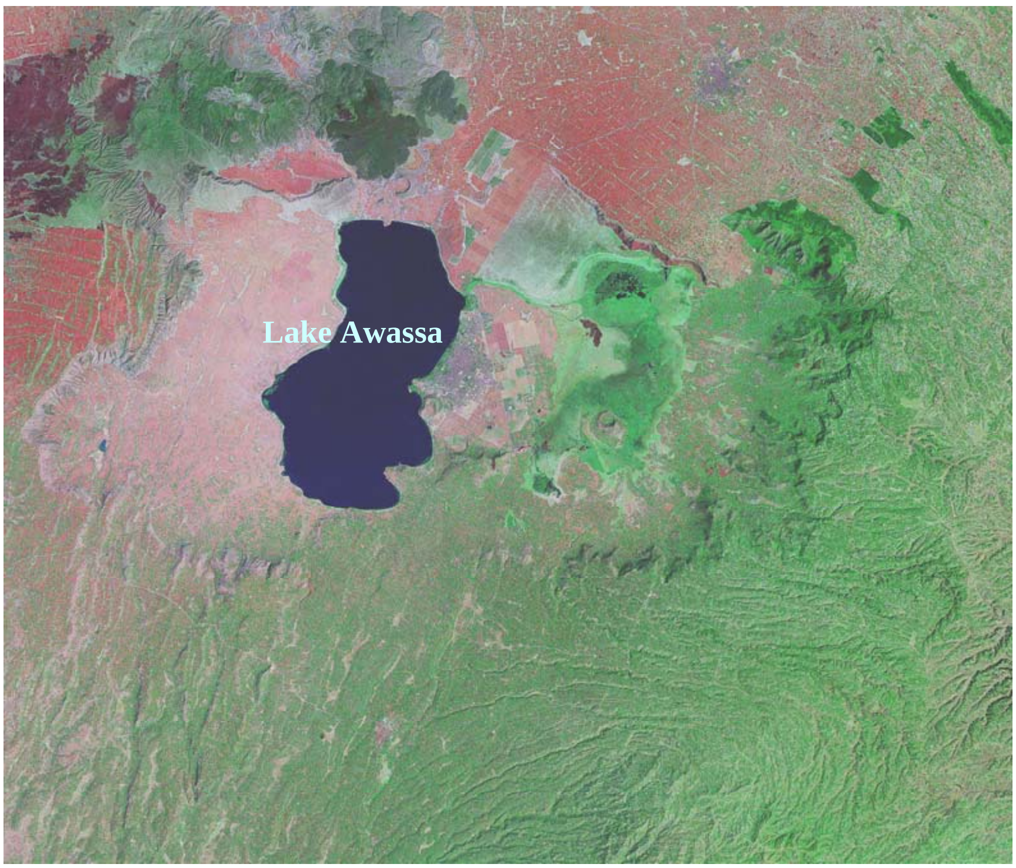
ASSESSING THE IMPACT OF LAND USE AND LAND COVER CHANGE ON GROUNDWATER RECHARGE USING RS AND GIS; A CASE OF AWASSA CATCHEMENT, SOUTHERN ETHIOPIA



A thesis submitted in partial fulfillment of the requirements for the Degree of Master of Science in Remote Sensing and Geographical Information Systems (GIS) Addis Ababa University; Ethiopia

BY: Lemlem Abraha

March, 2007

ADDIS ABABA UNIVERSITY

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Advisor: Dr. Dagnachew Legesse

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LISTS OF ABBREVIATIONS

EMR = Electromagnetic radiation

GIS = Geographic information system

ITCZ =Inter Tropical Convergence Zone

LC = Land cover

LU =Land use

FAO = Food and agriculture organization

MOWR = Ministry of Water Resources

NMSA: National Meteorological Service Agency

PET = Potential evapotranspiration

RF = Rainfall

RH = Relative humidity

RS =Remote sensing

W.W.C.S.E= Water works construction supervision enterprise

W.W.D.S.E: Water work design service enterprise

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ABSTRACT

Humans have exerted large-scale changes on the terrestrial biosphere, primarily through agriculture; however, the impacts of such changes on the hydrologic regime are poorly understood. The purpose of this study was to show the impacts of LU/LC change (vegetation cover reduction) on the subsurface portion of the hydrologic cycle by changing groundwater recharge. The hypothesis was examined through studies investigating the effects of land use/land cover (LU/LC) changes on groundwater recharge in the lake Awassa watershed. Vegetation cover has been changing negatively from 1973-1986 by 168.7 km^2area and from 1986-2000 by 108.1 km^2 area, and agricultural area has been changed positively from 1973-1986 by 143 km^2 and from 1986-2000 by 100 km^2. Similarly 6 km^2 built up area of 1973 has grown to 8 km^2 and 13 km^2 in 1986 and 2000 respectively that aggravate surface runoff by creating compacted surface which hinder infiltration.

