humidity, sunshin hour and wind speed data of five stations of the study area (Addis Ababa observatory, Addis Ababa Bole,Intoto,Akaki and Sendafa) have been collected and used for WetSpass modeling.
- Daily minimum and maximum temperature data of four stations of the study area (Addis Ababa observatory, Addis Ababa Bole,Entoto and Akaki) have been collected and used for WetSpass modeling.

Others

- **Primary data:** A preliminary field survey was conducted so as to get a general view on the physical condition of the area like on the vegetation cover, land use type, topography, geology, geologic structures and the like of the study area. On top of this information GPS reading from the major LU/LC class were collected, which serves as a ground truth for image analyses in the final work of the research.

- **Interviewing of the nearby residents:** Along with the various methods of data collection informal interviewing the neighboring people can give very good information about the past condition of the area, hence interviewing the people were included as one method of data collection in this study.
- **Reviewing different literatures:** It was tried to get some valuable information from already done research papers, from Internets and other resources (see Reference).

Materials and software used

- ERDAS Imagine 10 for Image processing, classification and sub setting AOI etc.
- Global mapper and surfer to extract 3D of the catchment
- ArcGIS 10.2 for GIS analysis and mapping
- Google earth and ArcGIS online to help assessment of the area before going to the field and to see change detection
- Global positioning system(GPS) and Digital camera
- ArcView 3.2 to prepare input data to WetSpass modeling and assessing impacts of LU/LC change on ground water recharge.

3.3 Methodology

This study was conducted using data collected from literature, secondary data collected from office, primary data gathered from field survey and laboratory analysis of remote sensing imageries. The method to be followed in this research study was based on the objectives formulated in section 1.3. The methodology used for this study was given below in the form of a flow chart (Fig 3.14).

3.3.1 Data acquisition

The first step in every research is to identify the information/data needed to solve the problem justified earlier. Literature review and collection of satellite images such as Landsat were the core methods that were employed at first. For this study, various data are used includes topographic data (DEM), Land use and land cover data, soil data, monthly data of climatic variables (monthly data of precipitation, maximum and minimum temperature, relative humidity, wind speed and solar radiation). The DEM and land cover satellite data were obtained from the USGS website, (http://earthexplorer.usgs.gov/). Soil and hydrological data were collected from the Ministry of water irrigation and Energy of Ethiopia. The climatic data were obtained from the Meteorological Agency of Ethiopia.

A pre field interpretation map was prepared and the confusing areas were verified by ground truth information that was collected by GPS survey. Recent and the current land use practices are noted in the field. The past land-use/land-cover information was gathered by informal interviews with the local people and assessment of high resolution google earth imagery of the past dates using the show historical imagery tool. The GPS points were downloaded and overlaid on the imagery and used for refinement of the pre field interpreted land use land cover map.

3.3.2 Image processing

The standard image processing techniques, such as image extraction, rectification, restoration, and classification have been used for the analysis of the satellite imageries using ERDAS imagine software.

This study was done using Landsat imageries of three bands (4, 3, 2) for Landsat TM and ETM+ and bands (5, 4, 3) to Landsat-8 to identify changes in land-use and land-cover distribution in the Akaki catchment over 29 years period from 1986 to 2015 G.C. Landsat TM and ETM+ and Landsat-8 Operational Land Imager (OLI) were selected for the period of 1986, 2000 and 2015 respectively. To avoid a seasonal variation in vegetation pattern and distribution throughout a year, the selection of dates of the acquired data were made as much as possible in the same annual season of the acquired years. The images used in this study area were orthorectified to a Universal Transverse Mercator projection using datum WGS (World Geodetic System) 1984 zone 37N. In order to view and discriminate the surface features clearly, all the input satellite images were composed using the RGB color composition. False Color Composites (FCC) of satellite imageries have been prepared for the all years (1986 and 2000) using band 4 (NIR), band 3 (Red), and band 2 (grean) and for Landsat 8 using band 5(NIR), band 4(Red) and band3 (green) combination as shown in (Fig 3.15). The images with complete coverage of Akaki catchment have been subsetted to area of interest of this research using ERDAS Imagine 2010. The detailed flow chart were given in Fig 3.16).

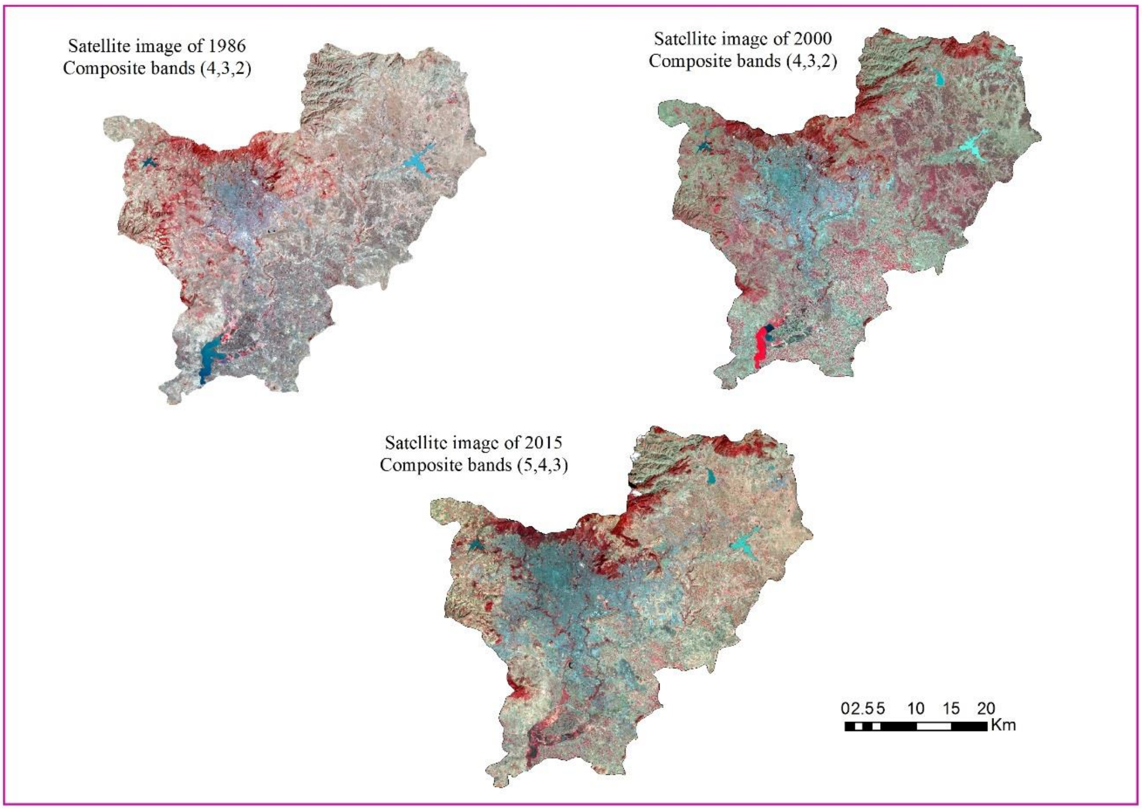

Fig 3.15 False Color composite of Landsat image of the year 1986, 2000 and 2015

The image data files were downloaded in zipped files from the United State Geological Survey (USGS) website and extracted to Tiff format files. The acquisition dates, sensor, path/row, resolution and the producers of the satellite images used in this study are summarized below (Table 3.4). The selection of the images is based on the following criteria:

- ✓ The images had no cloud cover over the study area
- ✓ The images were of good quality according to the USGS rating criteria
- ✓ The resolutions of the images were similar
- ✓ The images cover the same period as the meteorological data time series.

Table 3.5 the acquisition dates, sensor, path/row, resolution and the producers of the images

Path/Row	Acquisition date	Sensor	Resolution (m)	Producer
168/054	Jan 01, 1986	TM	30	USGS
168/054	Feb 02, 2000	ETM+	30	USGS
168/054	Jan 05,2015	OLI_TIRS	30	USGS

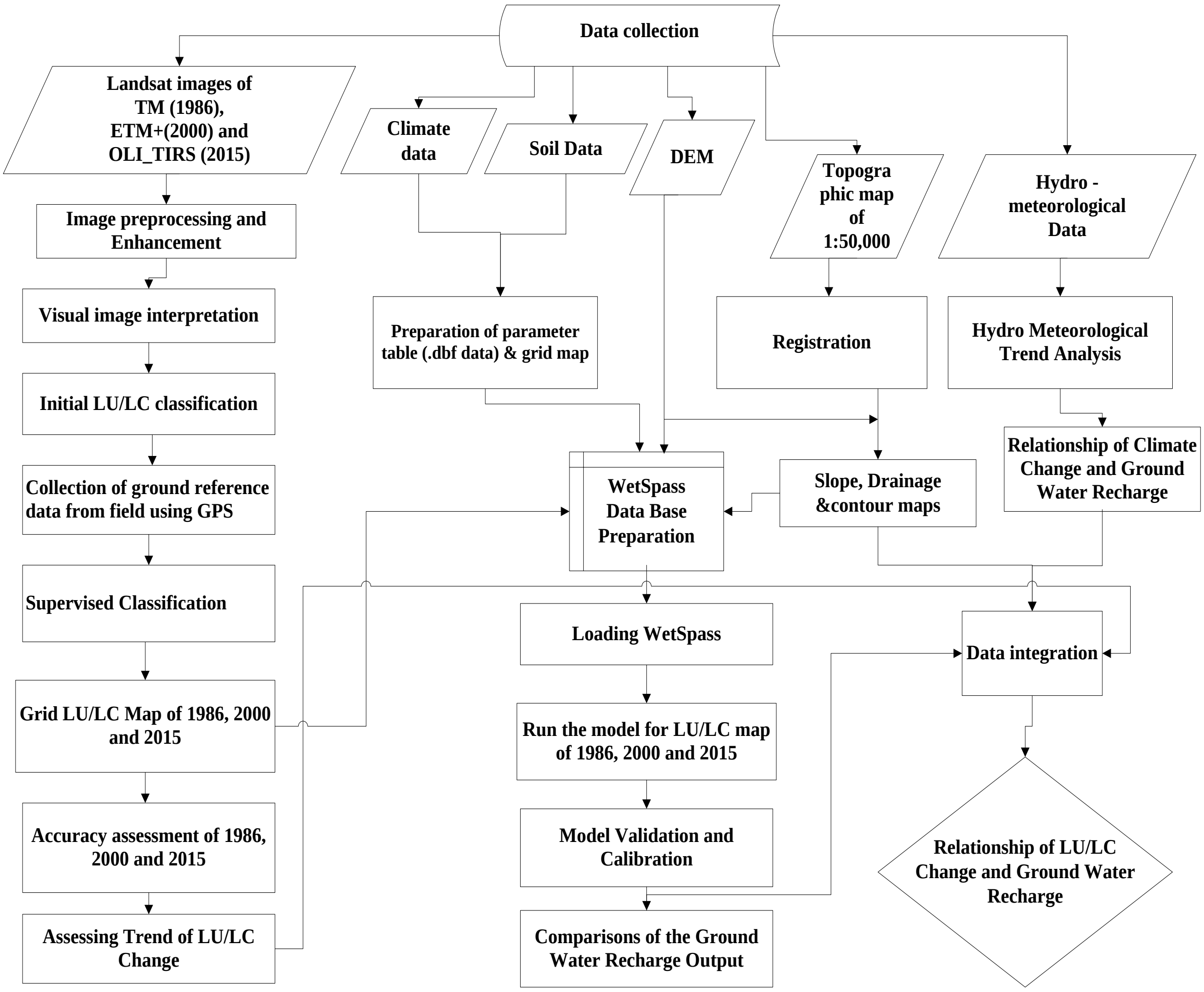

Fig 3.16 Flow chart showing the general frame work of the study

3.3.3 Land–use and Land–cover classification

After image preprocessing is finalized, the next step is to produce land-use land-cover map with the rectified images of the investigated area using the appropriate soft wares. Combining with a number of localized information and field investigation, the land–use land–cover patterns in the Akaki catchment for the past 29 years were determined by interpreting the rectified images of 1986, 2000 and 2015. A number of tools were used during the RS imagery processing and spatial analysis including ERDAS Imagine 10 and ArcGIS 10.2 packages.

Land-use change is a locally pervasive and globally significant ecological trend. In Ethiopia, the rate of conversion of forest, grassland and other natural land–cover to agricultural and urban areas is at its apex. In this study, land-cover classification is used to extract land-cover types that are of interest to the recharge estimation process through utilizing of WetSpass modeling. Remotely sensed images are vital in land-use/land-cover classification specially when dealing with large and inaccessible areas. To study the impact of land cover changes on recharge, image classification of the three Landsat images acquired in 1986 (TM), 2000 (ETM+) and 2015 (OLI_TIRS) are carried out. Normalized Difference Vegetation Index (NDVI) are used to study the seasonal growth of vegetation and the presence of groundwater. For example, areas with denser vegetation may indicate areas of higher rainfall and occurrence of recharge.

Different approaches and techniques were used in doing LU/LC mapping such as image rationing, enhancement, change vector analysis and classification of the mentioned satellite imageries were the widely used algorithms. Each has its own merits and no single approach is considered optimal or applicable to all cases. For instance, Image rationing mitigates the effects of topology like shadowing and illumination. Image enhancement improves the appearance of the imagery to assist in visual interpretation and analysis, and the change vector analysis detects changes present in the input of multispectral data (Berberoglu and Akin, 2009). Classification algorithms attempt to reduce the information contained in multi-band spectral reflectance imagery to a single thematic map by assigning each multi-band pixel to one of a limited number of classes. In this study, change detection has been carried out through the comparative analysis of the spectral classifications for 1986, 2000 and 2014. Landsat data of the three dates are independently classified using the maximum likelihood classifier and then compared. The general steps followed to extract land cover information are summarized in (Fig 3.17).

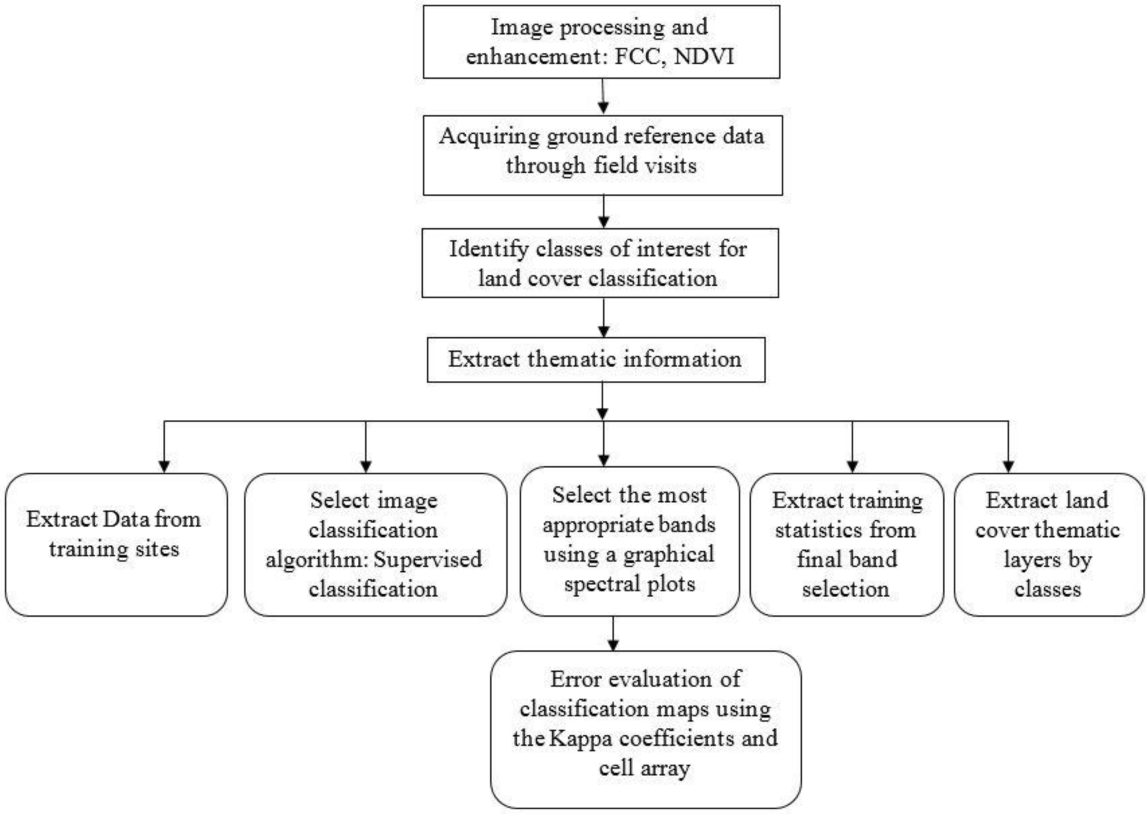

Fig 3.17 General steps used to extract land–cover maps from digital remote sensing data

3.3.3.1 Image preprocessing and enhancement

Preliminary image analysis was performed to extract meaningful information from the acquired satellite image. In order to generate valuable information ERDAS Imagine 10 has been used at different levels. Image enhancement was made to improve the appearance of the imagery to assist in visual interpretation and analysis. This includes spatial enhancement and spectral enhancement. Its function include contrast stretching to increase the tonal distinction between various features in a scene, and spatial filtering to enhance (or suppress) specific spatial patterns in an image. A number of methods can be applied to perform image enhancement. The most suitable must be selected to achieve the best color of images for visual interpretation. In this study, the following spatial enhancements have been applied:

I. Spatial resampling

As the images have different spatial resolution, it was difficult to perform change detection analysis. Therefore to have the same resolution in all periods of image spatial resampling was done using spatial resampling algorithm in ArcGIS 10.2 software by doing this the spatial resolution of all image becomes 30 m by 30 m which was important to perform change detection.

II. Band Selection for FCC (False color composite) Image Preparation

Because the human eye uses only three primary colors, and Landsat images returns more bands of data, one problem that inevitably arises is that of selecting the most effective three-band color composite images. In this research band selection was made through the analyses of the spectral reflectance properties of objects or features and the histogram behavior of the bands. ERDAS Imagine 10 was used to create the spectral profile of the different feature types (Fig 3.18).

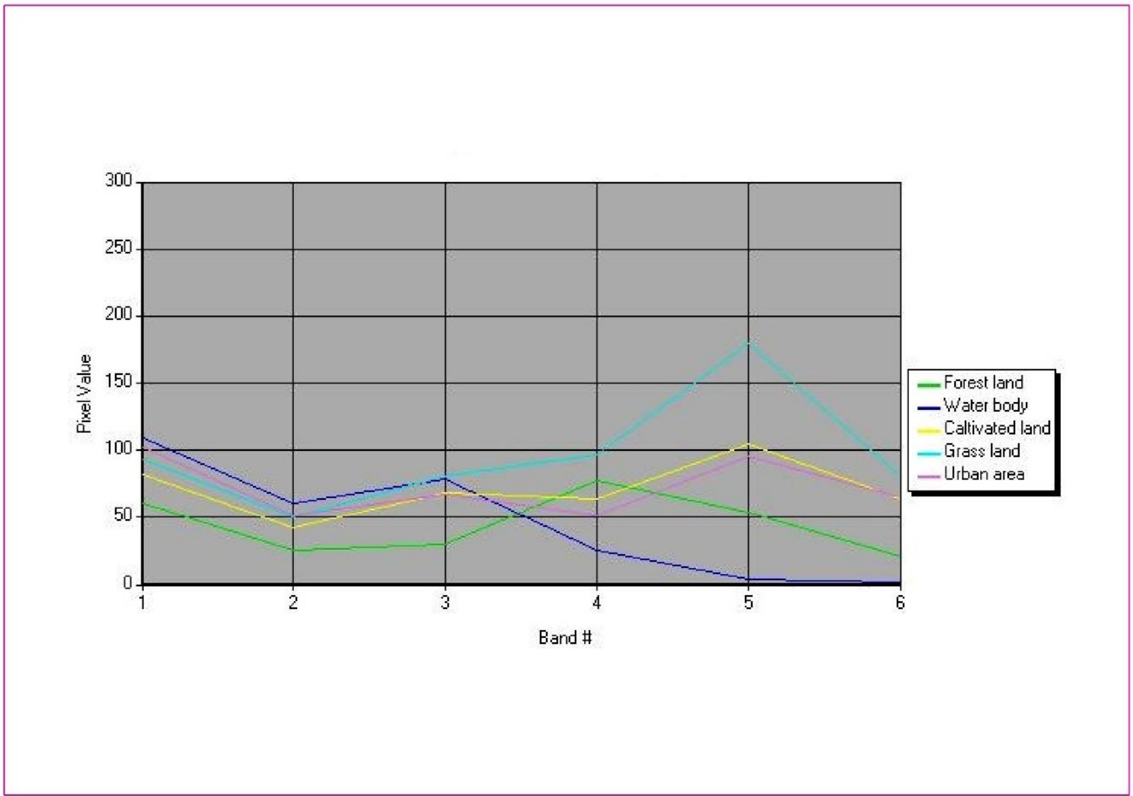

Fig 3.18 Spectral properties of different features

Different color composite images were prepared, in order to select the best band combination, that enhance the raw satellite images for the identification of the different land cover classes in the study area. Based on this analysis band 4-3-2 for both Landsat TM and ETM+ and bands 5-4-3 for Landsat-8 were chosen.

III. Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI)was one of the most widely used vegetation indices derived from satellite data for monitoring the location and distribution of vegetation changes. Several studies propose change detection techniques for monitoring land use change based on changes in the NDVI. It is used in this research for gaining information about the seasonal growth of vegetation and the presence of groundwater. NDVI has been also used to differentiate vegetation from other land cover classes. It was estimated by the division of the difference between the near infrared and red reflection (visible wavelength observations) and the sum of these measurements using the formula.

$$\mathbf{NDVI = (NIR-RED)/(NIR+RED)} \qquad \text{Eq (3.1)}$$

Where,

NDVI: Normalized Difference Vegetation Index

NIR: spectral band for near infrared, RED: spectral band for red

In this research study NDVI is calculated for the Landsat images of the 1986, 2000 and 2015 using the above formula to help to see how the vegetation cover of the catchment changes over the past periods. NDVI is regarded as an effective method to enhance the difference among spectral features and suppress topographic and shade effects. Therefore, NDVI results for different date's imageries has a potential to detect land cover change more effectively.

3.3.3.2 Identifying representative training samples

Information and pictures of different land covers with in the Akaki catchment have been collected to define the spectral signatures of these classes and evaluate classifications. After some part of the catchments specially to the south part are visited in the field, training samples representing land cover classes of interest are selected according to the classification scheme adopted. The training sites were obtained from relatively homogenous environments through digitizing of training data.

3.3.3.3 Identify land–cover classes

All classes of interest were carefully selected and defined to classify the images into land cover information. It was worth noting that there was a fundamental difference between information classes and spectral classes. The information classes was those that human beings define, while the spectral classes was those that was inherent in the remote sensor data and must be identified and then labelled by the analyst. In this research the information classes are grouped in to five classes as cultivated land, urban settlement, forest land, and grass land and water body.

3.3.3.4 Categorizing training samples

A spectral separability of training samples of each feature classes was evaluated to ensure that each pixel is categorized into the land cover it most closely resembles and that no overlapping of pixel classification was taking place. In addition, histograms are examined and an overall evaluation of all feature classes was performed using contingency matrices and divergence.

3.3.3.5 Supervised classification

After all the required prepossessing techniques of the Landsat images were done the last was to do the real classification of the LU/LC classes. Image classification can be done with two methods namely unsupervised and supervised classifications. Supervised classification was found to be more appropriate and less sensitive to radiometric variations when dealing with more than two scenes captured at different dates (Adla, 2010). In this research image classification was first done by unsupervised classification using the ISODATA algorithm. This produced a map with 10 classes which was then displayed over color composite images, and classes assigned to a specific land cover category. The output of this method was used as a guide in the selection of training sites for input into the supervised classification. Finally the ten classes have been reduced to five classes after information and statistics obtained from ministry of water irrigation and energy (MOWIE) and AAWSA. They were selected according to the needs of recharge estimations and its hydrological mechanism. The resulting classes are examined both spectrally and spatially with ground information from Google earth and field visits.

Five land cover classes were defined namely; Forest land, Grass land, cultivated land, urban settlement and Water body. The descriptions of these five land–use and land–covers classes are given as follows:

Forest land: Land covered with dense trees which includes ever green forest land, mixed forest and plantation forests.

Grass land: Areas covered with grass used for grazing, as well as bare lands that have little grass or no grass cover. It also includes other small sized plant species.

Water body: Area which remains water logged throughout the year, in this study this class mainly refers to manmade reservoirs.

Cultivated land: Areas used for crop cultivation, both annuals and perennials, and the scattered rural settlement that are closely associated with the cultivated fields.

Urban area: areas where there is a permanent concentration of people building, and other man-made structures and other activities.

The characteristic signatures from these classes are then used as input to a maximum likelihood classification process, which allocates pixels to the class to which they have the highest probability of belonging. The supervised classification is performed using the maximum likelihood algorithm in the ERDAS Imagine software. The classes selected are utilized in the classification process of all the land sat images to facilitate the comparison in the multi-temporal image suite. The maximum likelihood decision rule assigns each pixel having pattern measurements or features to the most probable class. It assumes that the training data statistics for each class in each band are normally distributed, that is, the Gaussian where both the variance and covariance of the category spectral response patterns are quantitatively evaluated. Given these parameters, the statistical probability of a given pixel value being a member of a certain land cover class is computed. Further, classified images have been assessed and refined based on ground truth data, maps collected from the field visit and the Google Earth images as references.