The trend analysis of the ground water recharge and LU/LC change (especially vegetation cover reduction) showed similar trend. The significant change in ground water recharge is due to land use and land covers change (especially vegetation cover reduction) in the catchment for the last three decades, which bring change in the runoff generation and recharge reduction. It is possible to conclude that the LU/LC change specially the vegetation cover reduction have great influence to the recharge reduction than that of meteorological elements. If condition goes like this there will be a significant ground water scarcity in the near future; and this needs an immediate action to reinstate the normal situation, in this regard it is highly recommended to protect the remaining patchs of vegetations in the area and apply both physical and biological conservation measure to reclaim the degraded areas.

Keywords: *GIS, Remote sensing, Awassa, land use land cover change, surface runoff, and Ground Water Recharge*

1. Introduction

1.1 Background

Humans have exerted large-scale changes on the terrestrial biosphere, primarily through agriculture and the land use /land cover changing; however, the impacts of such changes on the hydrologic cycle are poorly understood. The hydrological cycle; is the continuous process that describes the circulation and storage of water in the Earth (Maidment, 1993a) is influenced by many factors from the local to the global scales. Land cover change, associated with the intensification of agriculture, cattle rising and urbanization, has had a profound influence on the hydrological processes in small watersheds and at the regional level (Sahagian, 2000). The hydrological cycle regulates the natural variability of physical processes that impact the ecosystem (Elkaduwa and Sakthivadivel, 1998). Information on the hydrologic budgets of watersheds is useful in many environmental and public-use settings where this information is useful include urban planning and water supply, wildlife management, and environmental cleanup and remediation. From all components of the hydrological cycles ground water is Earth's largest freshwater and is highly useful and abundant resource (Sahagian, 2000). But in many countries like Ethiopia it is in a pre-development state. Hence knowledge of ground-water recharge is fundamental to understand the availability and quality of ground water. Ground-water recharge includes recharge as a natural part of the hydrologic cycle and human-induced recharge either directly through spreading basins or injection wells or as a consequence of human activities such as irrigation and waste disposal (Sahagian, 2000). but In this report, recharge is defined as precipitation that infiltrates the land surface, moves downward through the unsaturated zone, and enters the water table and this research focus only on recharge occurred due to precipitation. The balance between ground-water recharge and discharge controls ground-water levels and storage in a manner analogous to how deposits and withdrawals control savings in a bank account. Thus, recharge is an important component of the "ground-water savings account'' (Siamak et al., 2004).

All process related with ground water as one component of water cycle are affected by several factors like climate and Land use Land cover change; The combination of climate and land-use change may have profound effects on ground water in more significant ways than either acting alone. While land-use change is often a driver of environmental and climatic changes, a changing climate can, in turn, affect land use and land cover. The interaction between land use land cover and hydrological cycle should be well understood. Providing a scientific understanding of the process of land-use change, the impacts of different land-use decisions, and the ways that decisions are affected the hydrological cycle and increasing variability are priority areas for research. The major intention of this research is to analyze the effect of vegetation cover change of the catchemnt in particular and the Land use land cover change in general on ground water recharge.

The study area, Lake Awassa Catchment, is part of the Main Ethiopian Rift containing Lake Awassa. The Awassa catchment has been confronted with several land use land cover dynamics in the pervious decades (Yemane, 2004) and this can have a significant impact on the hydrological condition of the cathcment as several studies indicate that deforestation affects recharge on both the quantity and quality of groundwater. Reduced reliability of ground water supplies in the area with projected Land use/ land cover change in the next decades would result increased reliance on groundwater and eventually the ground water will be in danger. In the catchment widespread changes in LU/LC have occurred because of agricultural expansion and this can cause variations in recharge associated with LU/LC changes that would have a negative impact on groundwater recharge (Yemane, 2004).

Understanding impacts of land use/land cover change on the hydrologic condition in this area is needed for optimal management of natural resources in the area. Impacts of LU/LC change on subsurface components of the hydrologic cycle are less well recognized, particularly groundwater recharge. Hence quantifying accurate LU/LC change within a watershed is an important component of monitoring watershed quality. Therefore to estimate and understand the impact of land use/land cover 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 (Siamak et al., 2004).

1.2 Problem statement and justification

Before some decades, Awassa catchement was on of the undisturbed watershed by anthropogenic activities but now a days it is has been facing anthropogenic LU/LC change which intern have great impact on the hydrological condition but less recognized. As evidence, it is possible to take the flooding problem of Awassa town due to the level rise of Lake Awassa since 1998, which cause great economic damage (WWDSE, 1999). Therefore, the need for a scientific research is unquestionable so as to contribute in outlining the relationship of LU/LC and hydrological condition of the area. Specifically this research is initiated to understand and estimate the effect of LULC (Vegetation cover reduction) on the ground water recharge, which helps finally for a better use, and management of the natural resources. The development of a historic dataset, in which to base current and future changes, may then be used to estimate projected rates of LU/LC change and trend of ground water recharge in relation to the LU/LC of the watershed. And the out come of the research assumed also to contribute a lot to the use of the water resource and management of the watershed as well as input for further studies. Overall, the purpose of this study is to test the hypothesis that the conversion of natural vegetation to agricultural or other land uses and/or covers impacts the subsurface portion of the hydrologic cycle by changing groundwater recharge.

1.3 Objectives

General objective:

- ❖ The purpose of this study is to investigate the effects of vegetation cover change on groundwater recharge over the past 29 years

Specific objectives:

- ❖ To asses the trend of vegetation cover in particular and Land use Land cover change of the catchement in general
- ❖ To have a quantitative assessment of groundwater recharge at different period
- ❖ To analyze the relation of groundwater recharge with catchment factors (Climatic, land use/land cover and etc.)
- ❖ To forward some recommendations with respect to environmental protection

1.4 Previous works

As previous works are important for the Accomplishment of the study, the area has been a major interest for many researchers. Different issues related to geology, hydrogeology, engineering, environmental, land degradation, etc are conducted in the area. These have characteristics of more regional or general. Therefore, the present study will comprise detail works on the interaction of LU/LC change (Vegetation cover) and hydrologic cycle specially ground water recharge and lake level rise.

1.5 Research questions

1-How is the trend of land use land cover changes from 1973 to 2000 in the study catchment?

2-How the land use land cover change affects the hydrologic regime?

2. Theoretical back ground and Literature Review

2.1 Concepts of Land use and Land cover and their dynamics

2.1.1 Definitions of Land use and Land cover

Land cover refers to the vegetation (natural and planted), water, bare rock, sand and similar surface and also man-made construction occur on the earth's surface. While Land use refers to a series of operations on land, carried out by humans, with the intention to obtain products and/or benefit through using land resources including soil resources and vegetation resources which is part of land cover (DeBie et al. 1996). 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.

2.1.2 Mapping and change detection of land use and land cover

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. Over the past two decades, data from Earth sensing satellites have become important in mapping the Earth's features and infrastructure, managing natural resources and studying environmental change (Brandon and Bottomley 1998).

Land use and land cover change has become a central component in current strategies for managing natural resources and monitoring environmental change. Since the late 1960's (Brandon and Bottomley 1998), the rapid development of the concept of vegetation mapping has lead to increased studies of land use and land cover change worldwide. Since the beginning of domestication of crops about 10,000 years ago, the human population has increased from approximately 5 million to a full 6 billion people. 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, 1997a). 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.

2.2 RS and GIS techniques in LU/LC mapping and change Detection studies

2.2.1 Overview of Remote Sensing and GIS

Planners and resource managers need a reliable mechanism to asses 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. Remote sensing refers the technique of obtaining information about an object or feature through the analysis of data acquired by a device that is not in contact with the object or feature under investigation (Lillesand, 1994).

Remote sensing has helped in the development of various environmental management methodologies, providing the following advantages when compared to conventional ground based methods (Roy, 2005):
Synoptic view: Remote sensing facilitates the study of various features of earth's surface and the spatial relationship between features, · Accessibility: Remote sensing makes it possible to gather information about areas that are not accessible for ground surveys, like mountainous areas or foreign lands and Time: Since information about a large area can be gathered quickly, these techniques save time and effort.

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), provide a basis for model building.

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 (Wilkie and Finn 1996).

2.2.2 General principles of remote sensing

The sensors on remote sensing platforms usually record electromagnetic radiation. Electromagnetic radiation (EMR) is energy transmitted through space in the form of electric and magnetic waves. Remote sensors are made up of detectors that record specific wavelengths of the electromagnetic spectrum. The electromagnetic spectrum is the range of electromagnetic radiation extending from cosmic waves to radio waves.

The measured and recorded energy is converted and stored as a digital number (DN) value, which ranges from 0-255. Each pixel (picture element or unit area or ground cell) has a single DN value. Most sensors measure reflected sunlight however; some sensors detect energy emitted by the earth itself or provide their own source of energy (active remote sensing) (Ahmed, 2001). The figure below indicates the range of different waves of Electromagnetic Spectrum.