3.3.3.6 Classification accuracy assessment

A common question in digital satellite image classifications is:How accurate is the classification? This is because the result of a supervised classification usually has some percentage of misclassification, due to noise and unknown pixels. Therefore it was necessary to test the accuracy of the land use land cover classification results through field checking and using other ancillary data. In this research a quantitative evaluation of classification accuracy is done through choosing a set of pixels on the classified image and then comparing them to the actual image and ground truth data through blending tool in ERDAS Imagine software. The reliability of the classification results is assessed by producing an error matrix. As defined in section 2.7.1, the error matrix is a square array of numbers laid out in rows and columns that expresses the number of sample units assigned to a particular category relative to the actual as verified by the user (Lillesand *et al*., 2008). The error matrix summarizes the relation between the remote sensing derived classification map and the reference information where columns represent the reference data and rows indicate the classification generated. Using the ERDAS Imagine accuracy assessment utility, reference random test pixels in the study area are located which are not used in the training of the classification algorithm to eliminate to the possibility of bias of training samples chosen in classification. These pixels chosen are referenced on the ground with field trip as well as high resolution google earth imageries and used to assess the accuracy of classes in the remote sensing classification map. Adla et al. (2010) suggested a minimum of 50 samples for each land cover class or 250 reference pixels in the error matrix to be collected to assess the accuracy of the classification. The overall accuracy is weighted by the number of sample/pixels in each class, i.e. the sum of all samples on the diagonal divided by the total number of samples, based on this the accuracy for all LU/LC classification of 1986, 2000, and 2015 was performed. For this classification randomly samples of 50 test reference points for the LU/LC of 1986 maps, 100 test reference sample points for LU/LC of 2000 maps and 103 test reference points for LU/LC of 2015 maps were selected, and analysis of the confusion matrix was done. After the test reference information has been collected through field trip from the randomly located sites, it is compared on a pixel-by-pixel basis with the information present in the remote sensing derived classification map.

3.3.4 Hydrological data analysis methods

In line with the present state-of-the-art in the assessment of impacts of land-use land-cover changes on hydrologic cycle especially ground water recharge at the watershed scale, an attempt has been made to analyze changes in the hydrologic regime of the Akaki catchment in relation to changes in land -use land- cove and climate, which have taken place in the past 29 years. Meteorological data, which have a good relation with ground water recharge such as monthly rainfall data for a period of 27 years for five stations that found in the catchment, temperature, wind speed and evaporation data of 27year from Akaki meteorological station were collected from Ethiopia national metrological Service Agency (NMSA) so as to examine the trend of the meteorological elements.

After all the necessary data were collected the next step was data analysis, presenting results and discussion. This involves analyses of the different hydro - meteorological data to estimate and understand the ground water recharge and its trend. Eventually correlation analysis between ground water recharge and the factors which have great influence on recharge such as: climatic factor (Rainfall and evapotranspiration because it is the reflection of many climatic variables like wind speed temperature and relative humidity that is why it is used) and land use land cover factor (vegetation cover) to see and quantify the effect of the LU/LC changes on the hydrological regime in general and groundwater recharge in particular.

3.3.5 Groundwater recharge estimation

Estimation of recharge is of high importance for the assessment of groundwater resources of an area. Two dominant mechanisms occur: direct recharge, whereby water enters the saturated zone of the aquifer directly from precipitation infiltrating through the unsaturated zone, and indirect recharge, whereby recharge enters the saturated zone indirectly through some form of runoff infiltration. Various methods to estimate groundwater recharge are available. In this study the groundwater recharge is estimated using WetSpass model and the estimates are compared with previous studies. Since land use data are usually derived from remotely sensed images, the mixed pixel issue may increase uncertainty and inaccuracy if the grid cell is treated as a single land use category. The WetSpass model calculates the water balance of a grid cell while considering the fractions of vegetation, bare soil, open water and impervious area; therefore, it provides a good choice for estimation of long-term average spatial patterns of groundwater recharge (Batelaan and De Smedt, 2007).

WetSpass is a quasi-physically distributed seasonal-water balance model, which takes into account detailed soil, land-use, slope, groundwater depth, and hydro-climatological distributed maps with associated parameter tables for estimating groundwater recharge. The model uses seasonal (summer and winter) geographical information systems (GIS) input grids of the mentioned inputs to estimate annual and seasonal groundwater recharge values:

$$R = P - S - ET \qquad \text{Eq (3.2)}$$

Where, R is the groundwater recharge, P is the precipitation, S is surface runoff and ET is evapotranspiration, with mm units for all parameters.

The surface runoff depends on the land-use, soil, slope and precipitation intensity in relation to infiltration capacity of the soil. It is calculated using the classical rational formula:

$$S = C_{HOR}\, C\, (P - I) \qquad \text{Eq (3.3)}$$

Where, C_{HOR} is a coefficient that parameterizes the part of the seasonal precipitation that actually contributes to runoff, C is a runoff coefficient based on the rational formula and I is the interception (mm).

ET is calculated as a sum of evaporation, transpiration and interception.

In this research study ground water recharge of the catchment under different land use scenarios was estimated using the WetSpass modeling methods.

To assess the effect of land-use and land-cover change on the ground water recharge of the catchment, the WetSpass model was run for the three different time land-use and land-cover grid maps keeping the other impute parameter constant. Ground water recharge of a catchment is dependent on the interaction of climate, geology, morphology, soil condition, and land-use/land-cover condition of the area. The data are analyzed as presented in the next sub-sections of impute data preparation.

3.6 Model input data analysis

WetSpass requires a set of input data pertaining to the meteorology/Climatic, topography, land use, groundwater depth, and soil texture of the investigated area. The climatic data includes monthly precipitation, potential evapotranspiration, wind speed and monthly temperature. The soil parameters data consists of hydraulic properties and empirical coefficients for modeling evapotranspiration and surface runoff. There are 5 climatological stations with in the Akaki catchment. Climatological data such as temperature, relative humidity, evaporation, hours of sunshine, wind speed and rainfall are available for the period from1986 to 2013.

WetSpass was originally developed for conditions in temperate regions for Europe in particular, which have a fixed Land use, soil types and the number of harvesting months in a year that fall in the summer and winter seasons. In temperate regions of Europe, summer and winter have six month each while in Ethiopia summer contains four months(June to September) and winter covers eight months(from October to May). Therefore, to apply the model in Ethiopia some input parameters modification is needed. For WetSpass modeling to run two types of input data are use: Parameter tables (.dbf data) and grid (summer and winter) map. Inputs of land use, soil and runoff characteristics parameter tables (Dbase files) were required. These tables are containing universal values hence no modification is required. All climatic variables, as well as the land use and groundwater depth, were prepared using eight months of winter and four months of summer. The land use parameter table are modified and land use parameter tables for Akaki summer and winter seasons are developed and used in the modeling processes.

Precipitation and potential evapotranspiration are given in accumulated values, while others are prepared in the monthly averaged data. To prepare input parameters for WetSpass modeling, ArcView 3.2 together with its spatial analyst extensions and ArcGIS 10.2 were used. All input data other than the Parameter tables (.dbf data), were prepared as a map in grid file format as shown below.

3.6.1 Lana-use and land–cover map

Land-use/land-cover maps were extracted from LANDSAT images freely available from the USGS website, (http://glovis.usgs.gov/). The images were stored in the Geographic Tagged Image-File Format (GeoTIFF). This format enables referencing of a raster image to a known geodetic model or map projection. Wetspass model requires a summer and winter land-use/land-cover maps. However, for this study there is no land use /land cover change from summer to winter and thus it was not taken into account in the respective parameter tables for WetSpass modelling. Therefore, for this study the LU/LC map was prepared from Landsat images obtained on January and February with 30m cell size.

3.6.2 Precipitation

To prepare grid precipitation map of the catchment to be used as input to WetSpass model, the average of annual historic rainfall event (27-years) starting from 1986 till 2013 was collected from five meteorological stations located within the study area. Using spatial analyst extension in ArcGIS 10.2, Inverse Distance Weighted (IDW) interpolation approach was used to generate grid maps from these scattered set of point data. The simulation time for precipitation was divided into two periods, a dry season (from October to May) and a wet season (from June to September), corresponding to the winter and summer defined by WetSpass. Grid maps of winter and summer precipitaton used in this study are presented below in (Fig 3.19). It shows that the maximum precipitations for winter and summer are 355mm and 971.55 mm while the minimum precipitations are 227.1 mm and 726.354 mm respectively.

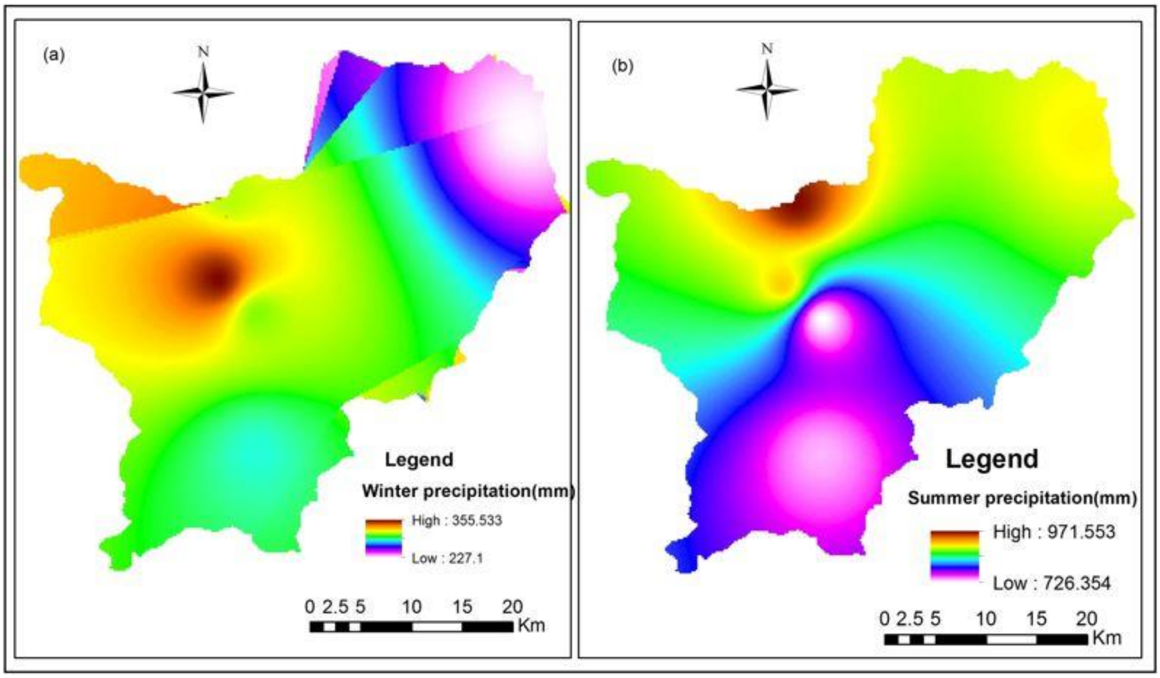

Fig 3.19 Input precipitation map: (a) Winter precipitation (b) Summer precipitation

3.6.3 Temperature

Monthly air temperature data for four stations located within the study area was obtained from the NMSA. Like the precipitation data, the simulation time for temperature was divided into two periods, a dry season (from October to May) and a wet season (from June to September), corresponding to the winter and summer defined by WetSpass. The annual temperature of the catchment for both winter and summer was interpolated with inverse distance weighted (IDW) approach based on the available temperature data collected from national meteorological service agency to produce grid map to be used as input for WetSpass modeling (Fig 3.20). It is shown from (Fig 3.20) that the minimum and maximum air temperature of winter for the catchment is 13.9^{o}C and 20.35^{o}C while for summer is 12.5 ^{o}C and 19.57^{o}C.

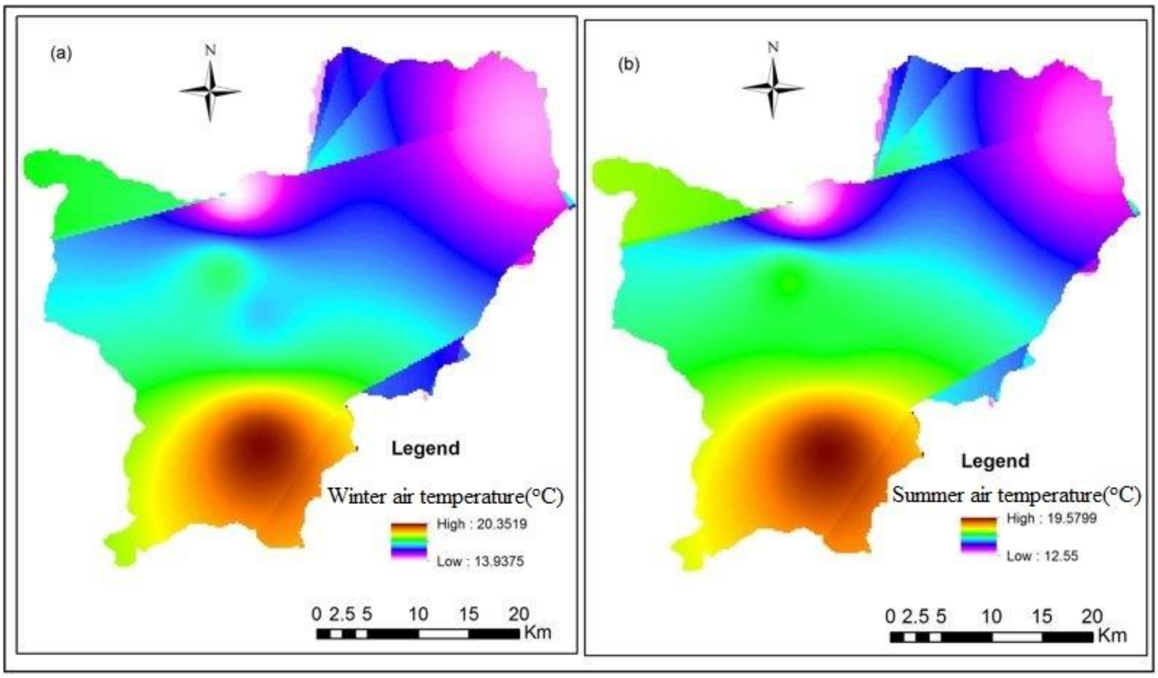

Fig 3.20 Input air temperature map: (a) Winter air temperature (b) Summer air temperature

3.6.4 Potential evapotranspiration (PET)

Evaporation is the process where liquid water is converted to water vapour through the energy supplied by solar radiation and the ambient temperature of the air. Potential evapotranspiration is the water lose, which will occur if at no time there is a deficiency of water in the soil for the use of vegetation. WetSpass modeling requires long term potential evapotranspiration grid maps as inpute. There are several methods for calculation of potential evapotranspiration such as: Blaney–Craiddle, Penman, Thornthwaite etc. For this research PET is calculated with thornthwaite method on a monthly basis using the formula:

PET= 16Nm (10Tm/I)a (Eq (3.3))

Where m is the months 1, 2, 3………………12,

Nm is the monthly adjustment factor related to hours of daylight and dividing it by 12

Tm is the monthly mean temperature °C, I is the heat index for the year, given by:

$I = \Sigma im = \Sigma(Tm/5)^{1.5}$ for m = 1…….. ...12 (Eq 3.3a)

$a = 6.7\times10^{-7}I^3 - 7.7\times10^{-5}I^2 + 1.8\times10^{-2}I + 0.49$ (Eq 3.3b)

After the PET value for four stations located within the catchment is calculated spatial interpolation approach using Inverse Distance weighted (IDW) method was applied to prepare grid map of PET (Fig 3.21). The simulation time is divided into two periods, a dry season (from October to May) and a wet season (from June to September), corresponding to the winter and summer defined by WetSpass.

Figure 3.21 shows that PET is high at the central parts of the catchment in Addis Ababa city. The minimum and maximum PET of Akaki catchment for winter time is 598.66mm and 1356.27 mm while for the summer is 238.96 mm and 535.85 mm respectively.

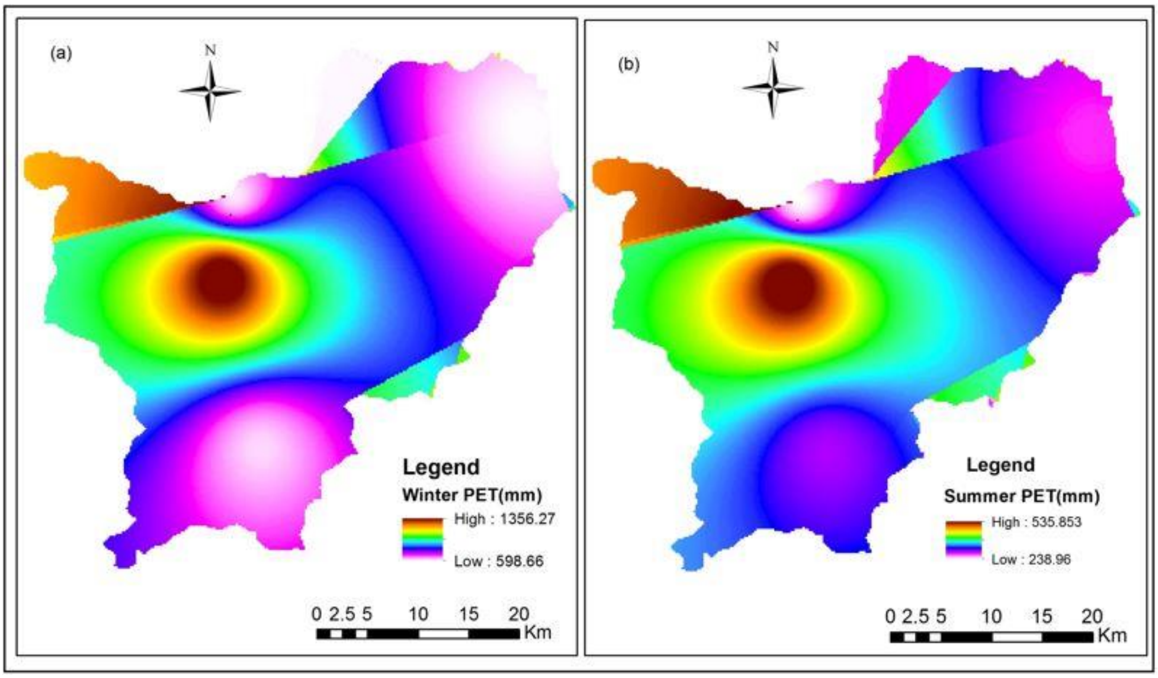

Fig 3.21 input PET grid maps (a) Winter PET (mm), (b) Summer PET (mm)

3.6.5 Wind speed

Wind speed data is only available for Addis Ababa observatory among the stations located within Akaki catchment. To make spatial interpolation of wind speed a few stations located around the catchment are selected based on their latitude and longitude GPS locations. Grid maps of the wind speed (m/s) data for summer and winter are presented in (Fig 3.22).

Like the climate parameters mentioned above, the simulation time for wind speed is divided into two periods, a dry season (from October to May) and a wet season (from June to September), corresponding to the winter and summer defined by WetSpass.

The grid wind speed map below shows the minimum and maximum wind speeds in m/s for the winter season are 0.92 and 1.77 while for the summer season are 0.49 and 0.62 respectively.

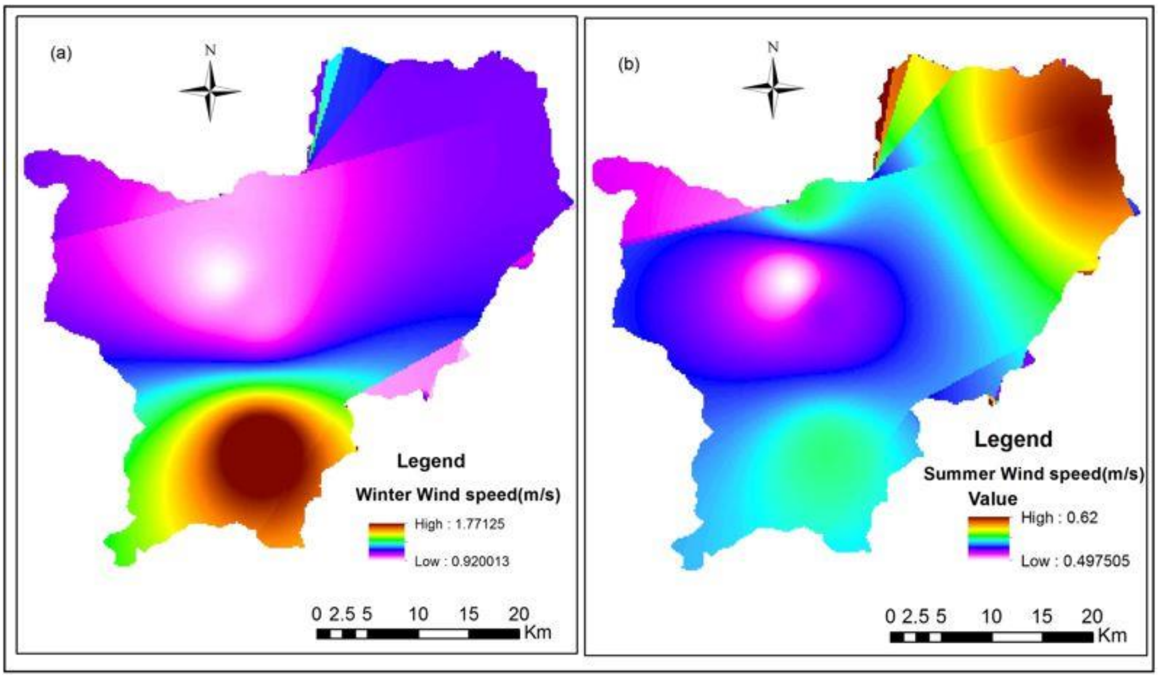

Fig 3.22 Input wind speed grid maps, (a) Winter wind speed, (b) Summer wind speed

3.6.6 Topography and slope

Digital Elevation Model (DEM) of the study area is used with a cell size of 30x30 m. The DEM is processed to prepare topographic, slope and stream network of the study area. The topographic grid map generated from the 30 m DEM is used to characterize the horizontal hydrological characteristics of the land surface whereas the slope data layer which was derived from the topography using Arcview 3.2 describes the maximum change in elevations. Topographic and slope grid maps used for WetSpass modeling are presented below in (Fig 3.23).

It is shown on figure 3.23(a) that the lowest elevation point in the catchment is 2024 m in the southern part and the highest is 3,239 m in the northern and western part, while the mean elevation of the catchment is 2,440.75 m. The slope map of the catchment is directly derived from the topography map using the ‘derive slope’ module in ArcView 3.2. The slope ranges from 0 to 35.87 % with a mean of 2.8% (Fig 3.23(b)).

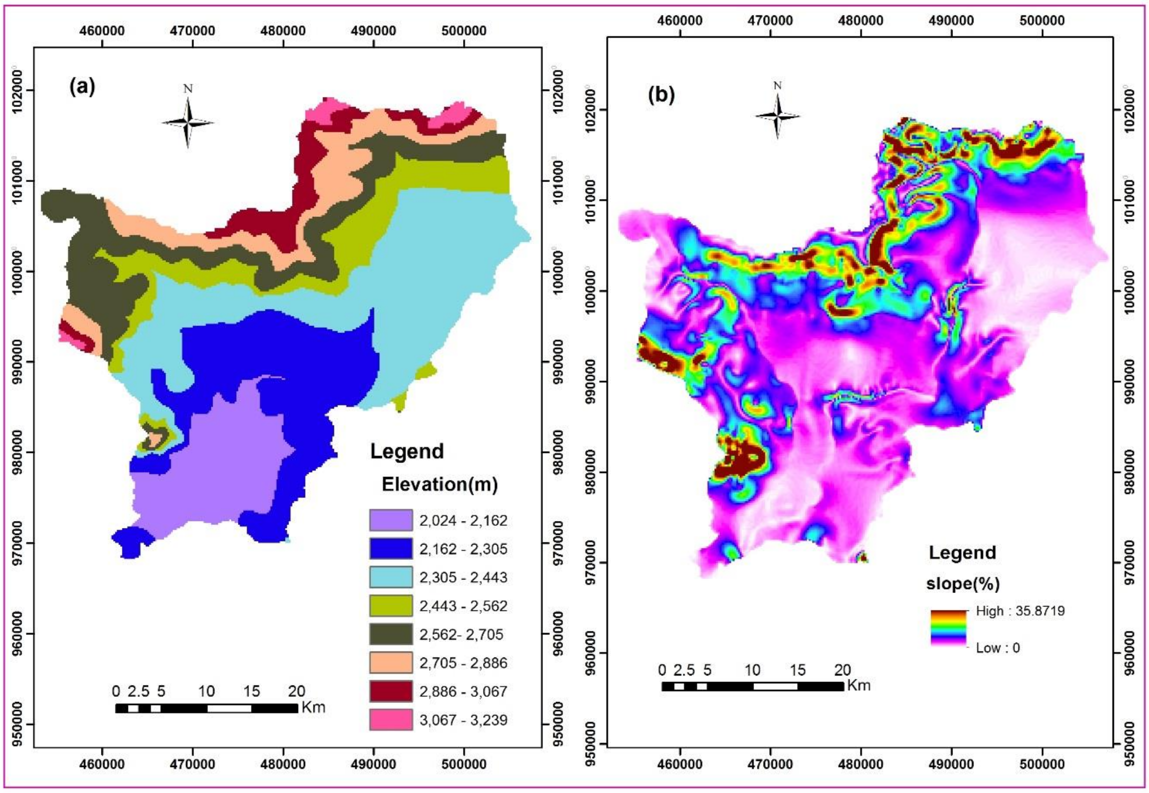

Fig 3.23 Input data for WetSpass simulation, (a) Topography (b) Slope

3.6.7 Soil

WetSpass modeling needs soil map in grid format with Standard USDA textural classification. For this study soil map was prepared using the shape file format soil data obtained from Ministry of water resource energy and irrigation GIS department with field observation (Fig 3.11). Soil type of the Akaki catchment was generated by digitizing of the Awash soil type shape file format data base in ArcGIS 10.2 and then converted to soil texture of the standard USDA classification using the major soil of the world data base FAO (1995) and the digital soil map of the world data base.