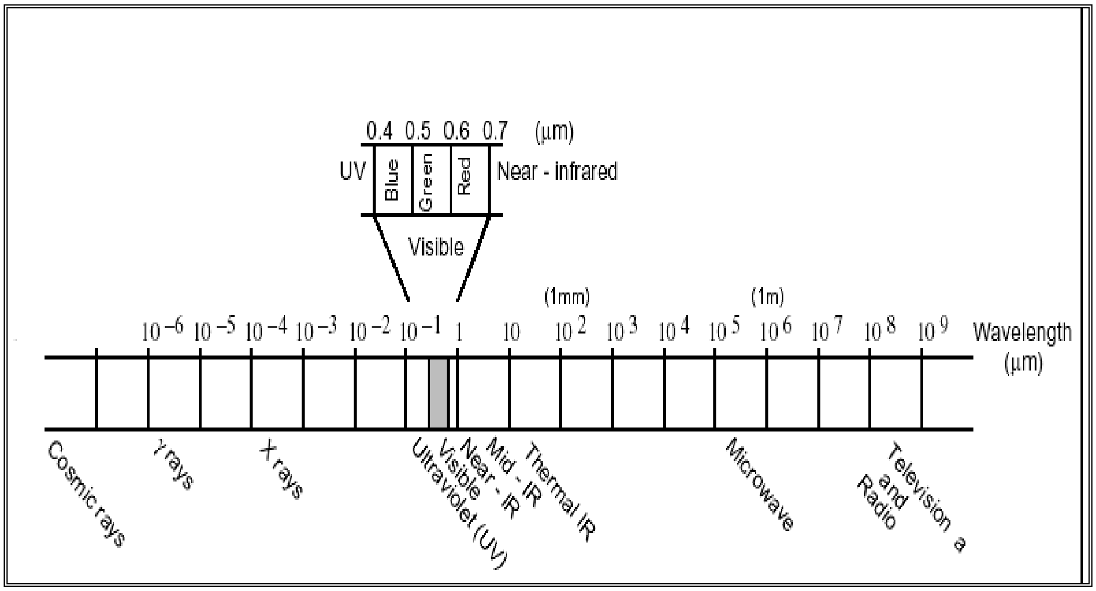


Figure 2.1 The rage of electromagnetic spectrum

2.2.3 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 fields mentioned above, demands 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. The most popular satellite is the landsat, which operated since early 1970s till 2003. This long period of operation makes landsat very important for environmental systems analysis. All types of satellites vary with their sensors, flight height, bands, and spatial resolution, spectral resolution etc.

A) Bands of the Landsat MSS Instrument & Their Application

Figure 6 shows the spectral bands of Landsat MSS and the principal application of these bands is summarized on Table 2.

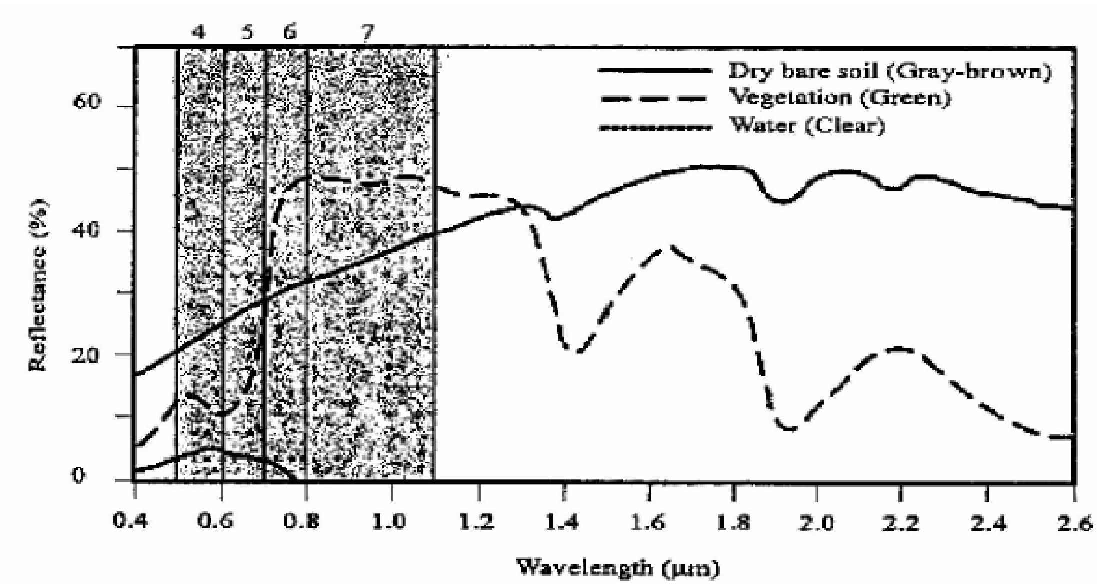


Fig.2.2 Spectral bands of Landsat MSS

Table 2.1 Application of the spectrsl bands of Landsat MSS

Band	Band name	Application
0.60-0.70	Red	This band scans the region between the blue and red chlorophyll absorption bands. It corresponds to the green reflectance of health vegetation, and it is also useful for mapping water bodies.
0.76-0.90	NIR	This is the red chlorophyll absorption band of healthy green vegetation and represents one of the most important bands for vegetation represents one of the most important bands for vegetation discrimination. It is also useful for discrimination of soil boundary and geological boundary delineation and cultural features.
0.70-0.80		This band is essentially responsive to the amount of vegetation biomass present in a scene. It is useful for crop identification and emphasizes soil/crop and land water contrasts.
0.80-1.10	MIR	This band is useful for vegetation survey and for penetrating haze.

B) Bands of the Landsat TM Instrument & Their Application

Fig.2.3 Shows the spectral bands of Landsat MSS and the principal application of these bands are summarized on Table 3.

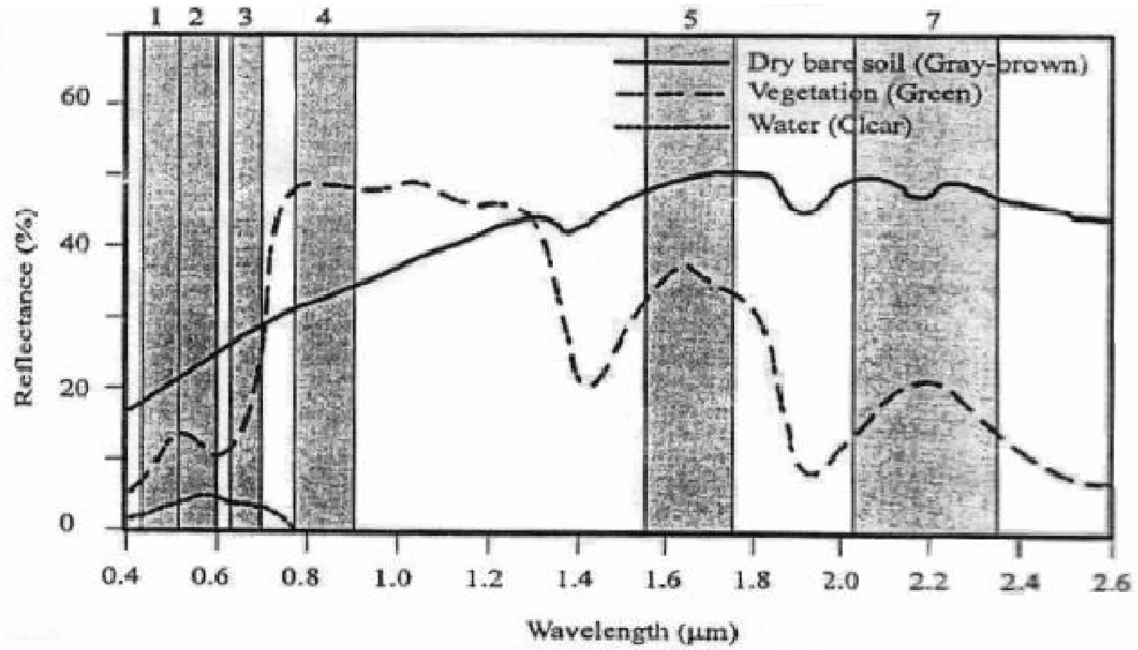


Fig.2.3 Spectral bands of Landsat TM

Table 2.2 Application of the spectral bands of Landsat TM and ETM

Band	Band name	Application
0.45-0.56	Blue	-Soil and vegetation discrimination -Bathymetry and coastal mapping -Cultural/ urban features
0.52-0.66	Green	-Green vegetation mapping and cultural/urban features
0.63-0.69	Red	-Vegetated and non vegetated mapping -Cultural/urban features
0.76-0.90	NIR	-Delineation of water body -Soil moisture discrimination
1.55-1.75	MIR	-Vegetation moisture discrimination -Soil moisture discrimination -Differentiation of snow and ice
10.4-12.5	TIR	-Vegetation and soil moisture analysis -Thermal mapping
2.08-2.35	NIR	-Discrimination of minerals and rocks -Vegetation moisture analysis

2.2.4 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 restoration, image transformation, image enhancement, and image classification (Lillesand et al., 2000)