3.6.8 Ground water depth

Ground water depth map in grid format is required as input to run WetSpass modeling. Time series groundwater depth is not available in the country. Groundwater monitoring and management is not as such carried out in Ethiopia. As observed in Addis Ababa Water and Sewerage Authority (AAWSA) database, the data sets mainly hold well location, the water yield, static water depth and in some instances well lithology. For this study a total of over 119 ground water wells were collected from AAWSA. The simulation time is divided into two periods in this study, a dry season and a wet season, corresponding to the winter and summer defined by WetSpass. Since the available data are a one-time documentation (during drilling), the winter ground water depth for this study is obtained by subtracting the measured static water level from the elevation (Z-value in m) of the well. While the summer ground water depth is calculated by adding 0.92 m to the winter ground water depth. This choice is taken because time series monitoring of ground water depth for one boreholes in the upper Awash river basin by Andarge Yitbarek (2009) shows, the ground water depth for summer season was increased by 0.92 m compared to the winter season. Ground water depth map in grid format of the study region is presented in (Fig 3.24).

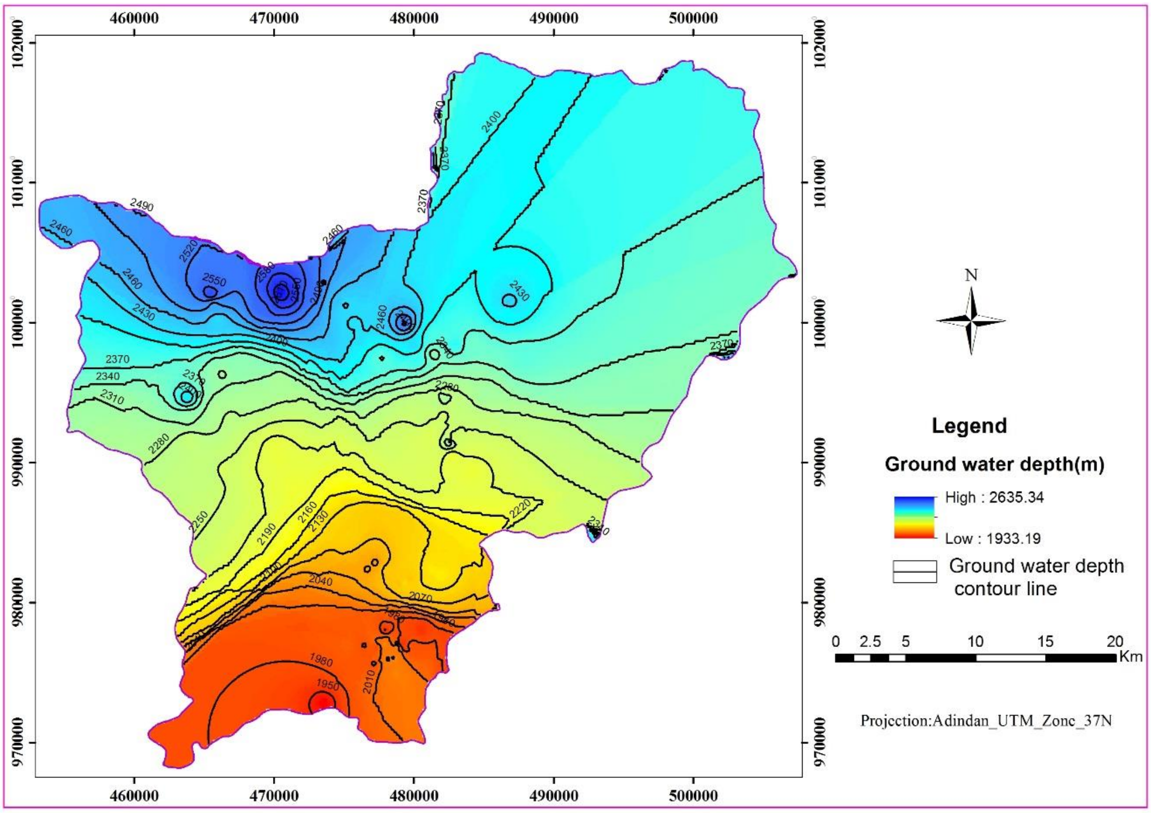

Fig 3.24 Ground water depth map

It is shown in (Fig 3.24), the ground water depth level is lower in the south, west and central part of the catchment while the higher is in the northern and eastern parts. It is also observed that, ground water depth is lower in areas of lower elevation and on the foothills of larger mountains.

CHAPTER FOUR

HYDRO-METEOROLOGICAL TREND ANALYSIS

4.1 Introduction

Ethiopia is one of the few African countries endowed with abundant water resources. Its geographical location and favorable climatic condition provide the country with relatively high amounts of rainfall in Eastern Africa. The project area lies within the Awash river basin, which has a total drainage area of 110,000 km^2 (Tesfaye Chernet, 1993).

Climate change is a change in the statistical properties of the climate system when considered over long periods of time. It significantly affects the various components of hydrological cycle like temperature, precipitation, evapotranspiration and infiltration. All these components together affect the rate of groundwater recharge. Hence understanding the effects of climate change on groundwater recharge is the need of time for the management of groundwater resources. In order to understand the environment and the possible impact of human activity on it a basic knowledge of weather and climate is required. The former is the physical condition of the atmosphere at a specific time and place with regard to wind, temperature, cloud cover, fog, and precipitation. Weather is highly variable and somewhat unpredictable. As a result, a longer-term trend of the hydro meteorological pattern of a particular locality is frequently more useful as these are the major sources of information to tell about the hydrologic condition of a catchment. In this research of the most useful meteorological elements only Precipitation and temperature were analyzed as temperature is the reflection of various meteorological variables like evapotranspiration, wind speed and relative humidity.

Trend analysis of the selected hydro meteorological elements was performed to investigate climate changed and its potential impact on ground water recharge in the catchment for the past years. The analysis was performed on the measured runoff, precipitation and temperature by drawing the Trend line to relate it with the ground water recharge of the catchment.

4.2 Meteorological data analysis

To estimate hydrologic balance for a given basin, each of the hydro-meteorological elements has to be quantified. However, this portion focusses on the analysis of spatial rainfall and temperature (the manifestation of evapotranspiration) characteristics of the catchment. Since rainfall is the primary source of runoff and recharge and evaporation affect these things, as it is the reflectance of different climatic variable (wind speed, relative humidity, temperature, etc.) that have great influence on runoff and recharge. Therefore analysis of these factors are very important to know their effect on ground water recharge.

4.2.1 Spatial rainfall analysis

Long-term monthly rainfall records of five stations for the past 27 years starting from 1986 till 2013 were taken from National Meteorological Service Agency (NMSA) in order to analyze the temporal and spatial variations in precipitation with in the catchment. All of the stations are located within the catchment. Spatially, annual rainfall of Akaki catchment varies from 1024.5 mm in the low land of Akaki station to 1283.99 mm in Intoto Mountain, the highest elevation area of the catchment. Rainfall is high for highland stations and relatively lower for low land stations with 74% of the rainfall occurring in wet season from June-September and the rest 26 % occurs in the dry season from October to May. The spatial distribution of rainfall is shown in (Fig 4.1).

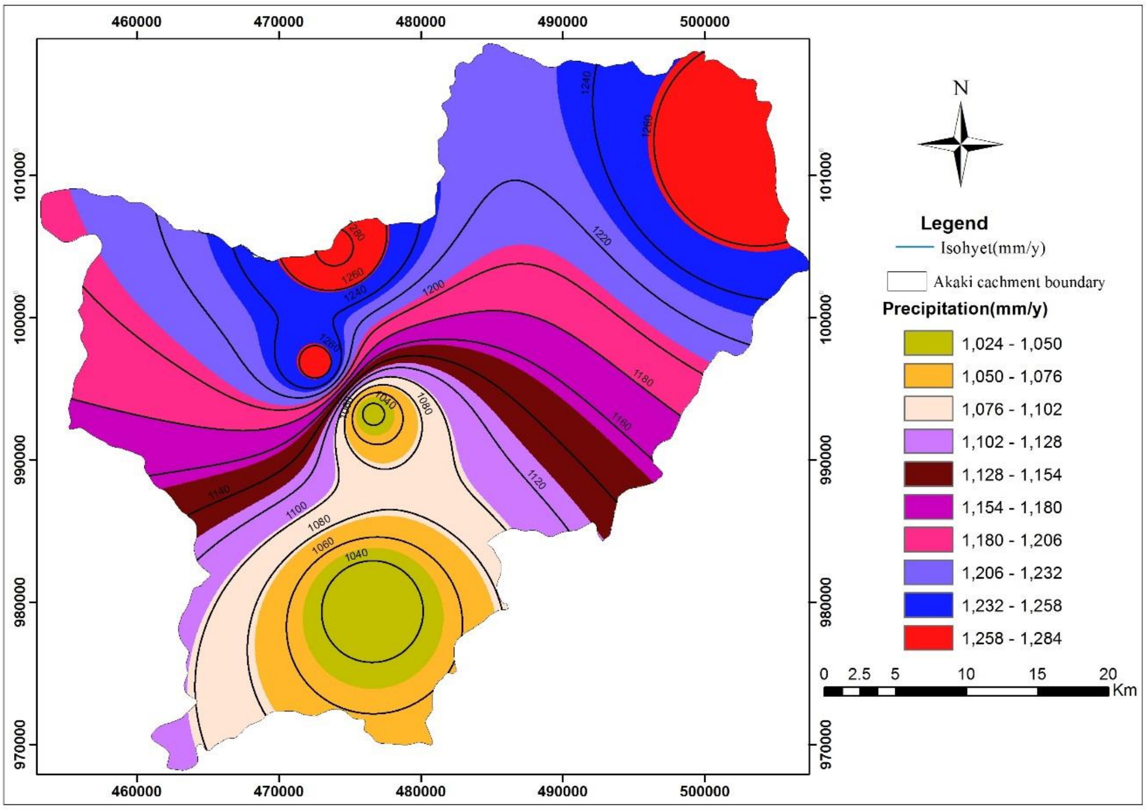

Fig 4.1 Mean Annual Rainfall of Akaki catchment

4.2.2 Trend of annual rainfall

To prepare a sustainable management strategy for groundwater development, it is important to understand the fluctuation of groundwater levels with reference to natural or artificial recharge in space and time domain. The rainfall comprises an important component of the water cycle and is the prime source of groundwater recharge. The rainfall on the catchment area is among the climate parameter that determines the hydrologic condition of a catchment. In this research long-term trends of rainfall for the catchment were analyzed to assess the impact of rainfall fluctuation on ground water recharge. Keeping the other factors constant the variation of rainfall in an area has a great impact on the recharge and surface runoff. Therefore, in the analysis of the hydrologic regime, the rainfall has to be taken as a major factor for the variability of the hydrologic condition in the area. In this regard, the average annual rainfall trend of the stations in the catchment area for the past 27 years were analyzed and presented in Fig 4.2 and Fig 4.3. From this result the trend of rainfall did not show clear change except fluctuation along the mean. Even though there was a slight decreasing tendency of the rainfall trend was observed, it can be generalized that the Akaki catchment has similar long term rainfall trend. Therefore, based on this it is possible to say the rainfall has no significant impact for the reduction of the recharge. Hence, the analysis of the other meteorological elements like temperature and evapotranspiration that, which have great influence on the recharge was mandatory.

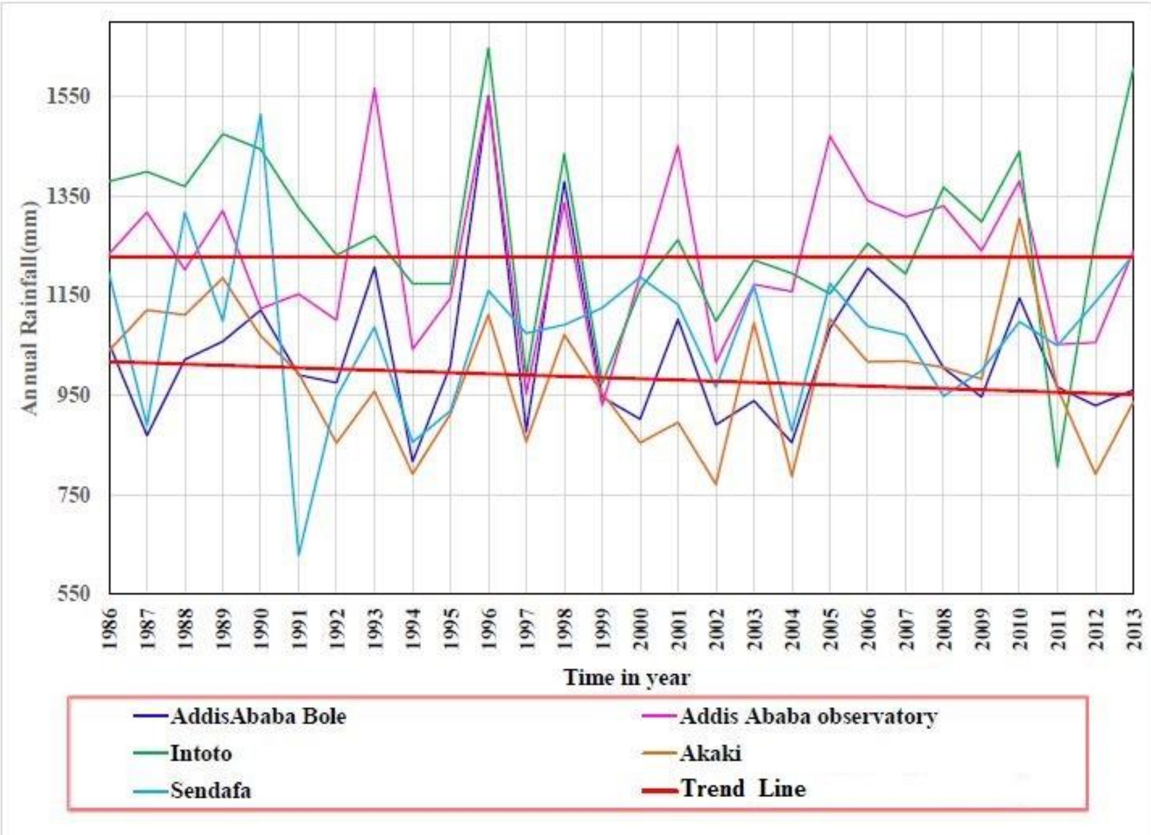

Fig 4.2 Trend of long term annual rainfall of stations within Akaki catchment (1986-2013)

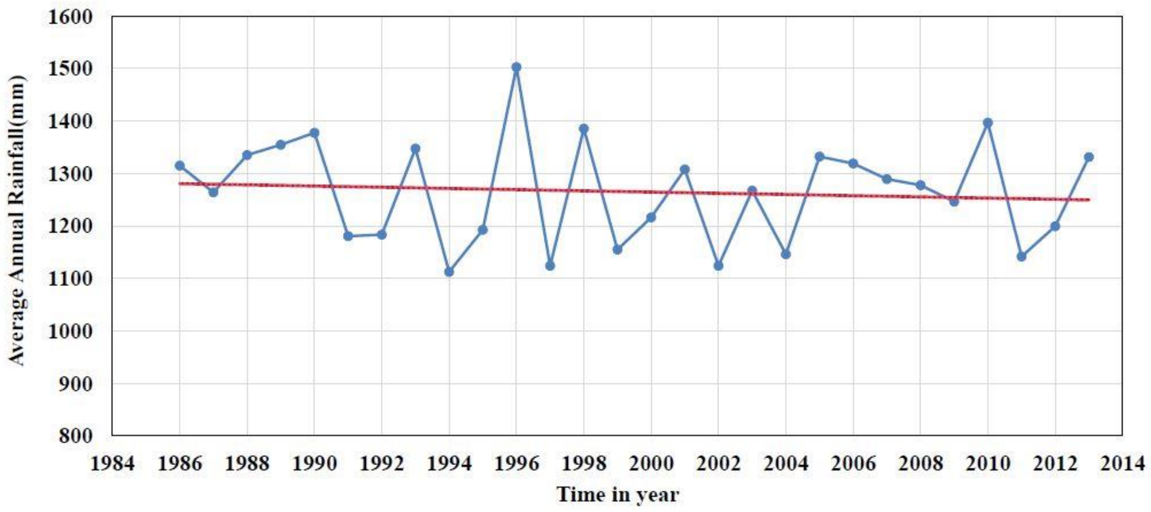

Fig 4.3 Trend of long term average annual rainfall of Akaki catchment

4.2.3 Spatial and temporal analysis of temperature

Long-term monthly maximum and minimum temperature records of stations in the catchment for the past 24 years starting from 1986 till 2013 were taken from National Meteorological Service Agency (NMSA) in order to analyze the temporal and spatial variations in temperature with in the catchment. Temperature is generally high towards the lowland to the eastern part and decreases to the highlands part of the catchment as indicated by the thermal map produced from average annual temperature (Fig 4.4).

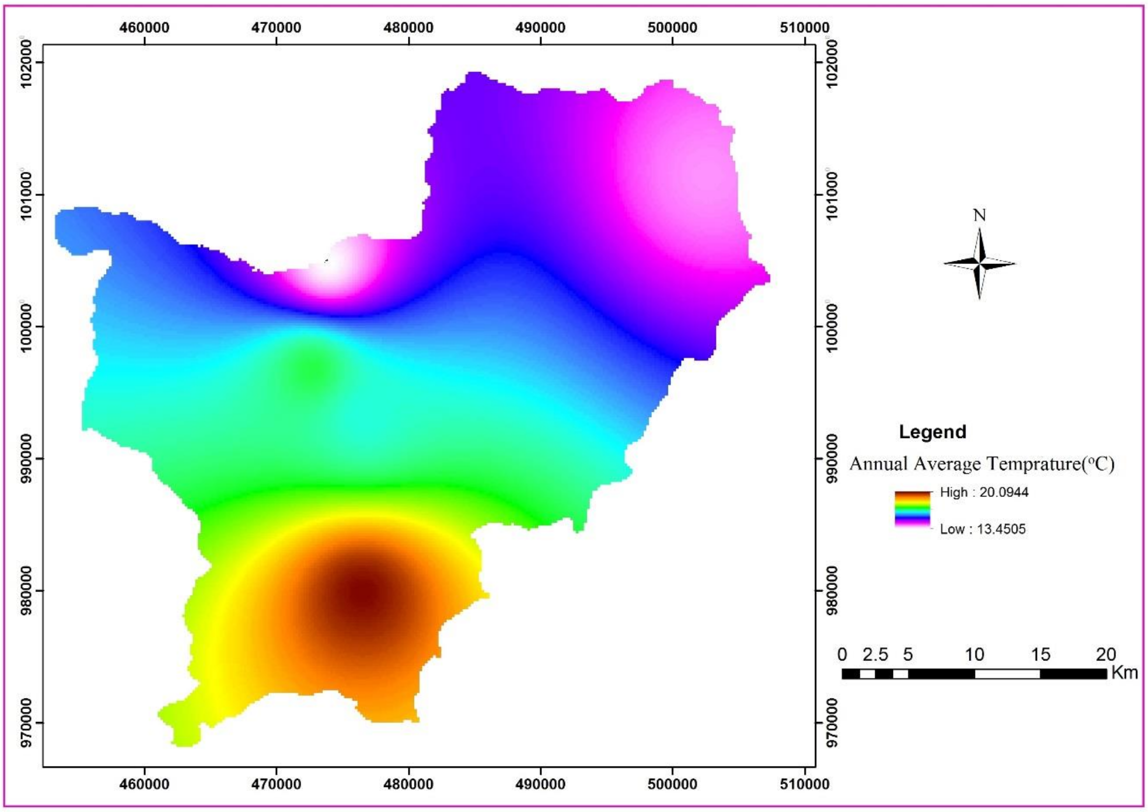

Fig 4.4 Mean annual temperature of Akaki catchment

4.2.4 Long term temperature trend in the Akaki catchment

A trend analysis was performed to investigate groundwater recharge and its relationship to temperature variability in the Akaki catchment. Monthly maximum and minimum temperature of four stations within the Akaki catchment were collected from NMSA. Trend line analyses of average maximum, average minimum and average annual temperature of the catchment shows as a slightly increasing tendency from time to time (Fig 4.5). This, however, serves as an additional observational evidence of warming which was consistently displayed in most part of the world (IPCC, 2007). Belete Berhanu and Semu Ayalew (2013) reported that Addis Ababa exhibits about 0.033^{o}C increases per decade from the mean temperature. Temperature increase from time to time affects the hydrologic cycle as most of the available water as well as the water coming from precipitation in the catchments are evaporated. However, it is shown in Fig 4.5 that the trend of temperature Vs time was almost insignificant.

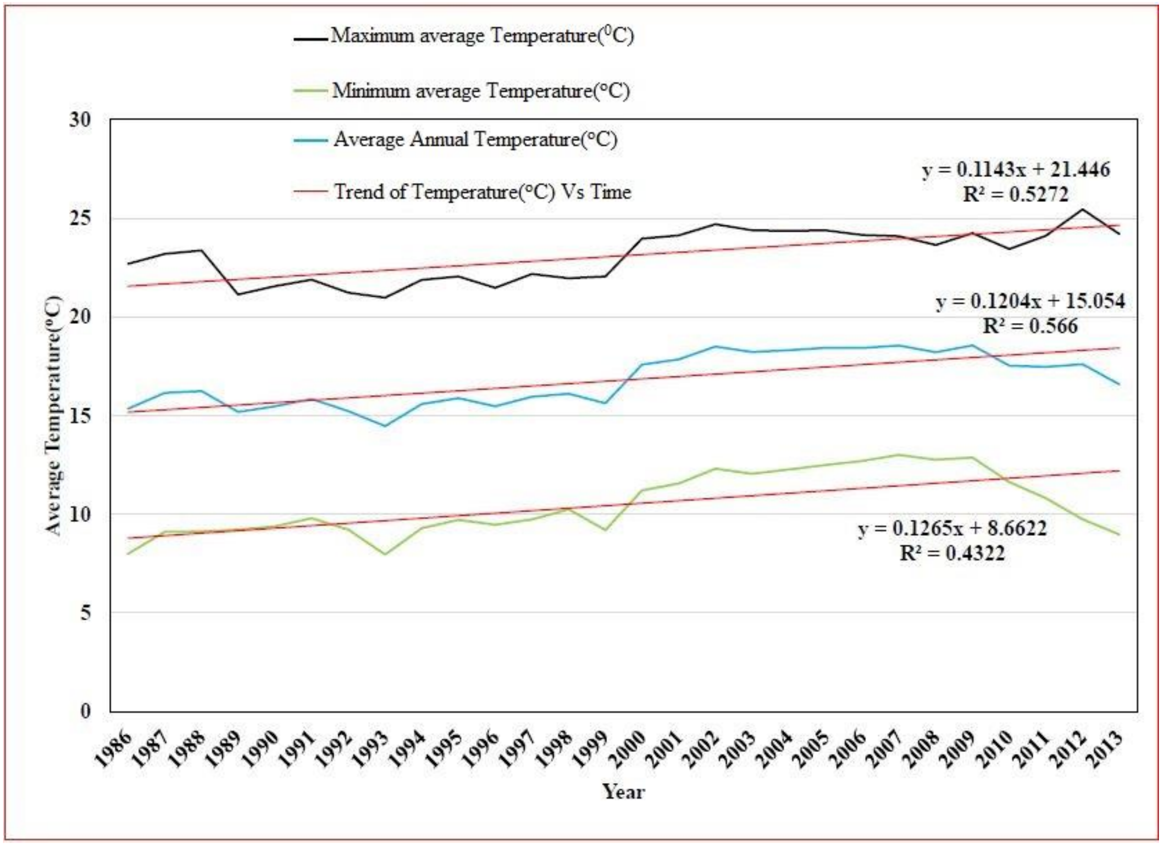

Fig 4.5 Long term temperature in Akaki catchment

Assessment of the trend of the climate factor changes, mainly precipitation and temperature showed no significant effect on the ground water recharge of the catchment.

4.3 Runoff analysis

Water that drains across basin into a stream channel as overland flow and groundwater contribution to a stream as base flow is collectively known as runoff. The flow of any stream is determined by climatic factors (particularly precipitation) and the physical characteristics of the drainage basin. The physical characteristics of the drainage basin includes land use, type of soil, type of vegetation, area, shape, elevation slope, orientation, type of drainage network, extent of indirect drainage and artificial drainage. In the study area most of the streams emanate from the steeply and rugged ridges of Entoto and flow crossing the city towards the relatively flat land areas of southern Addis Ababa. These and other natural conditions contribute for rapid movement of water in the rivers. The land of Addis Ababa which is located in the center of the study area is more or less built up with impervious materials like corrugated iron roof, asphalt or compacted gravel roads, drainage system, airfields, car parks, recreational areas and other man made impermeable structures. These human induced features significantly increase the amount and movement of water in the streams crossing the city.

The Big Akaki river was gauged near Akaki town on Addis Ababa - Debrezeit road. The station is equipped with an automatic water level recorder and is capable of discharge measurements. The average monthly and total annual runoff measured at the station from 1986 to 2004 is the available data obtained from ministry of water irrigation and energy and used in this study.

4.3.1 Trend of stream flow

Daily and monthly stream flow data of hydrological gauging stations for big and small Akaki rivers were collected from Hydrology Directorate of the Ministry of Water Irrigation and Energy (MoWIE) and reviewed for trend analysis of the stream flow. The temporal variation of stream flow in Akaki catchment is highly seasonal like rainfall pattern. In this study annual trend of stream flow of the big Akaki river for the past 21 year from 1983 up to 2004 was analyzed. The temporal trend of stream flow (Fig 4.6) for the catchment is increasing from time to time with some fluctuation in between. However, the trend of rainfall from time to time as shown in Fig 4.2 and Fig 4.3 above does not show any significant change. Therefore, it is possible to conclude that the ground water recharge of the catchment is decreasing as most of the precipitation is transported to stream instead of infiltration.

Stream flow increment at insignificant change of precipitation from time to time is a manifestation of land–use change.

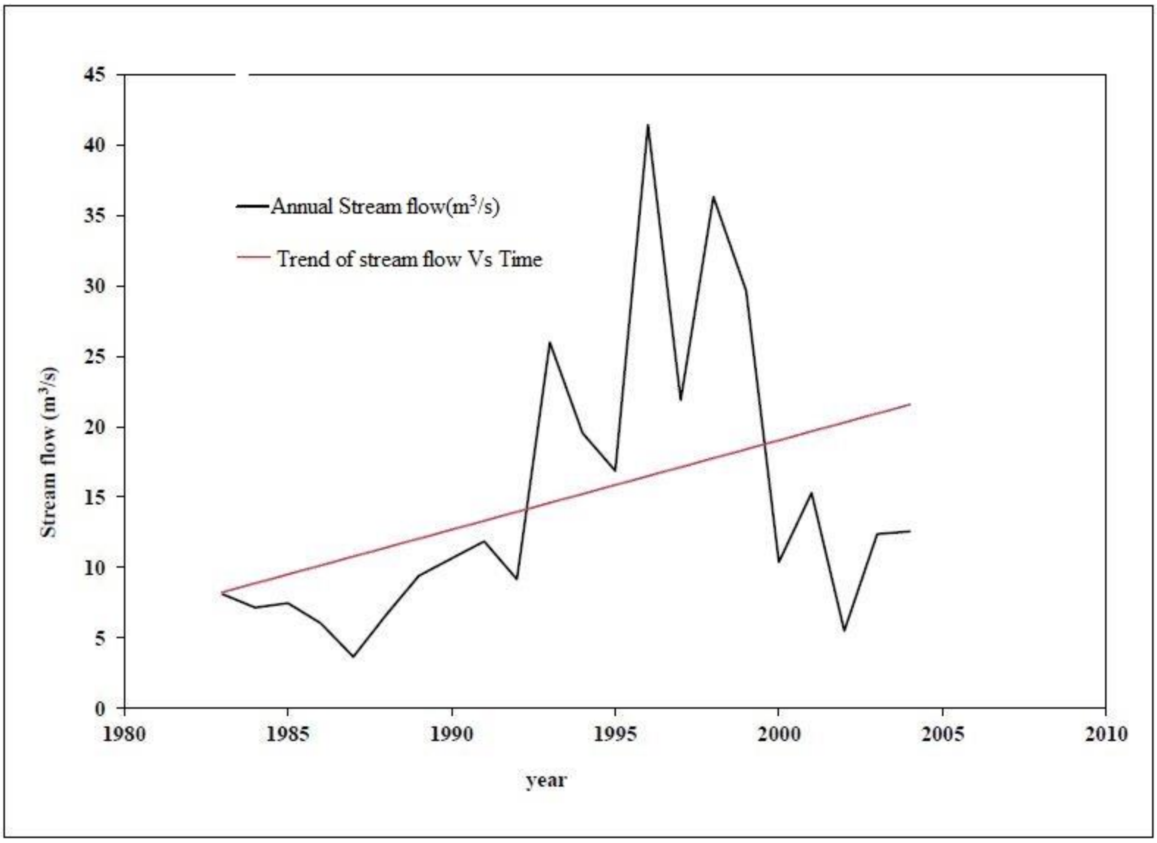

Fig 4.6 Temporal trend of stream flow

4.3.2 Trend of surface runoff

Akaki catchment is mainly characterized by urbanization and high annual rainfall. According to the report of Belete Berhanu and Semu Ayalew (2013) on hydro meteorological trend of Awash basin, for the periods of 1984, 1986 and 2002, hydrological modelling of the runoff for the same rainfall series indicated that the runoff potential has increased from 28% of rainfall in 1984 to 45% of the rainfall in 2002. Trend of the big Akaki river for the past 21 years show as, the surface runoff of the catchment is increasing from time to time with some fluctuations in between (Fig 4.7). By observing the trend of annual rainfall and surface runoff we can easily understand that how the recharge condition of the catchment is reduced.

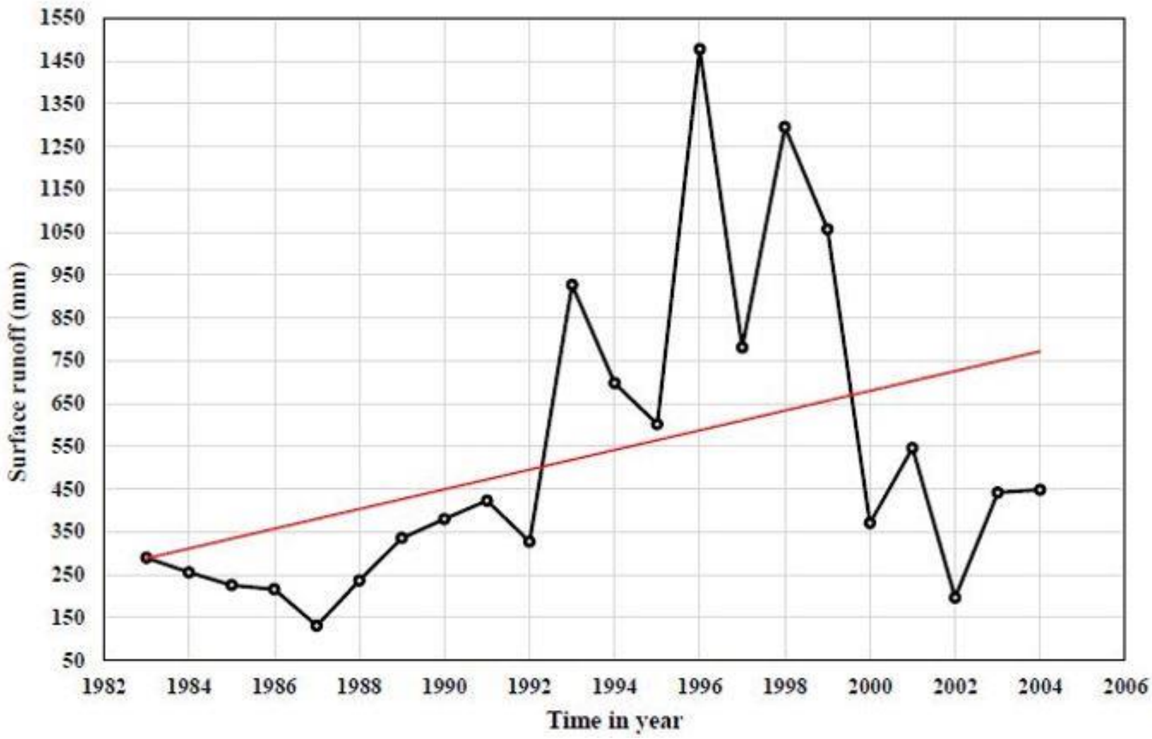

Fig 4.7 Temporal trend of surface runoff (1983─2004)

Analysis of the meteorological factors which control stream flow and surface runoff shows that meteorological elements does not have significant impact on ground water recharge however, trend analysis of both stream flow and surface runoff is showing dramatic increase with time. This situation directly causes the recharge of the catchment decrease. Generally all the meteorological factor have no significant effect on the ground water recharge but something else causes stream flow and runoff to increase dramatically which in turn reduces ground water recharge other than the meteorological elements.

The cause of runoff increase is mainly due to the rapid expansion of the city and the built environment. GIS computation of the three land–use map areas of 1986, 2000 and 2015 showed that the urban settlement area has increased from time to time. Comparative assessment of land-use/land-cover and climate change impact on ground water recharge shows that impact of land use/land cover change especially urban expansion is likely to be more significant. Therefore, most of the Akaki Catchment rivers are changing mainly due to urbanization of the Addis Ababa city. In the next chapter ground water recharge of of Akaki catchment under different land use/land cover scenarios is quantified with WetSpass modeling. It also discussed on the causes of land-use land-cover changes and percentage cover of the lad-use types for three different time to relate the changes to ground water recharge of the catchment.

CHAPTER FIVE

RESULTS and DISCUSSION

5.1 Land-use and land-cover change detection

The land–use maps for 1986, 2000, and 2015 for Akaki catchment are presented in (Fig 5.1). Comparison of classification results suggest that the principal land–cover changes observed in the study area between 1986 and 2015 are the urban settlement, grass land, forest and cultivated lands.

The area and percentage coverage of these five land–use classes during the four intervals are presented in Fig 5.2. It shows that the urban settlement and cultivated land areas were increased while that off forest and grass land declined continuously from 1986 till 2015.

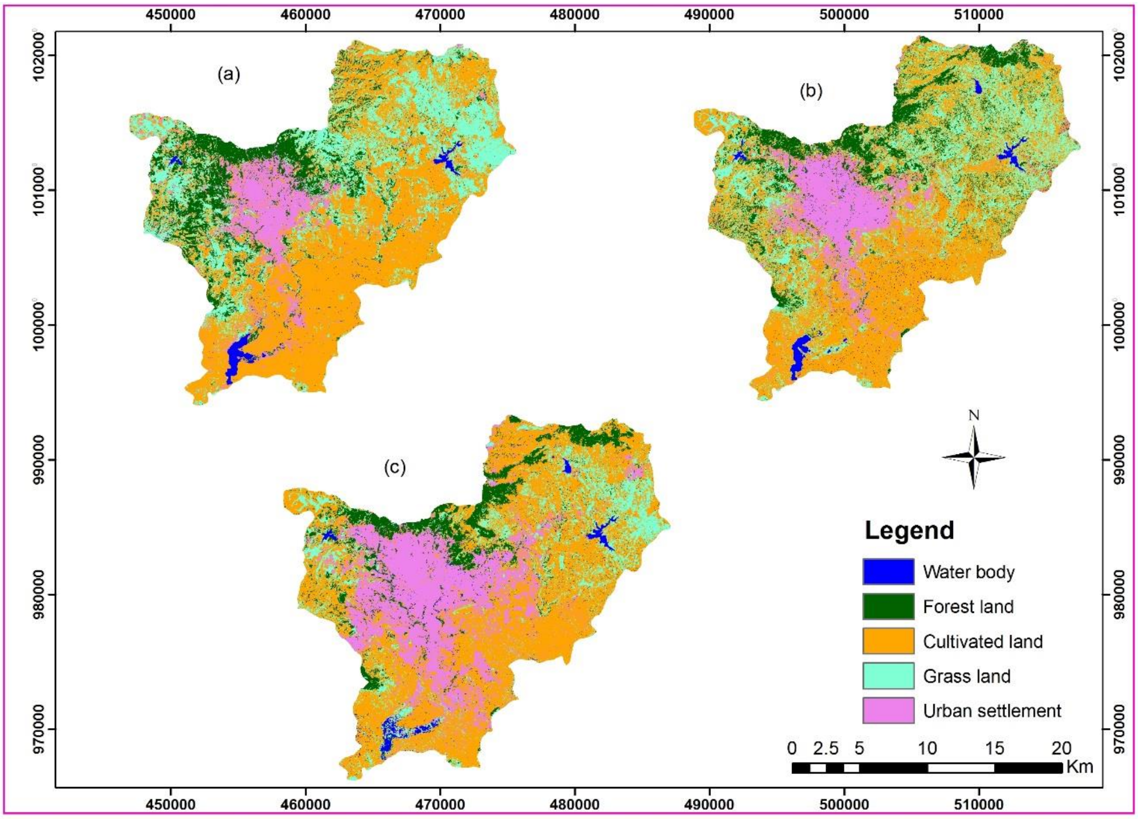

Fig 5.1. Land–use map of the years 1986 (a), 2000 (b) and 2015(c)

Table 5.1 Land-use/ land-cover categories in the study area during 1986, 2000 and 2015

Land-use classes	1986		2000		2015	
	Area in (ha)	Area in (%)	Area in (ha)	Area in (%)	Area in (ha)	Area in (%)
Water body	1552.62	1.059	1734.94	1.18	1624	1.1
Urban settlement	16005.8	10.91	22899.8	15.61	32052.1	21.86
Grass land	37708.3	25.71	31136.25	21.23	21512.2	14.67
Forest land	19886.26	13.56	18501.95	12.62	14563.1	9.9
Cultivated land	71502.9	48.76	72383	49.36	76904.5	52.44
Total	146656	100	146656	100	146656	100

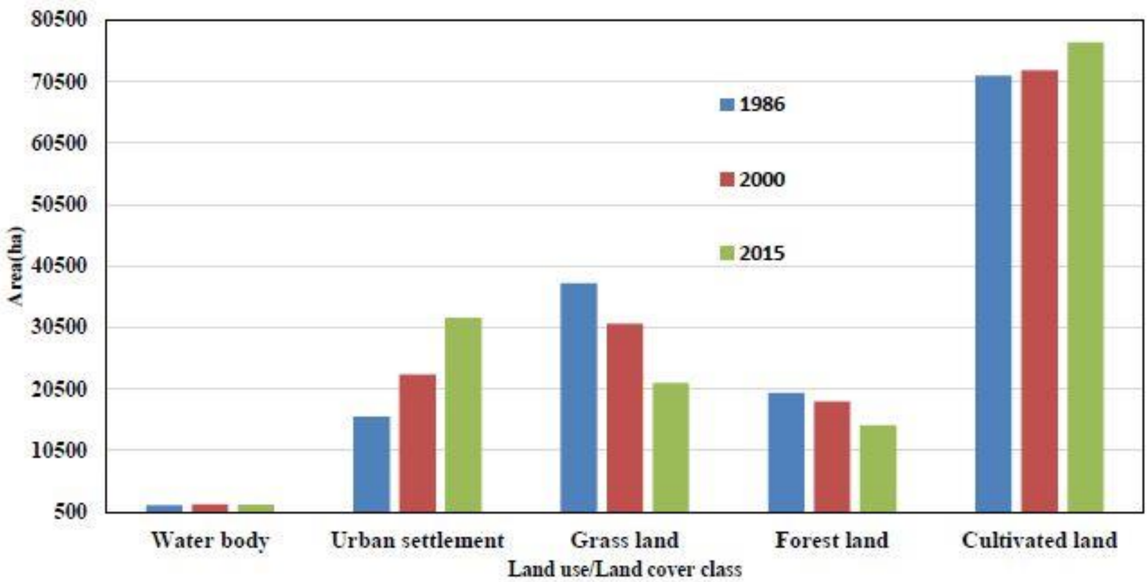

Fig 5.2 Land-use/land-cover change in the study area from 1986 to 2015

Table 5.1 and Fig 5.2 shows the spatial distribution of land-use/land-cover categories of the study area during the three years 1986, 2000 and 2015 in the Akaki catchment. For the year 1986,the land cover map is shown in figure 5.1a. The percentage coverage of each class is shown in Table 5.1 and Fig 5.2 and indicates that the highest area of the catchment is covered with cultivated land (48.97%), while forest, grass land, urban settlement and water covered 13.56%, 25.71%, 10.9% and 1.06%, respectively.

For land-use/land-cover map of 2000 as shown in Fig 5.1 (b), the areal coverage of cultivated land, urban settlement and water body was increased to 49.36% , 15.61% and 1.18% ,respectively, while the areal coverage of forest land and grass land was decreased to 12.62% and 21.23%, respectively.

The land–use/land–cover map for 2015 of the Akaki catchment is presented in Fig 5.1(c)in which the cultivated land is covered for about 52.44% of the areal extent of Akaki catchment. Whereas forest land, grass land, urban settlement and water body covered 9.9%, 14.67%, 21.86% and 1.1% of the areal coverage of the study area, respectively (Table 5.1 and Fig 5.2).

5.2 Change detection analysis results

To further evaluate real losses and gains of the different land–use classes, land–use changes from 1986 to 2000, 2000 to 2015 and 1986 to 2015 were established (Table 5.2).

Table 5.2 LU/LC classes and changes during the period 1986-2000, 2000-2015 and 1986-2015

LULC class	1986—2000		2000—2015		1986—2015	
	Area in (ha)	Area in (%)	Area in(ha)	Area in (%)	Area in (ha)	Area in (%)
Water body	182.32	0.124	-110.94	-0.08	71.38	0.041
Urban settlement	6894	4.7	9152.3	6.25	16046.3	10.95
Grass land	-6572.05	-4.48	-9624.05	-6.56	-16196.1	-11.04
Forest land	-1384.31	-0.94	-3938.85	-2.72	-5323.16	-3.66
Cultivated land	880.1	0.6	4521.5	3.08	5401.6	3.68

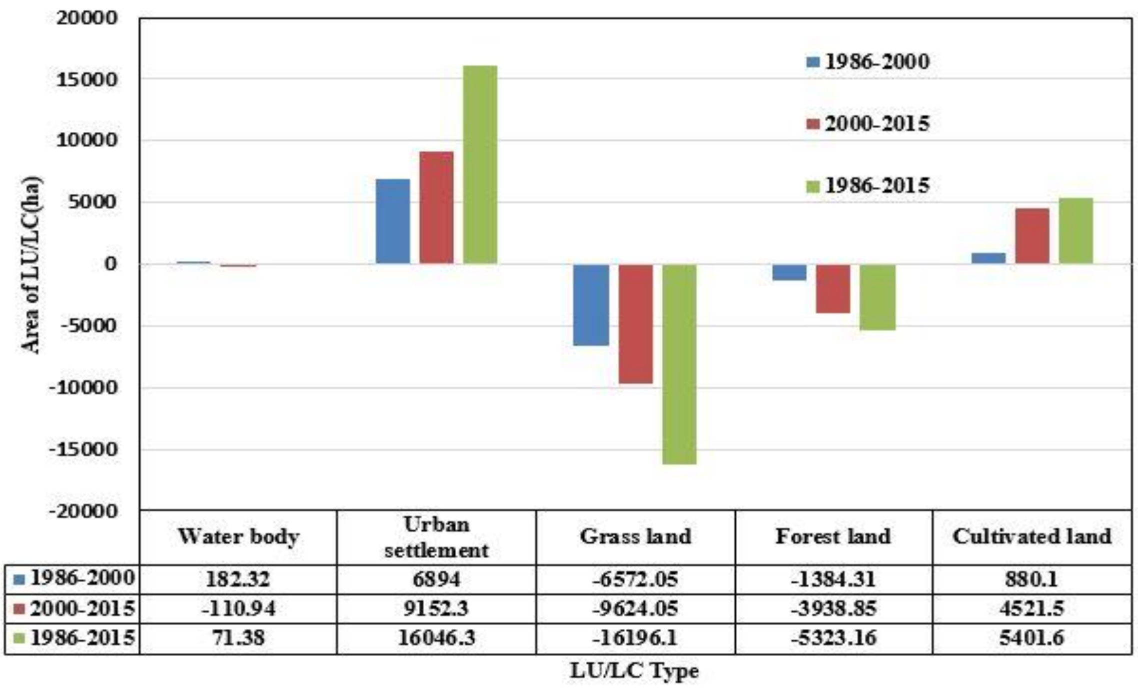

Fig 5.3 LU/LC change between 1986 -2000, 2000-2015 and 1986 -2015

Change detection analysis result on the periods between 1986 and 2000 (Fig 5.3) show that grass land and forest land were changed by -6572.05ha (-4.48%) and -1384.31ha (-0.94%), respectively. On the other hand the extents of water body, urban settlement and cultivated land were increased by 182.32 ha (0.124%), 6894 ha (4.7%), and 880.1 ha (0.6%) area, respectively. From this it can be concluded that urban settlement and cultivated land are increasing very dramatically during the study periods.

In the change detection of 2000–2015, the same land–use and land–cover change dynamics was observed in all land-use and land-cover classes except for water body. Change detection during 2000–2015 (Fig 5.2 and Table 5.2) shows urban settlement and cultivated lands were increased by 9152.3 ha (6.25%) and 4521.5 ha (3.08%) while water body, forest land and grass land where decreased by -110.94(-0.08%),-3938.85(-2.72%) and -9624.05(-6.56%), respectively.

The change detection from 1986 to 2015 shows, urban settlement, cultivated land and water body areal coverage was increased by 16046.3 ha (10.95%), 5401.6 ha (3.68%) and 71.38 ha (0.041%) while grass land forest land decreased by -16196.1 ha (-11.04%) and -5323.16 ha(-3.66%), respectively.

The main reasons for this dramatic change is high human population growth. According to the Central Statistical Agency of Ethiopia (CSA, 2007) projected report on population of Addis Ababa city, the number of the population was projected to increase from 2112737 in 1994 to 3275348 in 2015. Because of this high population increase, most of the catchment area was transformed into cultivated lands and settlement in the central and outskirts part of the catchment. In the analysis of change detection form the period of 1986 to 2000, water body increased by 182.32 ha (0.124%) while for the period of 2000 to 2015 it decreased by -110.94 ha (-0.08%). On the period during 1986–2000, high population increase was observed and this needed to construct additional water supply structure called Dere dam. During the period of 2000 to 2015 the water body areal coverage was decreased because some part of the big reservoir Abasamuel was dried and changed to swampy area.

5.3 Accuracy assessment of land-use and land cover-mapping

An error report containing the error matrix and accuracy report summarizing the agreement and disagreement are produced (Table 5.3 to 5.6). The Kappa coefficients are then calculated for each land–use and land–cover classification. The computation of Kappa and the overall accuracies for three scenes are summarized in Table 5.6. The Kappa coefficient lies typically on a scale between 0 and 1, where a Kappa coefficient value closer to 1 indicates complete agreement, and is often multiplied by 100 to give a percentage measure of classification accuracy. According to Rahman et al. (2006) the Kappa values are characterized into 3 groups: a value greater than 0.80 (80%) represents strong agreement, a value between 0.40 and 0.80 (40 to 80%) represents moderate agreement, and a value below 0.40 (40%) represents poor agreement. According to this range of Kappa coefficient, the land–use and land–cover classification of this research study lies on the value that shows strong agreement as the values of the Kappa are 0.85, 0. 89 and 0.91for the period 1986, 2000 and 2015 images classification respectively (Table 5.6).

✓ Producers accuracy

The producer's accuracy is also one result of the accuracy assessment and this tells us how well a certain area can be classified. It is obtained by dividing the number of correctly classified pixels in the category by the total number of pixels of the category in the reference data. The producer's accuracy is also known as an Omission Error, which is the probability of a reference pixels being classified correctly. It gives only the percentage of correctly classified pixels. The overall result of the producer's accuracy for all the three LU/LC classifications ranges from 71.43% to 100% (Table 5.3–5.5). The lowest values were misclassified due to similar spectral value of different land cover classes. For instance, grass land with forest land and cultivated land with grass land somehow affects the level of classification especially for image classification of 1986.

✓ Users accuracy

Accuracy report of image classification produces users accuracy as a results by dividing the total number of pixels correctly belonging to a class (diagonal elements) by the total number of pixels assigned to the same class by the classification procedure (row total). This result explains the probability that a pixel of the classified image truly corresponds to the class to which it has been assigned. In this study, for all the LU/LC classification the user's accuracy ranges from 78.23 % to 100 %. The lowest values were misclassified due to similar spectral value of different land cover classes (Table 5.3–5.5).