A) Pre-processing

Raw satellite image is full of errors and will not be directly utilized for features identification and any applications It needs some correction. Pre-processing is done before the main data analysis and extraction of information. Pre-processing involves two major processes: geometric correction and radiometric correction or haze correction. Remote sensing imageries are inherently subjected to geometric distortions. These distortions may be due to the perspective of the sensor optics, the motion of the scanning system, the motion of the platform (the platform altitude, attitude and velocity), the terrain relief, or the curvature and rotation of the earth (Lillesand, 2000). Pre-processing aims to correct distorted data in order to create more faithful representation of the original scene, this typically involves the initial processing of raw image data to correct for geometric distortions, to calibrate the data radiometrically, and to eliminate noise present in the data.

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 colour composite (FCC), Spatial re-sampling, etc.*

C) Image transformation: It 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

Image classification is an operation to replace visual analysis of the image data with quantitative techniques for automating the identification of features in a scene. This normally involves the analysis of multispectral image data and the application of statistically based decision rules for determining the land cover identity of each pixel in an image. When these decision rules are based solely on the spectral radiances observed in the data, we refer to the classification process as spectral pattern recognition. In contrast, the decision rules may be based on the geometric shapes, sizes, and patterns present in the image data. These procedures fall into the domain of spatial pattern recognition. In either case, the intent of the classification process is to categorize all pixels in a digital image into one of several land cover classes, or themes. These categorized data may then be used to produce thematic maps of the land cover present in an image and/or produce summary statistics on the areas covered by each land cover type. Therefore remote sensing is important in LULC mapping and change detection as it provides spatial and temporal information of a feature and GIS is used to analyze and present the attributed and spatial data together in GIS data base that helps the user to update and retrieve the data at any time.

2.3 Groundwater Recharge

Ground water recharge is the process by which external water is added to the zone of saturation of an aquifer either directly in to the formation or indirectly by way of another formation. Recharge can be broadly defined as water that reaches an aquifer crossing the water table from any direction, which contributes an addition to the ground water reservoir (Lerner, 1997). There are three principal mechanisms of recharge defined by (Lerner et al., 1990) as:

- Direct recharge (Diffuse): water added to the ground water reservoir in excess of soil moisture deficits and evaporation by direct vertical percolation from precipitation or irrigation.
- Indirect recharge: recharge to the water table through the beds of surface watercourses, such as beneath rivers and lakes.
- Localized recharge: an intermediate form of ground water recharge resulting from the horizontal, near surface concentration of water in the absence of well defined channels such as small depressions, joints and rivulets.

The above mechanisms usually do not occur individually rather in combination which makes the assessment complex. On the other hand, the recharge and discharge conditions of an area is controlled by several factors such as; climate, topography, drainage, geologic frame work, soil condition, land use/land cover and vegetation etc. For instance in semi-arid areas where potential evapotranspiration exceeds average precipitation, the ground water recharge depends on high rainfall events. Besides, this process is also controlled by soil infiltration capacity, hydraulic nature of sub surface material, the presence of surfacial fractures, joints and depressions so as to escape evapotranspiration, etc.

2.4 Interaction Of Land Use And Land Cover Change And Hydrology

To understand how LULC affects and interacts with global earth systems, information is needed on what changes occur, where and when they occur, the rates at which they occur, and the social and physical forces that drive those changes. Human impact on global land cover change, especially in terms of change from forest cover to other land cover, has been one of the important issues on global change research. In the primitive times when there was little human population and low level of economic activity, deforestation was not a problem because the natural regeneration of forest was adequate to cover for any loss of forest by the human beings. However, with the advent of modern civilization and industrialization and the increase in population, the forest loss to meet the ever-growing needs of the human population became so huge that it posed a problem for the global environment. The concept of different aspects of an effect of land use change on hydrology at local, regional and global scale is discussed in detail by (Maidment 1993a). Vegetation has a significant impact on infiltration both by providing canopy and litter cover to protect the soil surface from raindrop impacts and by producing organic matter, which binds soil particles and increases its porosity. Higher porosity increases infiltration and percolation rates and the water-holding capacity of the soil. Infiltration rates are positively related to litter and grass basal cover, being up to 9 times faster with 100% litter cover than for bare soil (Maidment 1993a). Therefore deforestation increases surface runoff and reduces recharge by affecting the above condition especially if the area is steeply sloped and recharge zone.