Note: CL=cultivated land,
WB=Water Body,
US=Urban settlement,
FL=forest land and
GL=grass land

Table 5.3 Confusion matrix for the classification of 1986

		REFERANCE DATA						
		CL	US	GL	FL	WB	Total	Users accuracy (%)
CLASSIFICATION DATA	CL	10	0	0	0	0	10	100
	US	4	5	1	0	0	10	50
	GL	0	0	10	0	0	10	100
	FL	0	0	1	9	0	10	90
	WB	0	0	0	0	10	10	100
	Total	14	5	12	9	10	50	
Producers accuracy (%)		71.43	100	83.33	100	100		

Table 5.4 Confusion matrix for the classification of 2000

		REFERANCE DATA						
		CL	US	GL	FL	WB	Total	Users accuracy (%)
CLASSIFICATION DATA	CL	15	1	1	2	0	19	78.95
	US	0	19	1	0	0	20	95
	GL	1	0	19	2	0	22	86.36
	FL	1	0	0	18	0	19	94.74
	WB	0	0	0	0	20	20	100
	Total	17	20	21	22	2	100	
Producers accuracy (%)		88.24	95	90.48	81.82	100		

Table 5.5 Confusion matrix for the classification of 2015

		REFERANCE DATA						
		CL	US	GL	FL	WB	Total	Users accuracy (%)
	CL	18	1	3	0	1	23	78.26
CLASSIFICATION DATA	US	0	20	0	0	0	20	100
	GL	0	0	15	0	0	15	100
	FL	0	0	0	20	0	20	100
	WB	0	0	1	1	23	25	92
	Total	18	21	19	21	24	103	
Producers accuracy (%)		100	95.24	78.95	95.24	95.83		

Table 5.6 Summary of overall classification accuracy and Kappa coefficient

Year	Overall Classification Accuracy (%)	Overall Kappa Coefficient
1986	88.00	0.85
2000	91.00	0.89
2013	93.2	0.915

5.4 Normalized Difference Vegetation Index (NDVI)

NDVI was calculated for the Landsat images of the 1986, 2000 and 2015 using the NDVI formula to see how the vegetation cover of the catchment changes over the past periods.

The NDVI results of 1986, 2000 and 2015 Landsat images were very important to obtain trend of land-use and land-covers specially vegetation and urban expansion over the past 29 years. Based on this analysis the vegetation cover trend of the catchment and the expansion of urban settlement are presented in Fig 5.4.

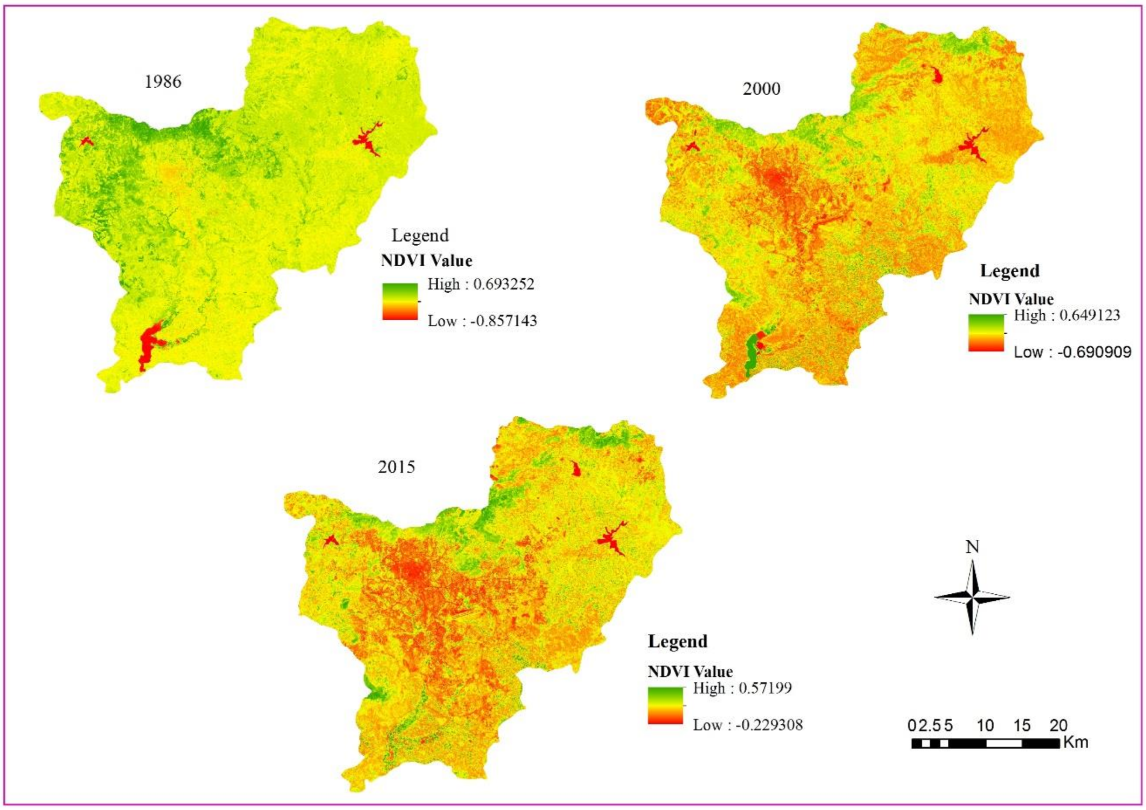

Fig 5.4 NDVI maps of the years 1986, 2000 and 2015

The NDVI values for vegetation range from a low of -0.857143 to a high of +0.6934 for the Landsat image of 1986, from a low of -0.6909 to a high of 0.649 for Landsat image of 2000 and from a low of -0.2293 to a high of +0.572 for Landsat image of 2015 (Fig 5.4). Non vegetated surfaces have NDVI values of less than zero and the highest NDVI values represent the maximum vegetation at that period. It was noticed that the NDVI was higher in the north and west of the catchment than the south and east. Such indication could be of interest in understanding the hydrology of the area. The value of the NDVI indicated the absence or presence of groundwater assuming that vegetation response to presence of water in the soil. Areas with denser vegetation, i.e. higher NDVI, may indicate areas with higher rainfall and presence of groundwater by deep roots, which was the case in the north and west of the area. Also, the presence of vegetation affects the soil moisture budgets and therefore recharge and the uptake of groundwater by the deep roots.

5.5 WetSpass model

WetSpass gives various hydrologic outputs grids on a yearly and seasonal (summer and winter) basis. Even though the model was originally developed to compute the long-term spatially distributed recharge of a basin, it also simulates runoff, evapotranspiration, interception, transpiration, soil evaporation and errors in water balance. The results of the modeling are given by digital grid maps of the spatial distribution of annual average values of actual evapotranspiration, surface runoff and groundwater recharge for the 29 years period from 1986 to 2015 under different land use scenarios.

5.5.1 Evapotranspiration

The results revealed that evapotranspiration is a source of water loss, varying from (348-1704) mm/y for land use of 1986 (Fig 5.5(1986)), (346–1729) mm/y for land use of 2000 (Fig 5.5 (2000)) and form (346.9-1889) mm/year for land use of 2015 (Fig 5.5 (2015)) with annual mean of 515 mm, 514 mm and 528.55 mm respectively. On average, evapotranspiration is the largest component of the yearly water balance. As shown in Table 5.7, WetSpass estimates the evapotranspiration in the catchment as 45%, 44.9% and 46% of the yearly average precipitation for land-use and land-cover maps of 1986, 2000 and 2015, respectively.

Evapotranspiration is largely determined by solar radiation, Precipitation and land–use/land–cover as a result, it varies little from year to year, especially in the dry season.

WetSpass also simulates the mean evapotranspiration of the catchment to be 348 mm for summer and 167 mm for winter. The summer evapotranspiration accounts for about 66% of the total annual evapotranspiration while the remaining 34% was released during the winter season. This variation occurs due to difference of precipitation with in the two seasons.

The simulated annual evapotranspiration map (Fig 5.5) shows open water bodies have high evapotranspiration values because the supplies of water is unlimited to keep evapotranspiration to its maximum. Evapotranspiration is low on the relatively lowland areas of the southern and eastern part of the catchment and is high on the higher elevation areas of the northern and western parts. This is because low elevation area receives low precipitation compared to high elevation areas and the availability of sufficient water due to precipitation results to high evapotranspiration.

Generally, the annual evapotranspiration of the catchment is increasing positively from 18,429,258.78 mm/y for land–use map of year 1986 to 18,940,043 mm/y for the land use map of year 2015.

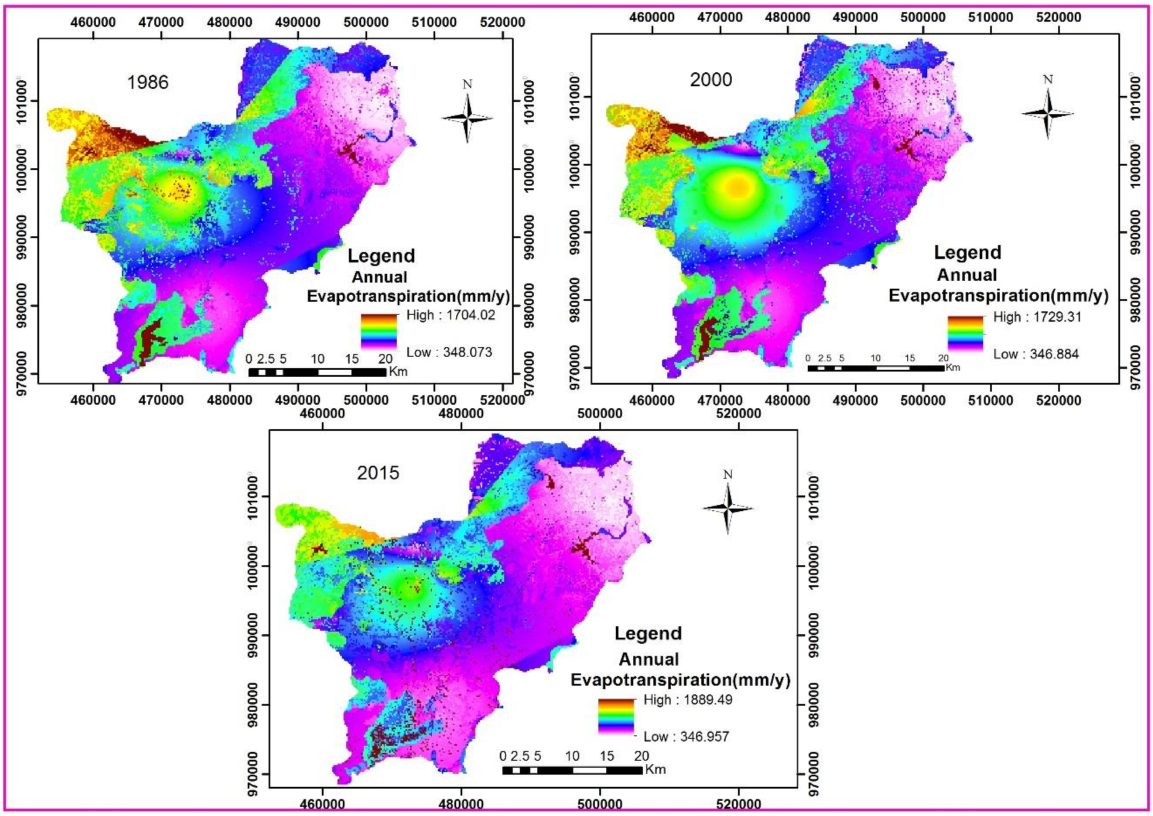

Fig 5.5. Annual evapotranspiration maps of years 1986, 2000 and 2015

5.5.2 Surface runoff under different land-use and land-cover scenarios

The surface runoff in the Akaki catchment varies spatially with topography, soil type and land–use of the catchment. Table 5.7 shows the Simulation results of WetSpass modeling for surface runoff and its variation under different land-use and land–cover scenarios and season (summer and winter).

The total simulated annual surface runoff of the catchment for land–use and land–cover-map of 1986, 2000 and 2015 is 13,009,423.59 mm, 13,185,735.17 mm and 13,242,414.59 mm respectively(Fig 5.6 and Table 5.7). The trend line on (Fig 5.6) also shows the runoff is increasing with changes in land–use and land–cover changes of the Akaki catchment.

Table 5.7 Comparison of surface runoff under different land use and land cover scenarios

Year	Average Annual surface runoff (mm)	Total Annual surface runoff (mm)	Average summer surface runoff (mm)	Average winter surface runoff (mm)	Annual Std. deviation
1986	360.96	13,009,423.59	247.12	113.605	227.567
2000	365.85	13,185,735.17	246.85	118.637	219.646
2015	367.43	13,242,414.59	251.1	116.057	218.71

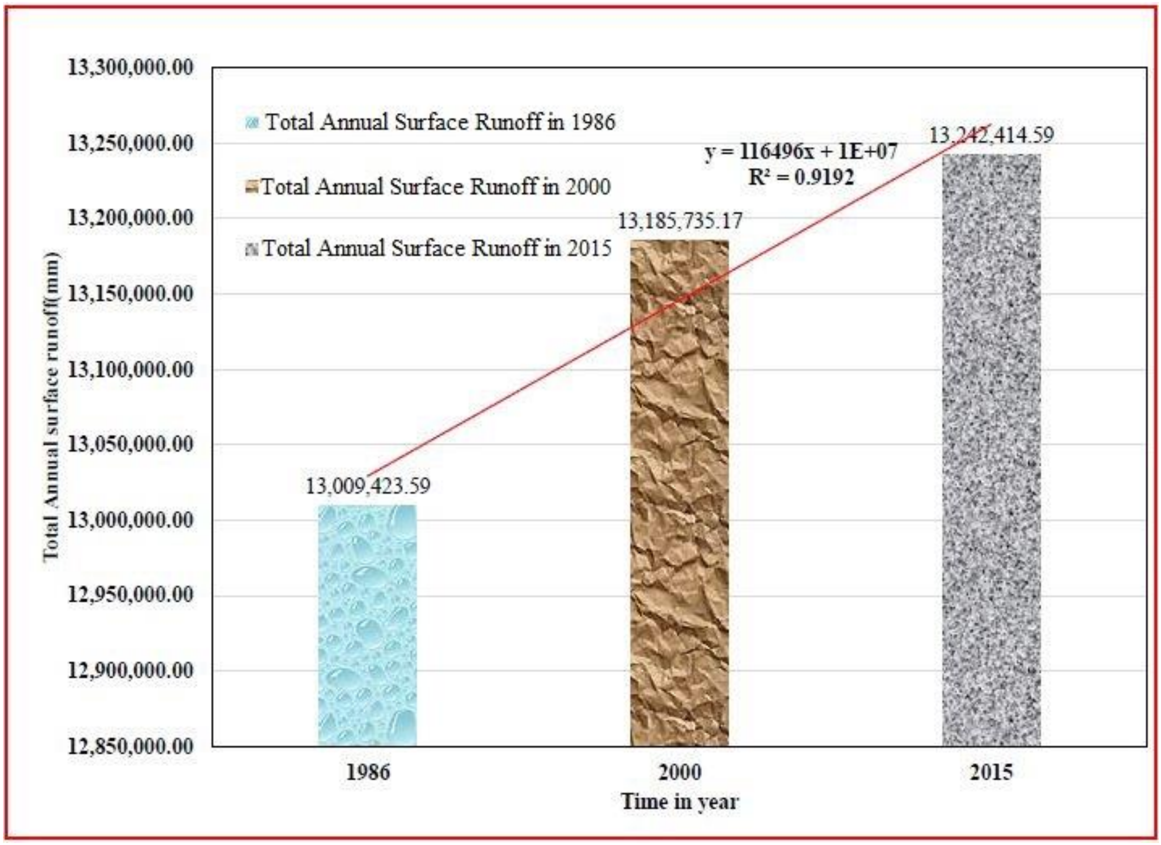

Fig 5.6 Annual runoff *vs* Time

Average surface runoff is larger for summer season compare to the winter season because of the different characteristics of summer and winter precipitation. A larger fraction of the total precipitation of the catchment falls at high intensity in the summer season and surface runoff occurs more. In the winter, on the other hand, most of the rainfall falls at a much lower intensity, which doesn't contribute to surface runoff. The rainfall exceeds the infiltration capacity of soil during the wet season which leads to high surface runoff. Annual Surface runoff of Akaki catchment for land–use and land–cover maps of 1986, 2000 and 2015 ranges from (2.95-731) mm, (2.9-737) mm and (2.95-745) mm with 362mm, 367mm and 368.86 mm mean annual surface runoff of, respectively (Table 5.7 and Fig 5.7).

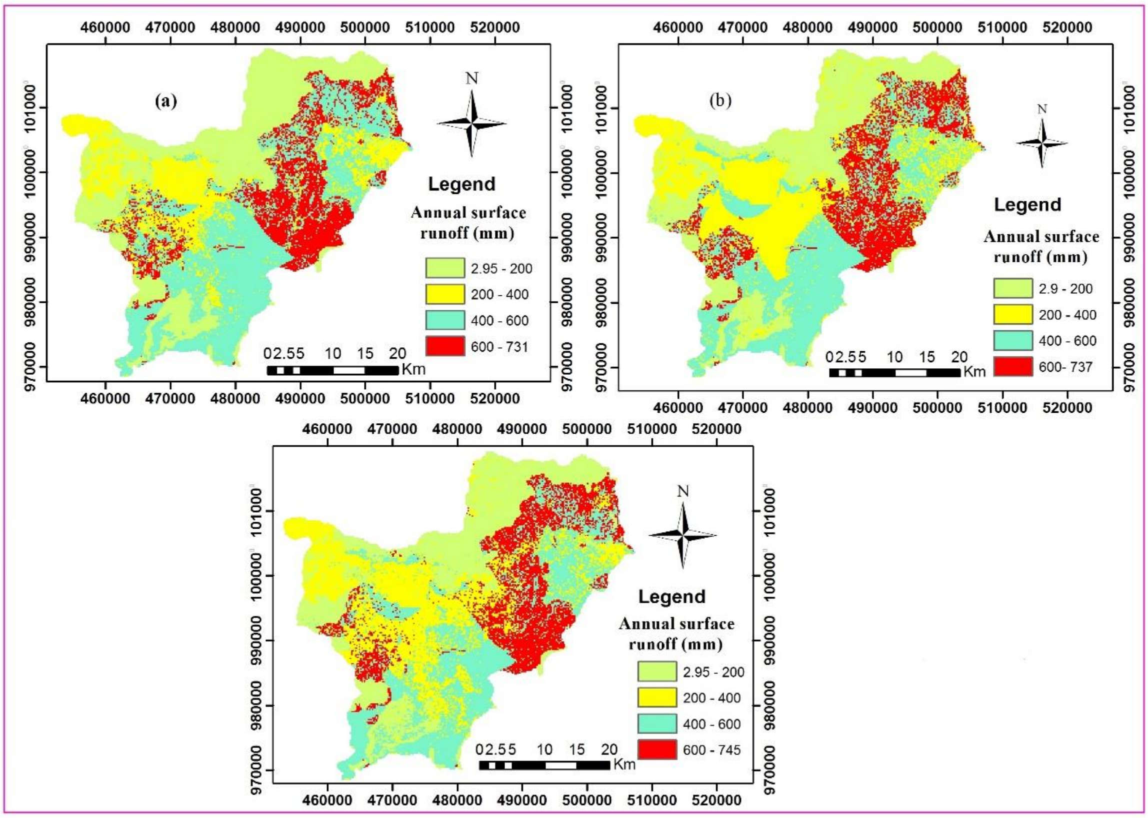

Fig 5.7 Annual surface runoff maps of the years (a) 1986, (b) 2000 and (c) 2015

According to the annually simulated surface runoff of the catchment (Fig 5.7), the south, south-eastern, central and eastern parts of the catchment had the highest rates due to the presence of clay soil and silt loam soil, whose low permeability enhances surface runoff. On the other hand, the northern part of the catchment presents less surface runoff, caused by sandy soil types associated with forest coverage of the area which contributes to reduction of surface runoff. The forest cover on the high lands of Akaki catchment like Entoto ridge and Wechecha mountains have contributions to the reduction of surface runoff of the catchment. It is shown on Fig 5.7 that, urban settlement and cultivated–land use types with clay soil yield the highest amounts of surface runoff in the catchment. This shows that soil types have a greater impact on the annual surface runoff of Akaki catchment compared to land-use and land-cover change, slop and topography.

5.5.3 Groundwater recharge under different land–uses scenarios

The WetSpass model was applied for the three different land–use maps to assess the impact of land–use and land–cover change on water balance of the catchment especially ground water recharge. It estimates seasonal and annual long term spatial distribution amounts of groundwater recharge by subtracting the seasonal and annual surface runoff and evapotranspiration from the seasonal and annual precipitation, respectively. Simulated results of WetSpass modeling for groundwater recharge was summarized for each period as an average map (Fig 5.8). The results indicated that the total annual ground water recharge for Akaki catchment was changed insignificantly from time to time with change in land–use and land–cover (Fig 5.9). The model estimates the simulated total annual ground water recharge of the catchment for land–use and land–cover maps of 1986, 2000 and 2015 to be 9,622,050.3 mm/y, 9,490,260.5 mm/y and 9,315,814.2 mm/y, respectively.

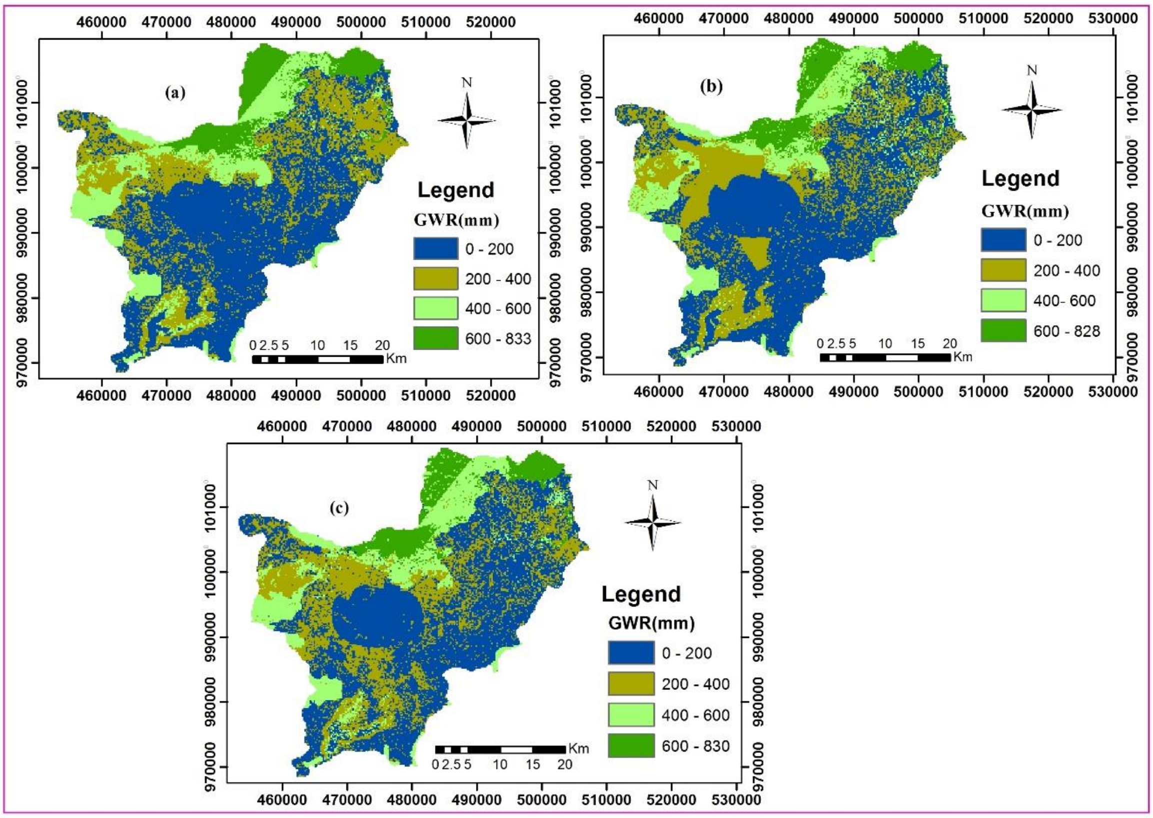

Fig 5.8 Annual ground water recharge maps of the years (a) 1986, (b) 2000 and (c) 2015

Table 5.8 shows the simulation results of WetSpass modeling for ground water recharge under different land–use and land–cover scenarios and season (summer and winter). It also shows both the annual and seasonal ground water recharge of the catchment was slightly decreasing with changing in land–use and land–cover.

Table 5.8 Comparison of surface runoff under different land use and land cover scenarios

Year	Average Annual ground water recharge (mm/y)	Total annual ground water recharge (mm/y)	Average summer ground water recharge (mm)	Average winter ground water recharge (mm)	Annual Std. deviation
1986	268.55	9,622,050.3	248	20.6	205
2000	264.9	9,490,260.5	247	17.9	197
2015	260	9,315,814.2	243	16.9	197

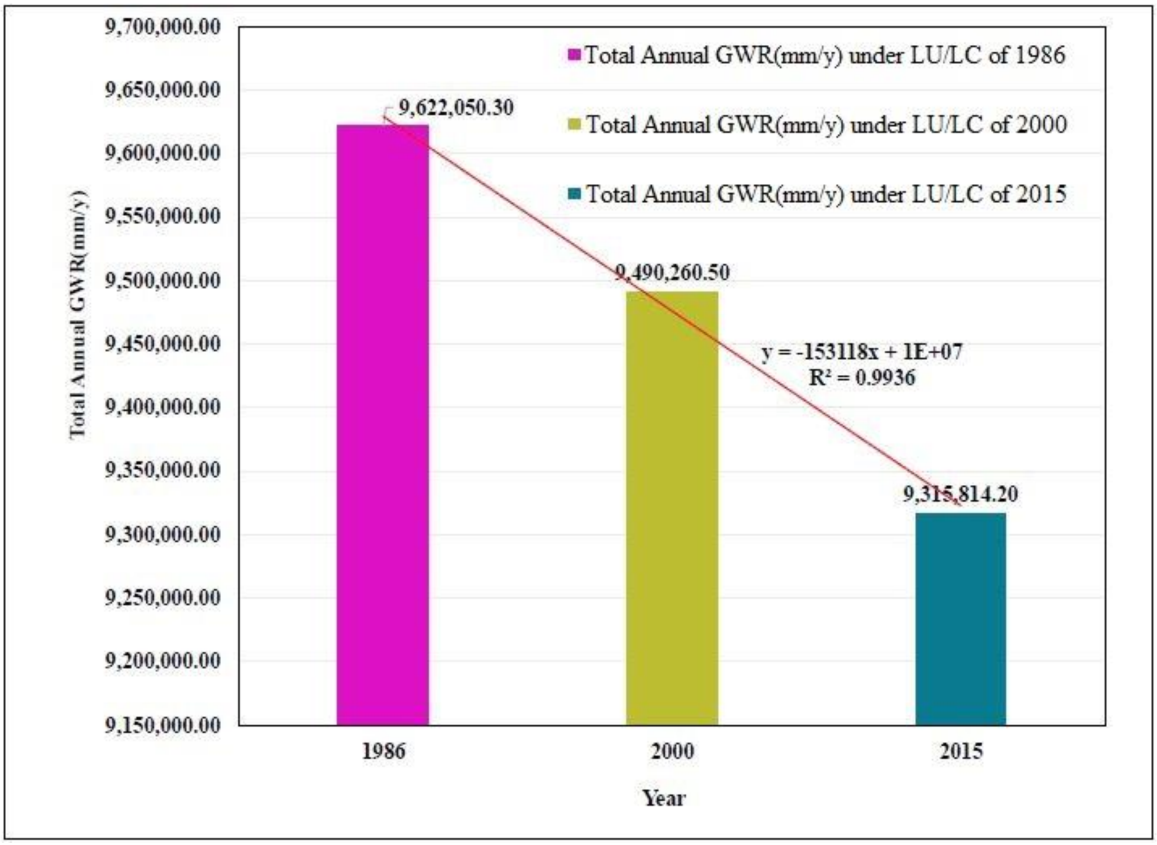

Fig 5.9 Annual ground water recharge *vs* Time

Interpretation of the different groundwater recharge maps with their Statistical calculations corresponding to different land–use conditions is presented below.

Land–use and land–cover map of the year 1986

A simulated map of average yearly groundwater recharge for the land–use and land–cover map of 1986 is presented in Fig. 5.8 (a). The simulated yearly recharge in this period varies from 0 to 832 mm/y, with a mean of 268.6 mm/y and standard deviation of 205 mm/y. The mean value represents 23.5% of the total annual precipitation of the Akaki catchment.

The mean groundwater recharge of the catchment in the summer season is 248 mm, while the mean recharge in winter was approximately 20.6 mm. About 92% of the annual groundwater recharge of the catchment occured during the wet season (summer), and the remaining 8% in the dry season (winter).The higher recharge rate primarily occurred along the highlands of Akaki catchment due to the presence of permeable sandy soils, high precipitation and high forest cover. On the contrary, the lower annual ground water recharge was occurred in the southern, eastern, south eastern and central part of the catchment due to low precipitation, impermeable clay soils and urban coverage.

Land–use and land–cover map of the year 2000

Annual groundwater recharge under land–use and land–cover conditions in 2000 was simulated to quantify differences due to changes in land–use and land–cover from 1986 to 2000. The model was run for the second time keeping all of the input parameters the same as in 1986, except for land–use map; therefore, the results reflect the impact of land–use change on groundwater recharge in the Akaki catchment from 1986 to 2000.The simulated annual groundwater recharge under the land–use condition in the 2000 varied from 0 to 825 mm/y, with a mean of 264.9 mm/y (23% of the annual precipitation) and standard deviation of 197 mm/y (Fig 5.8(b) and Table 5.8). The mean ground water recharge of the catchment for land–use of 2000 in the summer season was 247mm/y while for the winter season was 17.85 mm/y. Groundwater recharge shows the highest values in the catchments with a sandy soil and a high cover of forest in the northern part of the region. For land–use and land–cover map of 2000, the ground water recharge tends to decrease with increasing urban settlement and decreasing of forest cover.

Land–use and land–cover map of the year 2015

Annual groundwater recharge under the land use conditions in 2015 was simulated to quantify differences in ground water recharge due to changes in land use from 2000 to 2015. Simulation results show in 2015, all of the input parameters, except for land–use and land–cover grid maps, were kept the same as in 1986 and 2000. Therefore, the results reflect the impact of land–use change on groundwater recharge in the Akaki catchment for the period of 2015. Fig 5.8(c) shows the average yearly groundwater recharge map for the period 2015. The yearly recharge varies from 0 to 830 mm/y, with mean value of 260 mm/y and standard deviation of 197 mm/y. The mean ground water recharge of the catchment for land–use of 2015 in the summer season is 243 mm/y while for the winter season was 16.9 mm/y. About 93.5% of the annual groundwater recharge of the catchment occurs during the wet season and the remaining 6.5% in dry season.

In general high values of groundwater recharge are observed in the highlands area with high forest cover and sandy soils. This was due to good permeability of these soils, and high amount of precipitation. While the low amount of recharge was observed in the urban settlement areas and in the clay soil covered areas of the southern and south eastern parts of the study area. Forest cover favors recharge by hindering surface runoff while urban settlement favors surface runoff. This is because the incoming precipitation does not get more chance to infiltrate down the soil profile and to reach to the ground water reservoir.

In order to quantify impacts of land–use and land–cover changes on ground water recharge, the WetSpass model was run three times keeping the input parameters constant except for land use and land–cover maps, therefore the results enhances impact of land–use and land–cover changes. Fig 5.10 shows the summery of simulated yearly and seasonal water balance for the year 1986, 2000 and 2015 in the Akaki catchment.

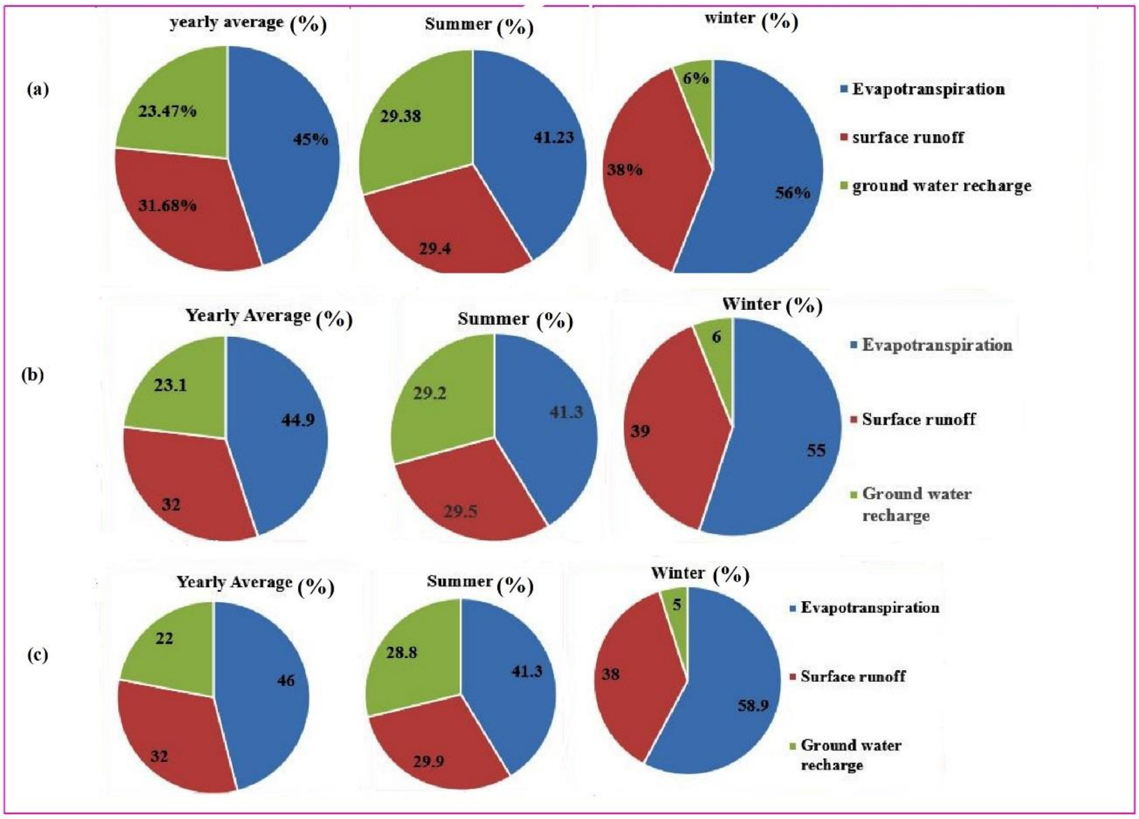

Fig 5.10 Average yearly, summer and winter water balance for the Akaki catchment in the year 1986(a), 2000(b) and 2015

On the average, evapotranspiration is the largest component of the yearly and seasonally water balance. The largest part of the total evapotranspiration occurs during winter when average temperatures are higher than in summer. The simulated result shows the average ground water recharge was decreased from time to time with changing in land–use and land–cover as shown in Table 5.9. Evapotranspiration results of the WetSpass modeling includes transpiration, interception, soil evaporation, and open water evaporation.

Table 5.9 Evapotranspiration, surface runoff and recharge in 1986, 2000 and 2015

Water balance components	1986	2000	2015
Evapotranspiration (mm)	515.02	514.2	528.6
Surface runoff (mm)	362.4	367.2	368.8
Ground water Recharge (mm)	268.6	264.9	260

5.6 Discussion

5.6.1 Impact of land–use change on groundwater recharge

Human activities in the Akaki catchment have increased drastically during the past three decades. Such Changes in land–use and land–cover alter both runoff behavior and the water balance that exists between evaporation, evapotranspiration, ground water inflow and outflow, surface water inflow and outflow in certain water shades under a given period of time, with considerable consequence for all water users (Mishra et al., 2014).
Based on three different periods of remote sensing and the long-term observed hydro-meteorological data from the 1986 to 2015, the impacts of land use changes in the groundwater system in the Akaki catchment were analyzed by estimating of groundwater recharge. Land-use and land-cover changes like urban settlement expansion and change of grass land and forest land in to cultivated land are found to be the major changes in the catchment. From the land–use land–cover classification result maps for the periods of 1986, 2000 and 2015, it has been observed that grass land and forest land have changed negatively during 1986 to 2015 change detection phase by -16196.1ha and -5323.16ha area while urban settlement, cultivated land and water body area have changed positively by 16046.3ha, 5401.6ha and 71.38ha, respectively. Such dramatic change was caused by the uncontrolled expansion of urbanization, industrialization and increase of population. It has been reported that in many parts of the world the water table is declining at the rate of 1–2 m/y as a result of population increase and land–use and land–cover changes particularly urban expansion and deforestation (Singh et. al., 2010).The effects of uncontrolled population growth are obvious such as forest destruction, pressure on land–and other natural resources, unsustainable pattern of land–use for agriculture, degradation of land–and depletion of resources. These environmental consequences in turn lead to other problems. For instance, vegetation destruction increases surface runoff by doing that it affects the ground water recharge. The above change also highly affects infiltration condition of rain water which supply to the ground water by increasing surface runoff due

to the reduction of forest cover which serves one as a barrier for reducing the speed of the runoff and also it reduces evaporation by increasing the humidity of the surrounding environment which have a great influence on the ground water recharge condition of the catchment. Similarly, the urban settlement which changed from 16005.8 ha to 32052.1 ha has high role to increases surface runoff through creating compacted surface that hinder recharge. The distribution of the different land-use and land-cover classes in the catchment can affects the groundwater recharge quantity. Beside the areal coverage and type of land–use classes in the catchment, the distribution and location of these classes can affect the groundwater recharge quantity. This situation was also found in some other studies like Albhaisi et al (2013) that considered land–cover change as a factor for reduction of ground water recharge quantity. For example, despite the increase in urban settlement area and decrease in forest area, the values of groundwater recharge by the period of 2015 have decreased compared with the value of ground water recharge by the year 1986. According to Liu (2006) most of the impacted are on a global scale can be expected from large-scale removal or planting of forests, which may have an impact on potential and actual evapotranspiration and on precipitation patterns and amounts. Similarly, the decrease in groundwater recharge of the catchment in this study is a result of the fast expansion of urban settlement in the areas of high recharge values (the high altitude areas of the central to northern parts) and a decrease of the forest cover in the northern and north western parts of the catchment. This situation was also found in some other studies like Jat et al (2009) that considered urban land to be impervious areas that promote surface runoff and prohibit infiltration. Increment in impervious area due to urbanization results in decreased infiltration, and finally affecting the groundwater storage. Nevertheless the factors governing the surface and subsurface hydrological conditions of a given catchment are not only controlled by the LU/LC dynamics rather many others are evolved. In addition to land–use and land–cover change other environmental changes, such as global and regional climate change, groundwater use, water retention in reservoirs and river management, can have a large impact on the catchment hydrology. The combined effect of land–cover change and other environmental factors and their interactions may be complex and may not have the same impact on the hydrological cycle as either of the factors operating in isolation (de Chazal and Rounsevell, 2009). As shown in Table 5.9, the sum of the simulated results for evapotranspiration, surface runoff and recharge slightly exceeded that of precipitation. This was caused by the high evaporation rate of open water reservoirs, in which the water balance was no longer in steady state.

Recharge is not solely driven by rainfall, but also influenced by other factors such as land–cover, soil type, geological conditions, in addition to terrain landscape and the depth to the water tables (Adla, 2010). The major recharge to the aquifer of Akaki catchment is limited to the summer rainy months of June to September. In the winter season, ground water recharge accounts very less percent. This is because significant amount of the winter rainfall is lost by evapotranspiration. It is evident that, the highest recharges originates from areas with high forest coverage. This explains that, Vegetation is considered an important controlling factor in the recharge process and the interaction between vegetation and recharge is considered critical to the assessment and determination of recharge (Hughes et al., 2008). Some previous works that make effort to estimate ground water recharge are available in the Akaki catchment such as the one published by Molla Demilie (2006), AAWSA (2000) and Derege Nigussa (2003). The model results for this research were continuously verified by the previous model results and independent runoff data. Molla Demilie (2006) estimates ground water recharge of the Akaki catchment by using the chloride mass balance (CMB) method and he was calculated the annual ground water recharge of the catchment to be 265 mm, which amounts to 23% of the weighted mean annual areal precipitation of the catchment. Comparison of this value with the present simulated model result appears to be in a good agreement. On the other hand Derege Nigussa (2003) estimates the average recharge of the catchment by using empirical model known as DRASTIC and GIS. However, this study appears to overestimate the recharge values estimated by AAWSA (2000) and Derege Nigussa (2003). The variation in the estimated values of ground water recharge by different methods indicates the requirements of relatively high quality methods of recharge estimation. Hence for successful estimation of groundwater recharge utilization of a variety of exhaustive and accurate independent methods is mandatory. The present investigation has demonstrated that the estimation of groundwater recharge using WetSpass is in good agreement with those obtained by other studies. Agreement of the WetSpass model result with some research studies indicates the validity of the simulated recharge.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Humans have exerted large–scale changes on the terrestrial biosphere, primarily through the land-use/land-cover changing. However, the impacts of such changes on the hydrologic cycle particularly groundwater recharge are poorly understood**.** Hence, groundwater recharge estimations under different land–use scenarios are essential for the management of groundwater aquifers.

The objective of this study was firstly to use RS imageries to see the changes on LU/LC of the catchment for the past 29 years. Secondly, to map areas of recharge and understand how land management practices could affect recharge through recharge estimation.

The data used in the study involves RS imagery, climate and hydrologic data. The RS data includes a LANDSAT TM image acquired in 1986(bands 4, 3 and 2), a LANDSAT ETM+ image obtained in 2000 (bands 4, 3 and 2) and Landsat 8 Operational Land Imager (OLI) image acquired in 2015(bands 5, 4, and 3). It also includes a 30 m resolution DEM and Topographic maps of (1:50,000). The climate data includes daily precipitation, relative humidity, sunshiny hour, wind speed and daily minimum and maximum temperature data. While the hydrologic information (river flow and surface runoff) data was derived from monitoring stations in the Akaki catchment.

In this study, a geospatial analysis approach based on RS-GIS technology and the seasonal steady-state water balance model, WetSpass, was implemented for the estimation of groundwater recharge in Akaki catchment under different LU/LC scenarios. The methodology used in this research to evaluate land–cover change effect on ground water recharge consists of the following three steps. In the first step land–use and land–cover maps of the Akaki catchment for three different periods 1986, 2000 and 2015 was compiled by a means of supervised classifications methods of Landsat satellite images. The purpose of land–cover classification is to incorporate it as an input to the WetSpass model to obtain a spatial distribution estimate of recharge rates under different land–uses. In the second step long term hydro meteorological and climate data trends was assessed to relate the changes with ground water recharge. Finally a WetSpass modelling was applied to estimate the ground water recharge, surface runoff and evapotranspiration for the three different land–

use maps keeping the other input parameters of the model constant. Hence, the result reflects the effect of LU/LC changes on ground water recharge.

Comparison of classification results suggests that the principal LU/LC changes in the study area between 1986 and 2015 are the urban settlement, grass land, cultivated lands and forest reduction. It indicates that the water body, urban settlement and cultivated land areal coverage from 1986 to 2015 increases form 1552.6ha, 16005.8ha and 71502.9ha to 1624ha, 32052.1ha and 76904.5ha respectively. While forest and grass lands are decreased from 19886.26ha and 37708.3ha to 14563.1ha and 21512.2ha, respectively.

Accuracy assessment is performed using the error matrix and the Kappa coefficients. The results of the Kappa analysis for all LU/LC classification lies on values that show strong correlations as the values are 0.85, 0.89 and 0.915 for land use maps 1986, 2000 and 2015 respectively. The LU/LC map of the year 1986, 2000 and 2015 has been classified with an overall accuracy of 88%, 91% and 93.2%, respectively. In general it is possible to conclude that remotely sensed images are vital in LU/LC change detection as it provides spatial and temporal information of the land-use/land-cover condition of the catchment.

Trend analysis of the meteorological factors which supposed to control ground water recharge shows insignificant effect on ground water recharge since rainfall and temperature does not show clear change. However, studies in the Akaki well field by the Addis Ababa Water and Sewerage Authority (AAWSA), shows that the groundwater level is declining. From this situation it is obvious that there is another factor that reduces ground water recharge that is land–use and land–cover change. Therefore, in this study ground water recharge under different land–use scenarios is estimated using WetSpass modeling and the study results indicated that that ground water recharge in the Akaki catchment did not change significantly. However, the land–use and land–cover in the catchment had remarkable changes in the period between1986 to 2015. Form the assessment of hydro meteorological elements and results of the WetSpass modeling it can be concluded that, most of the Akaki Catchment rivers are changing mainly due to urbanization of the Addis Ababa city however, the change in ground water recharge as a result of change in land–use and land–cover was not significant.

Results from the WetSpass model are in good agreement with some of the recent previous studies and indicates the validity of the simulated recharge. It is hoped that the findings of this research will contribute to developing future land and water resources management strategies to preserve aquifer systems in the catchment.

6.2 Recommendations

Generally from this specific study the following recommendations could improve similar research for future works:

- This thesis can be seen as a starting point to enhance the knowledge about the coupling of land–use/land–cover models and hydrological models. Also the knowledge about the potential impact of land–use and land–cover change on ground water recharge, surface runoff and evapotranspiration can steel be improved by utilizing different methods that fulfill the weak side of this model. Eg. A method that consider recharge from geologic structures.
- In this research when, using the WetSpass model there are a lot of model parameters like soil infiltration capacity and runoff coefficient that were assumed to be constant over space and time. However, in reality this may also change with time. Therefore, it is recommended for future research to be done by measuring value of the parameters in the field.
- Remote sensing data are powerful tools to improve our understanding of hydrologic systems. Various satellite data with different spectral and spatial resolutions coupled with digital image processing techniques help to accurately produce detailed land–use and land–cover maps. ASTER data are highly recommended for future land–use and land–cover map production because of their improved spatial and spectral resolution.
- The model simulation considered only land–use change effect by assuming all other thing constant. But change in climate and soil management activities and other land–use variables will also contribute great impact on both surface and subsurface portion of the hydrologic cycles of the watershed.
- A carful plan on land–use and development activities is required in order to avoid ground water resource disturbance.
- Awareness creation to the environmental decision makers and planners regarding the impact of development scenarios especially urban expansion through forest reduction is important to act to environmental thinking and public concern.
- Only Recharge estimation is not enough to manage ground resources of a catchment. Hence, it is recommended to study the recharge mechanism of the catchment through utilizing independently highly improved methods.

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Appendices

Appendix - 1 Well data used for WetSpass Modeling

name of boreholes	x	y	Z(m)	Depth(m)	SWL(m)	date of construction
Raskasa	475068	1001254	2532	260	106	Jan 14/08
Abo	475945	1000580	2473	252	43	12/21/2007
Dereke bridge	475638	999991	2448	232	23	16/03/08
Hamle-19	474518	1001467	2497	260	39.84	12/28/2007
Entoto kidanmihert	474238	102373	2537	230	67.9	21/03/08
Tsiyon-1	470504	1002135	2639	232	3	6/1/2008
Meketeya	472608	1002066	2551	250	9.61	22/03/08
Egzeabheirab	471026	1002023	2633	222	23	18/02/08
CMCVI	482682	994124	2293	240	38	4/30/2008
SMV6	481681	994296	2290	260	12	
SMV3	482349	995063	2326	210	52	Feb 19/08
SMV10	482109	993423	2278	288	36	4/182008
SMV13	484971	994879	2320	290	15.6	2/12/2008
SMV14	482290	994522	2315	290	12.42	2/27/2008
SMV19	482719	990450	2202	270	7	
SMV21	482497	991485	2320	270	7	2/21/2008
EBV3	480604	992935	2266	260	Flowing	Apr 2008
EBV22	481101	991646	2250	250	25.52	3/12/2008
EBV23	481061	992052	2252	270	28	3/20/2008
EBV24	480760	992453	2261	270	22	3/30/2008
Ankorcha-2	481462	998906	2451	200	72	3/31/2008
Ararat	480321	997370	2399	180	10.52	4/1/2008
Wondirad 2	481434	997787	2413	260	88	4/2/2008
Kara luke	482994	998429	2437	203	44	22/11/07
Legatafo-1	486790	1001357	2455	250	8	4/2/2008
Legatafo-2	487881	997599	2367	200	Flowing	4/2/2008
Legatafo-3	486723	1000881	2418	250	17	4/2/2008
Ankorcha-1	480029	998401	2450	144	20	22/07/07
Mikililand-1	465998	1000153	2434	193	Flowing	23/04/07
Yeka	477715	997474	2388	216	19	07/07/2007
Selam	484190	998500	2480	140	129	May 03/08
Salayish	464527	990017	2278	260	13	May 03/08
Mek1/96	469500	989600	2217	150	4	24/08/96
Mek2/96	470070	991000	2214	170	10	16/02/96
Mek2/97	466308	989421	2230	184	2.6	May-97
Mek1/98	470453	990127	2225	140	22	Apr 2006
Bole lemi 1/97	482790	989806	2209	175	Flowing	Oct 08/05
SiteNo.2	482784	991683	2245	205	14	Jul 10/06
SiteNo.5	484065	989378	2198	182	Flowing	Aug 01/06

SiteNo.7	481151	992112	2247	200	22	Jul 10/06
SiteNo.17	470387	995821	2300	177	4	Aug 13/06
SiteNo.23	465741	989188	2274	135	3	28/04/07
SiteNo.31	465591	989872	2274	257	7	19/03/07
SiteNo.33	463985	991540	2282	185	25	Dec 2006
Ayer tena-1	466050	993650	2360	136	71	
Lafto old	471400	988250	2205	84	9	
Success	466842	993128	2307	250	38	13/07/2008
Repi roll	463850	993100	2400	150	84.71	
Shegole new	469150	1001150	2547	240	Flowing	15/07/2007
Kera 1/96	463800	994650	2460	147	41	
Sansusi-2	465724	1002753	2590	270	52	07/072008
KOLV2	467660	996912	2334	270	12	21/05/2008
KOLV4	468268	996584	2323	252	5	2008
Agusta	468505	995156	2296	250	Flowing	22/05/2008
Keraniyo old	466300	996350	2368	131.5	60	Jan 5/1998
Asko1/95	465500	1002150	2580	176.4	2	Nov 08/2002
Asko1/97	465717	1001230	2524	174	43	15/07/1997
Booster station	478130	982300	2115	260	6	
Akaki -1	477252	982872	2066	260	Flowing	25/07/08
Akaki -2	476692	982390	2068	306	Flowing	
Fanta 1	480847	981623	2152	260	18	Jun 25/08
Fanta 2	481322	981799	2166	240	29	
fanta 3	481828	981943	2181	260	29	20/072008
EP01	479340	981400	2131	108.7	0.73	
EP02	481600	982850	2171	150	33.48	
BH3B	480522	978009	2019	130	63	
BH06	479697	976937	2087	145.53	67.82	
EP06	479226	977124	2018	129	71.7	
EP07	478760	977018	2025	126	64.82	
EP07	477992	978001	2017	130	73.48	
BH19	478019	977482	2070	150	51.5	
BH20	477907	977000	2088	148	50	
BH16	478326	976767	2068	148.56	47.5	
BH07	479405	976735	2019	151	67.26	
BH12	478783	976876	2071	152.4	21.6	
BH08	479040	976387	2087	144.18	67.2	
BH09	479246	977104	2019	146.38	58.7	
BH13	478695	976503	2074	149	51.17	
BH10	479032	976030	2091	130	72	
BH14	478558	976061	2079	130	34.53	
BH02	478357	975506	2072	122	52.5	
BH18	478139	975983	2074	140	21.83	
BH04	477993	975557	2068	132	48	