2.5 Contributions Of GIS And RS To Hydrology

During the last several decades, the application of computers for the planning and operation of water resource systems has rapidly become an important field of research. Recently, geographic information systems (GIS) have gained much attention in many research fields, where in the output can be displayed at a high quality and are easily understood (Meyer et al. 1993; Schultz 1996). GIS is designed to analyze data referenced to spatial or geographic coordinates and the corresponding non-spatial data (Burrough, 1986). Its main objective is to support and assist in making decisions for the management and conservation of natural resources (Valenzuela, 1991). In hydrology, GIS assists in hydro-meteorological (quantitative) and thematic data analysis (rock, landform, soil and land cover) (Meijerink *et al*., 1994). Thus, map data can be coupled to numerical data and handled in relational databases. Also GIS can offer spatial data management and analysis tools to assist experienced users in organizing, storing, editing, analyzing, and displaying local and attribute information about geographic data. However, GIS is seldom the environment into which water system analysis methods are directly implemented (Djokic and Maidment 1993). This is especially unfortunate in the field of water resources planning and management, where mathematical models are important tools to provide insight into water resources problems. Obviously, model applications could benefit from the spatial analysis and display capability of GIS (Maidment 1999a). Most of the advances in the use of RS in hydrology have arisen when trying to answer questions in areas where existing hydrological methods were not satisfactory, and where the data necessary for the analysis were scarce or nonexistent (Rahman et al, 2006). RS is transitional from a descriptive tool to a quantitative technology that provides spatial information (Meijerink *et al*., 1994). The integration of RS and hydrology allows for the estimation of variables needed to compute a water balance (such as precipitation, surface temperature, evapo-transpiration, soil moisture and land use land cover) from the transformation of digital data in the visible, infrared and thermal bands. These data are usually obtained from very low-resolution satellite sources (3 ´ 3 or 5 ´ 5 km per pixel, GOES and Meteosat); low-resolution satellite sources (1 km2, AVHRR); and high-resolution satellite sources (from 20 ´ 20 to 120 ´ 120 m, SPOT and Land-sat, respectively).

The main advantage of RS is its ability to provide spatially distributed data instead of point data. It has also the potential to provide measurements of hydrological variables usually not available through traditional techniques (such as soil moisture); in addition, RS may provide a significant amount of long-term data in inaccessible regions.

3. Materials and Methods

3.1 Description of study area

3.1.1 Location and accessibility

The study area is located with in the geographical co-ordinates of $6^{0}45^{'}$ to $7^{0}15$'north and $38^{0}15^{'}$ to $38^{0}45^{'}$ east latitude and longitude (UTM: 419485-470099E and 752392-799477N) respectively. It is found 275km south of Addis Ababa. The study area can be accessed through an asphalt road connecting Addis Ababa to Moyale, which is a town on the way to Kenya. The catchment can be accessed in different direction using quite a lot of weathered roads. The total area of the catchment is about 1376km^2, where the lake takes 100km^2 and the rest 1276m^2 of the catchment is occupied by surface land (Nardos, 2006).