BH22	477621	975921	2067	142	47.92	
BH25-2	477138	976053	2060	135	42	
BH01	477973	974860	2078	190	58.5	
BH05B	478713	974977	2083	142	49	
BH17	478186	976371	2065	141	45.95	
BH21	477945	976410	2064	151	44.68	
BH23	477477	977217	2064	145	44	
BH24	477330	976793	2019	130	43	
Kaliti	475300	984900	2120	93	Flowing	24/01/1987
BH26	477181	975680	2019	116	51	
BH25	477162	976038	2019	135	42	
F1	479000	981400	2110	120	9	
F3	479700	981700	2115	116	10	
F7	481337	982304	2167	135	20	
TW2 Test well N.2	473576	972821	2007	150	74	
TW3	484475	975622	2004	220	100	
TW4	489950	976019	1976	217	91	
Piezometer 3	475402	976807	2028.6	63	31.4	
Piezometer 4	482950	963800	1792.89	91	67.11	
Piezometer 5	475780	956477	1795.66	132	89.34	
Water wall iii monitoring well 01b	476454	976951	2019	129	42.2	
Water wall iii monitoring well 02	476523	976374	2019	60	35.55	
Water wall iii monitoring well 03	476972	976152	2019	120	40.3	
water wall iii monitoring well 04	477185	975729	2022	114	46.5	
Kotebe dehininet	479316	999941	2643	271	118.36	30/092014

APPENDIX–2 Meteorological data used for WetSPass modeling

Rainfall (mm) at Akaki Beseka Station

Latitude: 502651, Longitude: 993272, Elevation: 2354

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	0	95.4	67.7	148.7	83.2	143.4	189.4	216.5	86.1	9.4	0	0
1987	0	65.6	181.9	81.2	187.7	69.3	202	246.9	82.5	4.4	0	0
1988	0	44.5	0	96	23.8	124.6	255.9	278.1	253.5	35.4	0	0
1989	2.1	63.8	53.8	226.3	7.1	58.6	264.2	301	170.9	37.9	0	0
1990	7.7	120.6	48.4	159.1	37.3	78.9	280.7	222.9	107.3	5.8	1.2	0
1991	0	37.6	62.4	11.6	45.6	90.4	263.7	308.5	113.3	4.4	0	56.5
1992	33.5	24.2	30.5	15.5	25.6	100.4	218.4	276	86.7	43.3	0.2	0
1993	1.2	53.9	5.6	118.4	54.6	116.5	218	251.5	118.3	20.5	0	0
1994	0	0	62.7	72.2	20.2	131.2	219.3	181	94.5	0	11	0
1995	0	25.4	62.7	102.1	20.9	95.7	279	242.3	79.5	0	0	4.8
1996	15.3	0.3	79.7	38.8	90.5	240.1	292.5	234.1	119	1.9	0	0
1997	27.6	0	29.5	102.7	25.2	57	203.6	203.4	82.5	114.9	10.3	0
1998	32.7	30.2	19.6	69.3	159.9	116.9	207.8	280	118.5	36.9	0	0
1999	1.3	1.8	91.8	12.1	45.4	92.8	282.6	300.7	61.7	65	0	0
2000	0.0	0.0	29.1	93.0	64.9	100.1	188.9	210.0	124.1	17.2	23.4	3.8
2001	0.0	20.7	121.2	23.6	118.0	142.6	257.5	145.0	64.9	2.2	0.0	0.0
2002	31.1	10.5	87.8	53.9	76.6	108.0	167.1	166.3	52.3	0.0	0.0	17.7
2003	19.6	24.8	23.9	114.0	1.4	125.4	325.1	307.4	113.4	0.0	0.0	40.8

2004	15.6	15.8	61.4	154.5	15.4	95.2	150.3	189.1	80.9	4.8	3.4	0.7
2005	28.8	7.3	47.9	112.2	140.7	139.9	218.7	231.4	152.7	9.1	15.2	0.0
2006	2.6	44.2	56.3	79.7	22.0	84.3	276.4	262.6	148.1	38.0	0.0	3.2
2007	34.2	24.7	25.6	96.8	64.6	132.7	254.2	221.8	148.5	14.3	1.3	0.0
2008	0.0	0.0	0.6	34.2	62.4	140.2	253.5	252.3	110.0	7.2	64.8	0.0
2009	60.2	0.0	10.0	118.7	47.7	63.5	235.3	322.4	71.3	32.8	4.0	16.8
2010	0.0	63.8	126.2	170.0	95.2	164.8	334.4	169.8	154.1	5.2	14.8	7.8
2011	0.0	2.5	45.2	20.7	128.7	60.0	204.3	304.0	194.5	0.0	4.7	3.9
2012	0.0	0.0	66.1	61.0	101.0	80.6	228.0	243.9	122.9	0.0	0.0	0.0
2013	0.0	0.0	77.0	89.1	73.4	111.5	179.6	242.4	142.5	20.6	0.0	0.2

Rainfall (mm) at Intoto Station

Latitude: 496336, Longitude: 1013384, Elevation: 2964

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	0	35.7	88	197.6	125.4	179.5	180.1	264.2	127.8	36.1	0	
1987	0.5	63.4	248.9	82.4	241.3	92.9	196.5	254.4	115.2	21.3	0.8	
1988	9.7	53.4	5.3	144.6	16.6	106.2	277.9	299.3	135.6	28.9	0	0
1989	4	76	105.4	133.3	5.8	98.2	409.5	323.4	293.9	11.7	0	14.5
1990	0	156.6	42.8	117.9	17.6	100.5	324.5	499.7	180.8	1.5	1.5	0
1991	12.8	64.9	156.2	37.5	39	171.2	258.5	395.2	146.7	1.4	0	44.2
1992	52.7	31.5	14.6	42.7	84.6	131.6	247.8	387	188.4	42.4	0.7	8.1
1993	15.3	44.6	5.7	147.5	49	123.3	266.1	407.6	183.2	28.7	0	0
1994	0	0	62.2	56	91	154.8	336.3	307.2	142.5	0.3	24.4	0
1995	0	96.3	29.7	186.1	83.7	98	297	222.1	133.7	5	0.2	22.7
1996	31.1	12.2	121.6	78.3	95.2	242.7	387.2	493.9	184.7	1.2	0.6	0
1997	21.2	0	18.6	77.3	27.4	77.2	256.3	240.8	89.3	88.3	90	0.2
1998	25.3	25.3	45.2	47	149.5	149.2	369	376.3	204.8	44.5	0	0
1999	15.8	6.3	34.9	25.4	37	127.7	283.1	280.3	105	58	0.2	0
2000	0	0	5.2	108	91.4	110.7	303.8	359.1	132.8	17.2	33.5	1.7
2001	20.6	5.5	147.5	29.8	141.7	164.3	285.6	321.4	92.5	52.4	0	1.8
2002	17.9	50.4	88.8	67.4	49.2	138.7	293.1	262.9	92.1	10.7	0	28
2003	5.2	47.7	57.1	117.3	13.9	188	370.8	248.9	141.1	0	6.3	25.6
2004	28.8	31.3	46.7	124.6	13.8	166	271.9	334.7	124.8	49.7	1.1	1.6
2005	8.3	11.4	42.8	98.6	143.9	106.4	241.8	339.3	134.4	19.6	8.2	0
2006	0.9	19.1	93.8	66.5	79.1	131.5	371.1	311.5	128.7	36.1	0.6	16.5
2007	38.6	16.2	36.4	52.1	106.4	246.7	272.1	322.6	87	16.4	0	0
2008	0	9.3	1.5	74.8	45.3	142.5	399.3	359.5	190.6	50.1	95.1	0.5
2009	10.9	3.3	15.9	40.1	28.2	122.7	301.7	10.9	3.3	15.9		
2010	9.5	73.4	79.4	71.2	107.9	235.2	388.8	288.6	173.2	1.8	0	11.9
2011	0	0	50.3	51.7	180.8	185.5	28.1	4.5	203.7	16	73.5	11.6
2012	0	0	0	79.5	77.1	133.2	363					
2013	12.2	59.8	59.8	128.8	82.1	164.6	364.3	462.2	198.1	64.3	10.7	0.2

Rainfall (mm) at Sendafa station

Latitude: 502651, Longitude: 1011388, Elevation: 2560

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	0	28.1	117.3	193.7	32.3	164.7	270.9	244.5	143.2	0	0	0
1987	0.2	33.1	128.9	80.5	110.1	55.7	223.6	143.6	105.3	8.7	0	0
1988	0	32.9	0.9	132.9	22.1	104.6	451.1	330.2	237.6	5.2	0	0
1989	18	10.1	43.3	112	21.4	46.3	357.5	339.4	139.9	10.2	0.4	0.6
1990	21.5	190.4	35.7	148.4	38.2	87.8	282.7	469.9	-	3.8	2.4	0
1991	15.9	20.5	118.1	0.5	34.5	72.7	216.8	9.4	134.5		0	5.6
1992	10.7	46.5	1	-	-	69.6	253.2	357.9	151.6	55.5	0	0
1993	4.3	105.2	0	-	-		457.2	353.2	153.8	13.7	0	0
1994	0	0	0	64.1	11	130.7	337.7	184.1	122	0	6.4	0
1995	0	11.4	106.2	116.7	42.4	22.5	230.8	388.8	0	0	0	0

1996	69.4	5.6	99.3	-	-	187.2	339.2	338.6	121.4	0	0	0
1997	44.5	0	29.4	60	44.8	149.7	303.8	251.1	84.7	72	34.6	0
1998	0	28.9	23.3	5.8	27	38.2	68.8	359.1	289.7	152	98.9	0
1999	0	1.2	56.3	11.8	5.4	2	144.7	441.6	365.2	79.6	0	0
2000	0	0	35.5	44	87.9	166	352.2	373.4	113.9	5	10	0
2001	0	35.3	154.1	9.2	134.9	149.5	335.5	276.8	27.4	9.8	0	0
2002	21.2	3.4	67.2	20.6	60.9	144.4	246.8	289.1	85.4	0	0	27.4
2003	75.5	0	29.7	122.9	1.7	120.6	304.4	373.4	122.4	0	0	19.7
2004	15.2	7.1	2.2	118.9	0	69.8	315	319	30.6	0	0	0
2005	24.5	22.3	12.3	136.1	150.2	57.7	381.3	282.9	73.3	34.6	0	0
2006	0			77.2	31.1	126.2	455.8	398.7		0	0	0
2007	38		8.2	92.9	24.2	162	288.8	343.4	114.1	0	0	
2008	0	0	0	0	0	87.9	290.3	306.2	175.3	24.7	63.7	
2009												
2010	0	12.5	18	205.3	76.4	106.7	316.2	295.8	65.6	1.5	0	
2011				71.5	136.7	86.8	216.8	328.6				
2012												
2013	7.3	3.4	0	44.7	45.3	274.7	374.6	449	27.5	0	0	5.9

Rainfall (mm) at Addis Ababa Bole station

Latitude: 476590, Longitude: 993272, Elevation: 2354

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	0	37.6	56.2	216.6	37.7	175.2	167.9	222.3	107.4	31.6	0	2.5
1987	0	49.1	180.1	85.7	154.6	71.9	155.9	98.1	57	16.6	0	0.4
1988	4.7	33.4	6.7	157.9	34.7	93.2	181.4	265.3	187.3	57.3	0	0
1989	3.4	33.7	58.4	143.3	0	88.1	218.1	318.6	150	36.8	0	7.9
1990	3.2	161.1	60.4	144.5	25.2	48.3	194.2	293.6	143	46.1	2.1	0
1991	0.2	29.6	134.1	15	7.7	107.5	279.4	287.9	123.1	4.4	2.1	0
1992	14.5	28	35	58.6	55	82.2	254.8	223.3	157	64.4	2.2	0.4
1993	11.7	52.1	11.6	168.3	91.5	157.2	209.5	291.7	190.1	24.1	0	0
1994	0	0	52.9	70	29	112.4	242.3	199.3	99.4	0.5	11	0
1995	0	81.3	73.1	133.3	95.9	77.4	165.5	256.9	97	0	0	29.3
1996	20.5	15.8	134.4	96	124.6	290.2	346.3	312.7	211.4	0.2	0.4	0
1997	29.1	0	22.1	66.8	44.8	128	257	160.7	94.7	58.6	15.3	0
1998	66.6	40	43.8	99.8	197.7	111.6	270.7	236.8	173.4	139.4	0	0
1999	4.4	0	35	17.8	30.5	104.6	294	270.5	62.8	127.1	0	0
2000	0	0	17.6	87.8	95.2	102.1	192.9	221.9	157.5	19.6	7.5	0
2001	0	10.3	174.3	14.8	116.7	166	289.4	207.3	113.3	10.6	0	0
2002	30.6	25.9	79.4	36.6	49.6	115.5	213.9	233.6	72.6	0.5	0	32.8
2003	4.8	34.1	48.9	111.5	18	111	204.3	238.4	130.2	4.6	0	33.3
2004	26.1	11.7	32.4	7	114.5	240.6	230.1	122.1	50	0.6	0	26.1
2005	55.4	14.1	41.8	116.2	164.6	159.1	174.3	248	77.6	25.8	7.2	0
2006	2	36.6	107.8	93.9	37.8	115.1	313.2	331.1	132.5	35.9	0	0
2007	9.9	21.3	61.1	86.8	134	157.6	191.3	305.4	130.9	37.2	0.1	
2008	0	0	0	34	75.3	73.1	295.1	259.1	192.7	22.2	53.1	0
2009	40.9	0	12.4	46.1	52	77.5	238.2	269.5	86.1	42.4	2	79.9
2010	0.4	115.2	75.6	159.5	94.7	107.2	320.2	138.8	105	0	13.8	15.7
2011	3.4	13.6	27.9	86	148	183.1	296.5	141.3	0	11.9	0	3.4
2012	0	0	34.5	75.1	58.5	72.8	228.8	281.6	176.9	1.2	0	
2013	0	0	63.5	114.4	78.5	101.4	157.6	270.2	126.7	45.3	3.2	0

Rainfall (mm) at Addis Ababa observatory station

Latitude: 472710, Longitude: 996727, Elevation: 2408 station

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	0	35.7	88	197.6	125.4	179.5	180.1	264.2	127.8	36.1	0	0
1987	0.5	63.4	248.9	82.4	241.3	92.9	196.5	254.4	115.2	21.3	0.8	0.3
1988	9.7	53.4	5.3	144.6	16.6	106.2	277.9	299.3	229.7	59.9	0	0

1989	0.8	75.9	75.7	154.4	0.5	120.9	357.7	325.3	187.7	14.8	0	7.6
1990	0.8	155.9	59.2	106.4	20	88.8	218.7	268.6	184	16.2	6	0
1991	0	74.5	106.6	34.7	-	-	248.9	262.6	126.4	3.4	0	50
1992	20.2	33.7	20.2	41	52	109.1	248.5	294.7	209.4	69.7	0	2.9
1993	10.8	67.2	16.1	157.9	97.2	208.3	274	426.5	243.3	62.1	0	4.5
1994	0	0	82.4	82.3	63.3	123.4	308.9	225	142	0.5	14.7	0
1995	0	69	41.5	174.4	68.2	102.9	190.2	314.9	136.1	0	0	-
1996	28.1	5.2	106.8	128.2	122	258.5	266.4	338.7	294.2	0.2	0.2	-
1997	39.2	0	24.5	51.3	38.5	104	272.6	194.3	113.8	62.4	50.3	1.5
1998	55.2	20.5	49	48.5	154.2	124.4	285.4	260	213.6	126.9	0	0
1999	2.9	0.3	28.8	16.3	23.8	119.6	-	305.3	88.4	75.4	0	0
2000	0	0	17.6	49.9	110	144.5	244.8	306.2	250.6	46.4	21.1	0
2001	0	12.2	210.8	25	168	216.2	428	246.4	131.7	13.7	0	0
2002	14.7	21	90.2	56.3	63.1	172.5	256.9	215.9	108.8	0.2	0	16.5
2003	10.5	53.3	62.6	99.3	20.2	151.8	291.8	233.3	193.3	0.8	1.5	54.9
2004	24.8	20.3	49.5	139.9	30.1	141.9	238.5	272.6	164	76.9	0	0
2005	45.9	51.6	83.2	160.9	133.7	179.8	246	315.2	162.5	-	4.4	0
2006	0.7	11.2	-	78.9	74.6	150.1	356.3	243.6	239.1	54	0.3	8
2007	51.3	19.1	59.8	73.8	120.1	-	261.8	381.2	147.6	24.8	0	0
2008	0	13	0	49.4	94.3	88.9	277	360.9	256.7	88.2	79.4	22.9
2009	21.3	2.7	28.4	80.6	58.9	82.6	349.9	388.3	112.7	45.8	4.4	65
2010	2.6	79.8	55.5	97.8	74.4	271.1	313.9	205.8	237.8	1.8	25.7	15
2011	14.1	13.1	44.3	22.8	66.1	182	180.9	340.8	146	0	42.3	0
2012	0	0	15.8	-	50.2	69.4	324.2	298	215.5	2.3	0	9.8
2013	4.4	0	-	92.3	85	153.2	-	353.2	-	58.4	22.3	0

Monthly maximum temperature in Addis Ababa observatory station

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	23.9	24.5	23.9	22.5	24.4	21.8	21.4	21.2	21.9	22.8	23.4	23.6
1987	23.4	24.5	23.2	23.5	23.7	22.8	21.9	21	23	24	24.1	24.1
1988	24.2	24.6	27	24.9	25.8	23.2	19.9	20.9	21.1	22	22.5	22.6
1989	23	23	24.5	22.4	24.8	23.5	20.4	21.3	21.1	22.3	22.8	22.3
1990	23.3	22.6	23.6	23.5	25.4	23.5	21.2	20.9	21.2	22.5	23	23.1
1991	24.5	24.4	24.3	25	25.3	25.6	20.5	20.9	22.1	22.9	22.8	22.3
1992	22.4	23.3	25.7	25.5	25.5	23.7	20.7	19.7	21	21.7	22	22.8
1993	23.2	22.7	25.8	23.2	23.6	22.2	20.9	20.9	20.7	22.4	22.8	23.2
1994	24.6	26.2	25.3	24.9	25.6	22.4	20.3	20	21.6	23.4	23.3	23.6
1995	24.7	25.5	25.5	23.5	25.2	24.4	20.4	21	22.1	23.8	24.6	24
1996	23.2	26.7	24.7	24.5	24.3	21.7	20.9	21.3	22	24	23.8	24.1
1997	24.2	25.5	26.5	24.4	26.8	24.6	21.8	22	23.6	23.3	22.6	24.1
1998	24.4	25.7	25.4	26.8	25.4	24.8	21.5	21.4	21.8	22.2	23.1	23.1
1999	24.4	26.6	25.2	27.2	26.2	24.7	21.2	21.5	22.5	21.9	23	23.5
2000	24.9	26.1	27.3	25.7	25.3	23	21.6	20.5	21.5	22.2	23	23.8
2001	24.5	25.9	23.7	25.4	24.5	22.5	21.6	21.2	22.6	23.9	24	24.3
2002	24	26.2	25.1	25.7	26.2	24.2	22.6	21.2	22.3	24.2	24.3	23.5
2003	24.4	26.3	25.3	24.6	26.7	24	21	21	21.6	23.5	23.4	22.8
2004	24.5	24.9	25.7	23.7	26.1	23.1	21.3	21.4	21.8	22.5	23.5	23.7
2005	23.8	26.5	25.8	25.6	24	23.7	21.4	22.1	21.4	23.1	23.3	23.7
2006	24.6	25.6	25.4	24.3	25.1	23.5	21.5	21.2	21.8	23.8	23.8	23.5
2007	24.4	25.2	26.6	24.8	25.8	23.7	21.5	21.1	21.9	23.2	23.6	23.5
2008	24.9	24.9	26.5	25.8	25.1	22.7	21.1	20.8	22	22.8	22	22.6
2009	23.2	24.8	26.6	25.2	25.8	25.5	21.3	21.3	22.9	23	23.9	22.2
2010	23.8	23.8	23.5	24.1	24.1	22.8	20.4	20.9	21.3	23.5	22.5	22.8
2011	23.5	25.3	24.6	26.1	25.3	23.6	21.9	20.9	20.9	23.3	22.7	23.2
2012	24.9	25.7	26.9	24.5	25.9	24.4	21.3	21.4	22.2	23.4	24.6	23.4
2013	24.2	26.5	26.5	25.8	24.8	22.9	21.1	20	22.8	22.4	23.4	24.7

Monthly minimum temperature in Addis Ababa observatory station

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	7	10.5	10.4	11.3	11.7	10.8	10.4	10.3	10	9	8.4	8.4
1987	7.8	10.1	11.9	12.3	12.4	11.9	11.8	11.9	12.5	11	9.3	9.2
1988	10.2	12.5	11.9	12.8	12.5	11.7	12.1	11.7	11.5	10.5	7.8	7.8
1989	7.8	9.9	11.5	11.8	12	11.2	11.3	11.2	11.3	10.2	8.9	10.5
1990	9.1	11.9	11.4	11.9	12.4	10.9	11.4	11.1	11.3	9.5	9.2	7.7
1991	10.4	11.6	12.4	13	13.3	12.3	12	11.9	11.6	9.7	8.3	8.9
1992	10	11.2	12.4	12.4	12.7	11.3	11	11.8	10.9	10.1	8.8	9.2
1993	10	10.8	11	12.2	12.3	11.4	11.3	11.3	11	10.1	8.2	7.5
1994	7.8	9.2	11.9	12.1	12.1	11.2	11.5	11.1	10.6	9.3	8.5	7
1995	7.4	10.4	11.4	12.6	12.3	11.4	11.7	11.8	10.6	10	8.5	9.2
1996	9.9	9.8	11.9	11.5	12.2	11.5	11.4	11.2	10.9	9	8.2	7.8
1997	10.3	7.9	11.7	11.5	11.6	12	11	11.1	11.4	11	10	8.1
1998	10.6	12	12.7	12.8	13.2	12	12.1	12	11.2	10.6	7.7	7.51
1999	8.5	9.6	11.4	12	12.2	11.2	10.9	10.9	10.9	9.5	7.3	7.2
2000	7.4	8.2	10.2	12.1	11.7	10.6	11	11	11.3	12.3	12.1	8.9
2001	8.5	9.2	11.7	11.9	11.8	10.8	11.1	11.6	10.6	10.1	7.8	8.4
2002	8.7	10.2	11.7	12.3	12.9	11.4	11.3	13	14.5	12.8	8.7	10.4
2003	9.7	10.9	11.3	12.4	13.3	11.7	11.7	11.8	11.4	9.3	8.4	7.7
2004	10.3	8.9	10.3	12.2	12.2	11.3	11	11.3	10.9	8.9	7.8	8.1
2005	8.3	9.3	11.8	12.5	12.5	11.4	11.3	11.4	11.3	9.5	7.9	6.3
2006	8.6	10.8	11.5	12.2	11.8	11	10.7	10.8	10.1	10.4	8.4	8.6
2007	8.7	10.3	10.9	11.9	11.9	11.1	11.5	11	10.6	9.6	8.3	6.9
2008	8.8	8.6	10.2	11.9	12.5	11.5	11.3	11.2	11.3	10.5	8.9	8.1
2009	9	10	11.9	12	12.8	12.3	11.6	11.6	11.9	10.5	8.7	10.7
2010	9.6	12.2	12.3	13.3	13.3	12	11.6	12.2	11.7	11.2	9.5	8.9
2011	9.8	9.6	11.4	13.4	13.2	12.2	12	12	11.9	10	10.5	8
2012	8.7	9.4	11	13	13.4	12.4	12	11.8	11.1	10.9	9.6	9
2013	9.6	10.7	12.9	13	13	12.1	11.7	11.5	11.5	11	9.7	7.6

Monthly maximum temperature in Addis Ababa Bole station

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	23.5	24.1	24.1	22.5	23.6	21.9	21.1	20.85	21.6	22.8	23.1	23.1
1987	22.9	24.3	23.2	23.6	23.7	22.7	22.1	21.7	23.1	23.9	22.8	24.3
1988	24.7	23.75	27.3	25.1	25.8	23.4	21	21	21.2	21.9	22.5	22.8
1989	22.7	23.2	24.5	23	24.9	23.6	20.7	21.2	21.55	22.8	23.1	22.8
1990	24	23.2	23.9	23.6	25.3	23.5	21.4	21.4	21.9	23	23.5	23.6
1991	25	24.8	25.6	25.6	25.75	23.05	21.3	21	22	23.1	22.7	22.9
1992	22.5	23.4	25.7	25.8	26.2	22.825	21.1	19.7	21	21.9	22.2	23.1
1993	23.4	23.3	26.4	24	23.8	22.6	20.9	21.1	21.2	22.9	23	23.5
1994	23.8	25.7	25.9	26.1	26.7	23.1	21.2	20.8	22	23.3	23.5	23.5
1995	24.2	25.4	25.1	23.9	25.2	24.5	21	21.5	22.3	23.8	24	23.9
1996	23.6	26.4	25	24.7	24.5	21.1	20.9	21.4	22.1	23.6	23.3	23.1
1997	23.4	25.2	26	24.5	26.9	24.9	21.7	21.9	23.3	23.1	23.05	24.2
1998	24.3	25	25.4	26.6	25.2	24.7	22.3	21.9	21.9	22.2	22.8	23.2
1999	24.7	26.7	25.5	27.6	26.9	24.6	20.5	20.6	22.1	21.9	22.7	22.7
2000	24.1	25.5	27.3	25.7	25.4	23.1	21.5	20.6	21.1	22.5	22.9	23.8
2001	23.5	25.2	24	25.5	24.3	22.5	21.5	21	22.9	24.7	24.2	24.2
2002	24.2	26.2	25.7	26.7	27	24.9	23	21.8	22.4	24.3	24.3	23.8
2003	24.3	26.2	26.3	25.1	26.8	24.5	21.2	20.8	21.9	23.7	23.6	23.9
2004	25.1	26.4	26.35	23.9	26.8	23.95	21.5	21.5	22.2	22.3	23.7	24
2005	24.1	26.6	26.4	25.9	24.1	23.4	21.1	22.1	22.4	23.6	22.9	23
2006	23.8	25	24.5	24.3	25.1	23.1	20.8	20.1	21.6	24.2	23.5	22.8
2007	23.6	24.7	25.9	24.4	25	22.4	20.7	20.2	21	22.4	22.9	22.6
2008	24.1	24.3	26.3	25.9	25.5	22.8	21.2	20.7	21.9	23.4	22.2	22.9
2009	23.2	25.2	26.9	25.9	26.4	26	20.9	20.8	22.6	22.5	23.2	22
2010	23.4	23.7	23.6	25.3	24.1	23.3	20.9	20.9	21.9	24.1	22.9	22.8

2011	23.7	25.4	24.7	25	24.9	23.7	21.8	20.7	21.5	24.2	23.5	22.8
2012	24.5	25.5	26.7	24.7	26.5	24	21.2	20.7	22	23.9	24.4	
2013	**24.5**	**26.3**	**26.3**	**26**	**25.1**	**23.3**	**21.3**	**20.8**	**22.8**	**23.2**	**23.9**	**23.4**

Monthly minimum temperature in Addis Ababa Bole station

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	4.4	9.8	9.3	11.5	10.4	9.7	8	7.6	10.1	3.7	5.2	6.3
1987	6	8.5	11.3	10.3	10.8	10.2	11	11.1	10.4	8.5	5.8	5.4
1988	7.4	10.9	9.4	11.5	10.2	10.4	11.6	11.2	10.4	8.1	3.9	4.5
1989	5.5	8.1	9.8	10.7	9.3	9.8	10.8	10.6	9.9	8.4	5.8	8.4
1990	6.1	10.9	9.9	10.6	9.9	9.8	10.8	10.9	10.5	7.5	6.7	4.7
1991	8.1	9.6	11.2	11	10.2	10.7	11.6	11.2	10.3	7.2	5.2	6.2
1992	8.6	10	10.8	10.7	10.5	9.8	10.5	11.6	9.7	8.1	6.2	7.3
1993	8.3	9.3	8.7	11.4	10.8	10.4	11.1	10.8	10.1	8.3	5.5	4.8
1994	5	7.3	10.6	10.9	10.9	10.9	11.6	11.2	9.6	7	6.7	4.9
1995	5.2	9.5	10.5	12	11.1	10.2	11.4	11.5	10	8.3	6.3	7.8
1996	8.9	7.7	11.1	10.5	11.1	11.3	11.1	11	9.8	7.1	6.3	5.7
1997	9.3	6.1	10.3	11.2	11.1	11.7	11.3	11.5	10.6	10	5.5	6.6
1998	9.8	11.7	12	12.1	12.6	11.2	11.7	12.3	11	9.2	4.7	3.4
1999	6.7	7.3	10.4	10.4	10.5	10.3	10.5	10.4	9.9	9.2	5.4	5.6
2000	6.75	5.8	10.2	12.1	11.1	10.1	11	10.8	10.6	8.9	6.8	8.9
2001	6.8	7.8	10.8	10.9	11.3	10.5	11.1	11.6	9.8	8.6	5.9	6.4
2002	7.7	8.7	10.9	11.4	11.8	10.8	11.2	10.9	10.5	8.9	6.5	9.6
2003	8.5	9.8	10.3	11.8	11.4	10.9	11.5	11.9	11.4	8.2	7.4	6
2004	9.9	8.7	10.3	11.9	11.1	11.2	11.4	11.5	10.9	8.3	7	7.8
2005	8.5	8.6	11.2	11.7	12.1	11	11.5	11.8	11.5	8.7	7.4	5.8
2006	9.1	11	11.2	12.2	11.9	11.8	11.9	11.9	11	10.3	8.7	8.6
2007	9.4	10.7	11	12	12.4	11.8	12.1	11.8	11.8	9.3	7.6	5.6
2008	8	8.4	9.1	12	12.4	11.8	11.4	11.5	11	9.8	7.8	6.8
2009	9	9.7	11.4	11.8	12.4	12.1	12	12	11.5	9.8	7.7	10.1
2010	8.9	11.6	11.7	12.6	13.2	12	11.9	12.5	11.5	10.1	8.4	8.1
2011	9.3	9	11	12.35	12.8	12.3	12	12.3	11.9	9.3	10.5	7.3
2012	8	8.5	10.7	12.1	12.7	12.3	12.1	11.9	11.7	9.9	9.5	8.1
2013	9.3	10.4	13	13.2	12.8	12.1	11.9	12	11.4	10.5	9.8	7.9

Monthly maximum Temperature of Akaki

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996												25.4
1997	25.8	26.3	28.1	26.3	28.6	27.1	24.2	24.3	25.9	25	24.8	25.7
1998	25.8	27.3	27.4	29	27.6	26.6	24.1	23	24.4	25	25.3	24.9
1999	25.9	27.2	26.5	28.3	28	26.4	23.4	23.6	25.1	24.6	25	25.3
2000	26.2	27.1	28.5	27.3	27.1	26.1	24.6	23.8	24.7	25.2	25.7	25.8
2001	26.3	27.3	26.2	27.7	26.9	25.6	24.6	24.7	25.8	26.9	26.5	26.4
2002	26.0	27.6	27.5	27.9	28.5	26.9	25.8	24.7	26.1	27.0	26.5	26.2
2003	26.7	28.3	28.0	27.3	28.9	27.1	23.7	23.6	24.9	26.6	26.6	25.6
2004	27.4	27.5	27.8	26.5	28.6	26.3	24.7	24.3	25.7	25.9	26.6	26.7
2005	27.1	29.0	28.2	27.8	26.8	26.3	23.7	24.5	24.6	26.2	26.3	26.1
2006	26.5	27.9	27.9	27.3	28.6	26.0	24.3	23.8	24.9	26.4	25.8	25.6
2007	26.3	27.4	28.8	27.5	28.2	25.5	23.9	23.4	24.7	26.0	25.8	25.8
2008	27.2	27.0	29.3	29.0	29.0	25.6	24.0	23.3	24.9	26.4	25.2	26.2
2009	26.5	28.0	28.0	28.5	30.0	29.3	24.5	24.4	26.0	25.9	25.5	26.2
2010	27.0	27.2	26.9	27.5	27.2	26.8	23.4	23.7	24.7	26.7	26.0	26.2
2011	26.6	28.1	27.6	29.5	28.7	27.0	25.3	24.0	25.2	26.6	26.2	25.7
2012	26.8	26.9	28.0	27.8	29.7	27.4	24.1	24.0	25.1	26.7	26.9	26.5
2013	27.0	28.7	29.1	28.9	28.2	26.7	24.5	23.6	25.9	26.0	26.1	25.1

Monthly minimum Temperature of Akaki

1997	15	14.5	15.9	16.8	16.6	15.5	14.8	14.9	15	14.5	14.8	11.5
1998	13.9	14.4	15.9	16.1	15.8	14.9	14.9	14.5	14.5	14.3	11.3	9.4
1999	10.5	10.5	13.8	14.5	15.1	14.3	13.7	13.3	14.3	13.3	10.8	9.4

2000	9.3	10.0	12.9	15.0	15.7	13.9	14.0	14.2	14.2	13.4	11.8	10.4
2001	10.1	11.5	13.4	15.3	15.5	14.0	13.9	14.7	13.6	13.1	14.4	15.2
2002	15.4	16.4	14.3	14.6	15.8	14.8	14.5	14.2	13.8	13.8	12.7	13.9
2003	11.8	13.2	14.2	15.1	15.0	15.1	14.2	14.1	15.0	14.9	14.9	12.8
2004	14.6	14.2	14.6	15.9	16.2	15.6	14.7	14.6	14.9	14.6	14.2	14.5
2005	13.6	15.2	16.5	16.2	16.1	15.4	15.8	15.5	15.6	16.0	14.6	13.6
2006	15.3	15.4	15.5	16.0	16.3	15.3	15.1	15.3	15.4	15.6	15.0	14.8
2007	15.0	15.1	15.6	16.2	16.5	15.3	16.6	16.7	17.3	17.4	17.1	16.5
2008	17.8	18.0	16.0	16.2	17.7	16.5	14.4	14.3	15.6	16.0	14.2	14.0
2009	14.3	16.1	17.0	17.2	17.9	18.2	15.3	15.7	16.3	15.7	11.0	10.7
2010	13.6	14.6	15.3	16.3	16.5	14.2	13.2	13.2	12.7	9.4	7.8	7.4
2011	9.3	8.5	9.9	12.4	13.2	13.0	12.6	13.0	12.8	8.2	18.1	5.4
2012	6.7	6.8	9.2	10.5	10.8	11.9	12.5	12.3	11.7	8.8	7.5	3.4
2013	4.1	5.0	8.5	8.7	8.3	8.1	8.8	8.4	7.2	7.7	8.8	6.7

Monthly Maximum Temperature of Intoto

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	-	-	-	-	-	-	-	--	-	-	-	-
1987	-	-	--	-	-	-	-	-	-	-	-	-
1988	-	-	-	-	-	-	-	-	15.7	17	18.1	18.1
1989	18.4	18.2	19.3	17.2	19.8	17.4	15.6	16.6	17.5	18.1	19.3	
1990	19.7	18.6	19.5	19.6	20.9	18.6	16.8	16.2	17.3		18.8	19.3
1991	19.9	19.5	19.3	19.9	20.5	19.1	15.9	16.3	17.3	19	19	18.9
1992	19.2	19.1	20.2	19.4	19.2		15.5	14.5	15.8	16.9	16.9	17.9
1993	17.8	17.8	20.5	17.5	18	16.6	15.5	15.2	15.2	17.1	17.8	18.3
1994	19.2	20.3	19.5	19.7	20.1	17.1	15.5	15.4	16.3	18.2	17.9	18.4
1995	19.4	19.5	19.7	17.8	19.3	18.8	15.5	15.7	16.5	18.4	19	18.5
1996	17.6	20.8	19.2	18.9	18.5	16.2	16	15.3	16.2	17.8	17.7	18
1997	18.2	19.8	20.6	18.8	20.7	18.8	16	16.4	17.7	17.9	17.2	18.8
1998	19.1	20.1	20.1	21.1	19.5	18.6	15.9	15.9	16.4	16.9	18.1	18.2
1999	18.9	21	19.8	20.9	20.4	18.8	15.7	15.9	16.5	16.3	17.7	18.3
2000	19.1	20.2	21.2	19.7	19.6	17.7	16.5	15.8	16.1	17.6	18	19.2
2001	19.5	21.3	18.4	20.3	19.6	17.1	16.6	16.8	18.2	18.7	19.4	19.8
2002	19.2	21.1	19.8	20.8	21.4	19.2	17.7	16.5	17.7	19.5	20.4	19
2003	19.9	21.7	20.8	20	22	19	16	16.6	16.7	19.4	19.9	19.5
2004	20.3	20.6	21.6	19.3	21.5	18.2	16.6	16.7	17.4	17.9	20	20.3
2005	20.2	23	21.9	21.7	19.1	18.7	16	17.3	17.8	19.6	20.2	20.5
2006	21.1	21.9	20.8	19.3	20.2	18.2	16.3	16.5	17.2	19.4	20.3	20
2007	21.1	21.3	22.5	20.4	20.8	18.2	16.2	16.2	16.8	19.2	20.3	20.4
2008	16.4	19	17.9	17.4	16.2	15.4	14.4	14.5	15.2	16.5	15.5	15.7
2009	15.5	17.3	17.3	16.2	19.6	18.7	15.1					
2010	16.8	16.9	17.3	17.2	17.6	16.1	14.3	14.2	15	17.8	17.4	17.1
2011	18.2	19.1	19	20.3	18.9	17.4	16.2	14.8	16.5	18.8	16.8	16
2012	19	20.6	21.3	17.9	18.2	17.6	14.7	14.3	14			
2013	18.8	20.4	20.3	19.3	19.1	17.6	15	13.5	13.8	16.1	18.2	19

Monthly Minimum Temperature of Intoto

1986	-	-	-	-	-	-	-	-	-	-	-	-
1987	-	-	-	-	-	-	-	-	-	-	-	-
1988	-	-	-	-	-	-	-	-	-	-	7.2	7.3
1989	6.6	7.9	9.1	8.6	9.8	8.5	8	7.8	8.6	7.6	7.5	
1990	7.2	9	8.8	9.5	10.2	8.6	7.9	8.1	8.5		8.4	7.3
1991	8.7	8.8	9	10	10.1	9.4	8.7	8.4	8.6	8.2	7.3	7.7
1992	7.4	7.8	7.8	7.6	9.8		8.2	7.6	5.9	5.6	5.6	6.1
1993	6.5	5.3	4.4	4.1	4.3	3.7	2.3	2.4	2.5	4.1	4.1	6.2
1994	8.4	8.5	9.5	9.9	10.3	8.8	8.8	8.7	9	8.4	7.8	7.4
1995	8.2	9.2	9.5	9.7	10.3	10.1	8.7	8.9	9.1	8.5	8.2	8.2
1996	8	9	9.2	9.8	10	8.8	8.1	8.5	8.9	8.3	7.9	7.7
1997	8.6	7.9	10	9.5	9.9	9.6	8.7	8.6	9.5	9.1	8.5	7.8

1998	9.2	10	10.7	11	11	9.8	8.9	8.9	9.1	8.9	8	7.4
1999	7.9	9.6	9.2	9.7	10.2	9.1	7.5	8.2	8.9	8.6	7.1	7.2
2000	8.1	8.7	9.1	9.2	9.8	8.8	8.1	8.2	8.9	8.3	7.8	7.6
2001	7.5	8.6	8.8	9.8	9.8	8.5	8.1	9	9.2	8.7	7.4	7.8
2002	7.6	9.4	9.4	9.5	10.3	9	8.7	8.4	9	8.8	8.1	8.6
2003	8.3	9.5	9.7	9.9	11.2	9.1	8.6	9	9	8.7	7.8	7.3
2004	9	8.3	8.9	9.6	10.4	9.2	8.3	8.8	8.8	8.1	7.7	7.7
2005	7.9	9.4	9.7	9.8	9.4	9	8.9	8.9	8.9	8.1	7.3	7.2
2006	8	9.1	9.1	9.5	10.1	8.7	9	8.7	9	8.6	8.1	7.5
2007	7.7	8.9	9.6	9.9	10	8.8	8.6	8.2	8.9	7.9	7.3	6.8
2008	7.8	7.6	9	9.3	9.7	8.9	8.1	8.3	9	8.3	7.3	6.8
2009	8	8.4	9.5	9.3	10.2	9.6	8.3					
2010	8	9	9.3	9.1	9.5	9.1	8.4	8.8	8.9	8.6	8	7.4
2011	7.8	8.2	9	9.8	10.1	9.5	8.1	8.5	9.1	8.3	8.6	8.5
2012	8.9	8.1	9.6	8.8	10.1	9.7	7.9	8.2	8.6			
2013	8.7	10	9.9	10	10.1	8.8	6.9	7.1	9.6	9.1	8	8.6

APPENDIX-3 Monthly flow data of Akaki river (mcm) at Akaki station

Latitude 8:53 0N Longitude 39:49 E Altitude 2050

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	3.2	3.2	5.7	8.3	4.09	8.92	28.67	70.7	41.09	11.68	4.908	1.77
1987	1.9	2.17	6.97	11.03	10.38	8.23	25.19	33.61	8.928	2.548	2.661	2.82
1988	3.9	3.60	2.89	5.127	3.084	4.36	25.29	80.66	61.58	9.321	5.944	3.61
1989	2.6	3.0	2.72	7.12	4.443	6.28	47.99	150.1	60.52	6.291	3.86	4.37
1990	3.8	8.5	8.95	16.85	5.055	6.19	39.75	173.2	55.63	11.93	4.322	4.15
1991	3.8	4.2	5.14	4.164	3.029	9.52	56.8	148.2	112.3	11.52	8.4	9.01
1992	7.1	8.04	4.93	5.369	5.797	6.48	36.75	108.6	84.95	10.69	5.326	5.73
1993	4.8	6.18	4.00	14.11	10.51	22.4	95.25	251.2	280.2	61.71	36.89	35.6
1994	34.	29.3	34.8	34.66	36.56	42.2	103.0	144.2	92.13	24.8	21.70	21.6
1995	21.	23.9	23.2	29.85	25.19	25.4	57.95	199.4	66.82	22.53	19.72	20.4
1996	20.7	17.6	22.7	22.77	27.59	77.4	250.3	543.1	174.2	61.31	49.72	49.0
1997	48.9	39.9	43.9	41.04	38.51	45.2	103.2	167.7	62.46	37.79	33.16	31.1
1998	33.5	30.0	32.3	32.39	51.25	45.9	169.8	390.2	203.3	78.65	43.55	42.4
1999	42.9	36.3	42.6	38.93	40.72	53.9	181.2	440.5	31.8	14.13	12.54	8.82
2000	7.09	4.4	5.93	10.93	10.91	10.2	34.92	190.4	34.31	10.31	6.094	4.91
2001	4.6	3.9	7.79	5.747	8.974	16.3	168.4	215.7	41.83	6.199	4.846	4.81
2002	5.19	4.1	5.64	6.568	4.881	8.8	47.27	58.22	22.09	4.381	3.716	4.25
2003	3.85	3.9	3.94	6.161	4.146	6.93	57.36	213.9	63.23	12.25	9.148	9.71
2004	9.00	7.82	8.8	12.38	8.195	11.3	51.95	156.0	99.46	13.62	9.315	9.79

Appendix-4 Ground Control points (GCP) used for Accuracy Assessment of LU/LC Classification

X	Y	Land use type	X	Y	Land use type	X	Y	Land use type
470597.39	998241.99	Urban	454095	1007648.67	grass	465023.81	969747.87	grass
472519.95	992210.82	Urban	454147.31	1008037.65	grass	465469.41	970040.64	grass
476453.63	995605.65	Urban	456550.45	1006650.55	grass	467889.8	971510.54	grass
468305.17	998830.97	Urban	457114.37	1007414.19	grass	460677.61	971415.34	grass
472447.59	1004048.53	Forest	457238.44	1008117.52	grass	488745.4	1002402.1	grass
474801.37	1000835.71	Forest	456985.02	1008403.17	grass	485150.01	1006836.48	grass

477347.01	1000495.41	Forest	459140.18	1001536.53	grass	481065.71	992443.61	grass
484396.22	997991.16	Forest	459378.32	1001931.41	grass	481975.57	989473.9	cultivated
475481.45	1006534.03	Forest	458557.54	1001037.98	grass	484699.43	990862.4	cultivated
472755.5	1004289.42	Forest	457285.06	1000148.75	grass	485401.48	991435.18	cultivated
466473.72	1000377.53	Forest	465023.81	969747.87	grass	487440.47	994000.39	cultivated
463380.3	997617.37	Forest	465469.41	970040.64	grass	488889.52	995700.98	cultivated
462235.7	991016.75	Forest	467889.8	971510.54	grass	488792.06	1000660.58	cultivated
464474.57	983260.11	Forest	460677.61	971415.34	grass	488624.47	1003771.02	cultivated
467817.44	975946.74	Water	488745.4	1002402.1	grass	486929.96	1005183.57	cultivated
459395.2	1002453.63	Water	485150.01	1006836.48	grass	484861.73	1004543.55	cultivated
467447.85	974217.83	Water	481065.71	992443.61	grass	470433.77	987549.49	cultivated
469419.3	972588.31	urban	481975.57	989473.9	cultivated	470994.19	984758.16	cultivated
471410.23	972895.01	cultivated	484699.43	990862.4	cultivated	473182.93	982958.97	cultivated
487403.33	1004432.7	cultivated	485401.48	991435.18	cultivated	482417.03	977502.02	Forest
477400.65	1005965.63	forest	487440.47	994000.39	cultivated	461415.41	993433.67	Forest
474173.13	1003494.65	Forest	488889.52	995700.98	cultivated	457256.78	1002618.26	Forest
456312.72	1006898.44	grass	488792.06	1000660.58	cultivated	462243.2	1005557.26	Forest
453984.39	1007143.7	cultivated	488624.47	1003771.02	cultivated	482675.69	998655.81	Urban
457537.22	997447.24	cultivated	486929.96	1005183.57	cultivated	485764.97	996646.85	Urban
483977.39	1017321.51	cultivated	454095	1007648.67	grass	475027.48	990216.56	Urban
483122.34	1008680.72	Forest	454147.31	1008037.65	grass	471742.38	989462.29	Urban
486938.41	1005058.73	cultivated	456550.45	1006650.55	grass	465023.81	969747.87	grass
1005058.73	1001412.96	urban	457114.37	1007414.19	grass	465469.41	970040.64	grass
477147.43	996888.75	urban	457238.44	1008117.52	grass	467889.8	971510.54	grass
474180.92	979427.39	cultivated	456985.02	1008403.17	grass	460677.61	971415.34	grass
482317.92	990942.07	cultivated	459140.18	1001536.53	grass	488745.4	1002402.1	grass
485489.66	1019008.21	Forest	459378.32	1001931.41	grass	485150.01	1006836.48	grass
455812.2	1007477.06	grass	458557.54	1001037.98	grass	481065.71	992443.61	grass
455628.79	1006052.44	grass	457285.06	1000148.75	grass	481975.57	989473.9	cultivated

484699.43	990862.4	cultivated	475027.48	990216.56	Urban	460502.36	1001953.44	Water
485401.48	991435.18	cultivated	471742.38	989462.29	Urban	459808.58	1002936.64	Water
487440.47	994000.39	cultivated	477027.89	979715.42	Urban	467204.69	971443.37	Water
488889.52	995700.98	cultivated	467309.9	995716.09	Urban	468156.18	976660.24	Water
488792.06	1000660.58	cultivated	467799.32	1000308.3	Urban	468678.57	975421.38	Water
488624.47	1003771.02	cultivated	464623.4	1002620.5	Urban	472147.63	975085.87	Water
486929.96	1005183.57	cultivated	469662.34	1002102.39	Urban	474357.32	976736.97	Water
484861.73	1004543.55	cultivated	468124.63	998817.15	Urban	497113.29	1002828.04	Water
470433.77	987549.49	cultivated	470831.64	1002413.01	Urban	496035.82	1002400.77	Water
470994.19	984758.16	cultivated	471803.76	471803.76	Urban	497647.14	1001515.64	Water
473182.93	982958.97	cultivated	465273.27	994437.01	Urban	492748.58	1012810.35	Water
482417.03	977502.02	Forest	482770.58	1009218.89	Forest	492859.93	1011358.7	Water
461415.41	993433.67	Forest	477520.84	1000413.96	Forest	492427.97	1011455.43	Water
457256.78	1002618.26	Forest	460052.14	1004701.11	Water	471113.05	998039.74	Urban
462243.2	1005557.26	Forest	459932.6	1004038.4	Water	472958.71	998539.82	Urban
482675.69	998655.81	Urban	458865.19	1002586.23	Water	496500.39	1002715.87	grass
485764.97	996646.85	Urban	458749.12	1001849.59	Water			

DECLARATION

I hereby declare that the thesis entitled "**GEO-SPATIAL APPROACH FOR ASSESSING THE IMPACT OF LAND-USE/LAND-COVER CHANGE ON GROUNDWATER RECHARGE: A CASE STUDY OF AKAKI CATCHMENT, CENTRAL ETHIOPIA**" has been carried out by me under the supervision of Dr. K.V. Suryabahagavan and Dr. Dessie Nedaw, School of Earth sciences, Addis Ababa University during the year 2015 as part of Master of Science Program in Remote sensing and GIS. I further declare that this work has not been submitted to any other University or institution for the award of any degree or diploma and all sources of materials used for the thesis have duly acknowledged.

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Mearg Belay (Candidate) Date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge and it has been submitted for examination with my approval as a university advisor.

………………………………… …………………….

Dr. K.V. Suryabahagavan Date

……………………………. ………………………

Dr. Dessie Nedaw Date

Place and date of submission: School of Graduate Studies, Addis Ababa University

June 2015