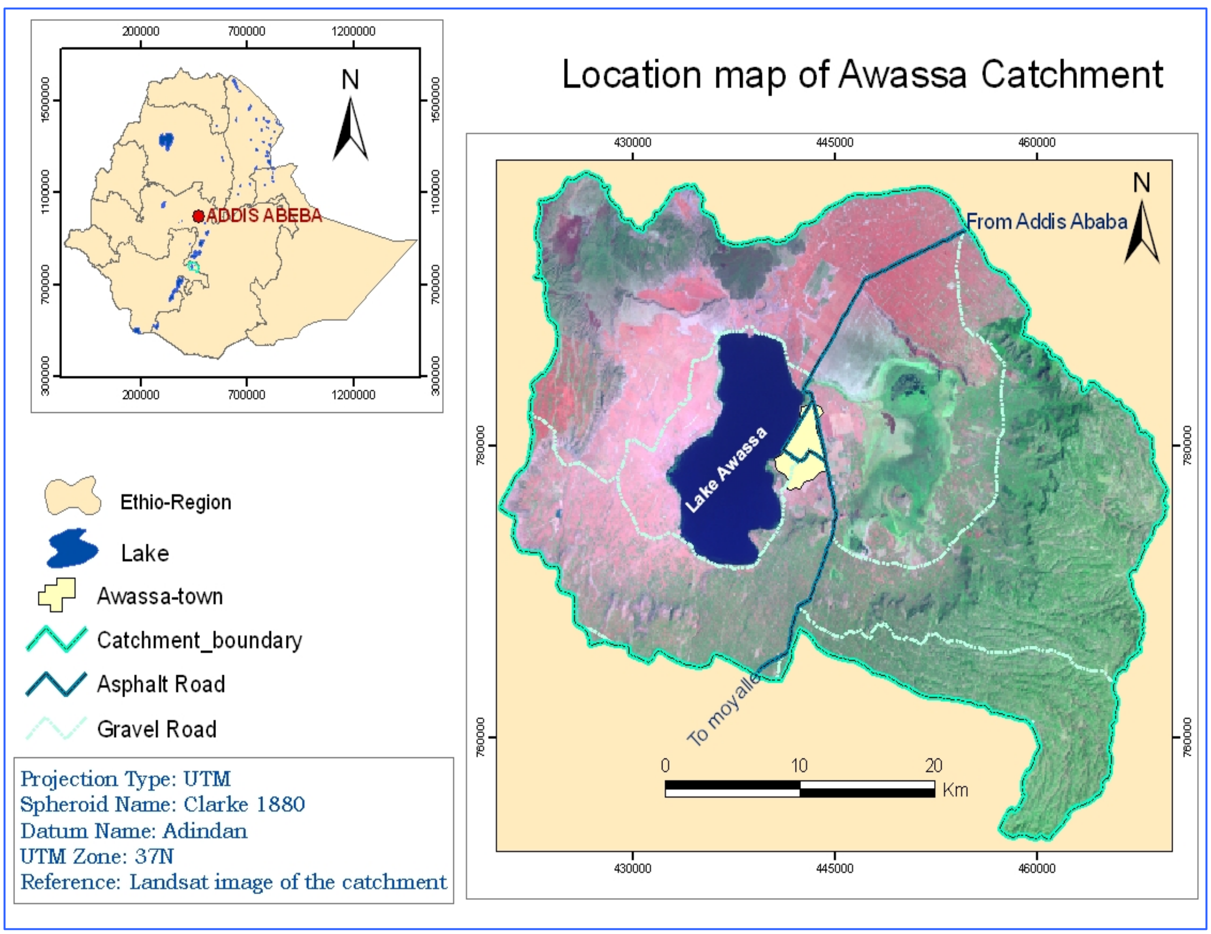


Fig.3.1 Location map of the study area

3.1.2 Physiography and Drainage of the study area

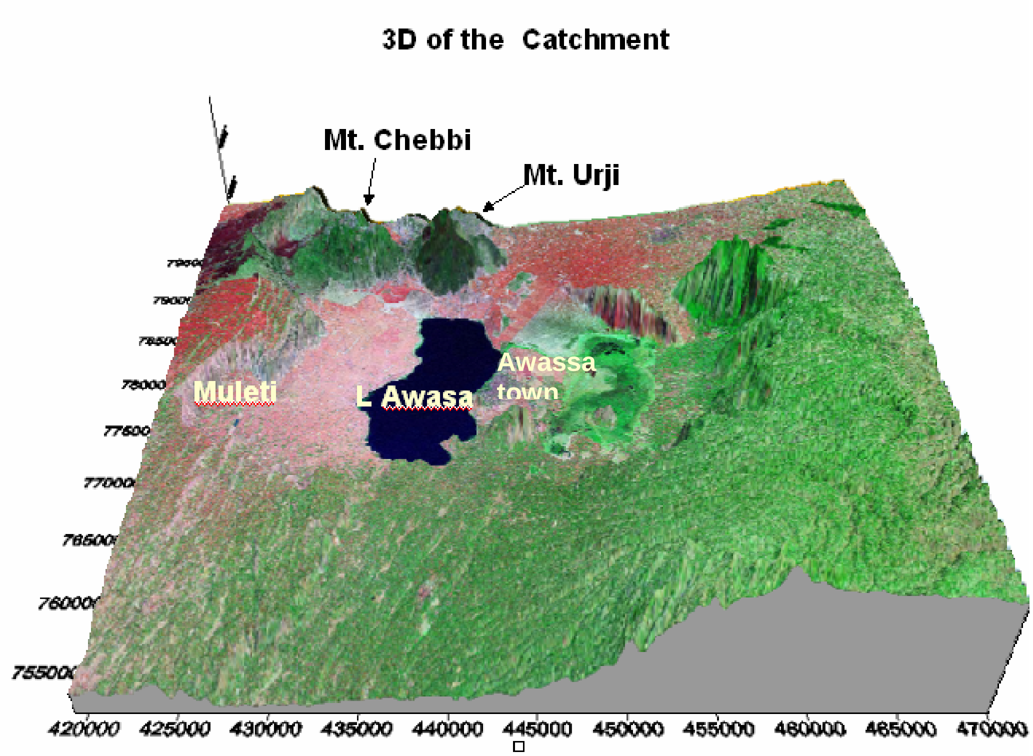


Fig. 3.2 3D view of the Awassa catchment

The figure above depicts the topographic nature of the study area. I.e. the catchment is mainly characterized by a flat-lying topography with scattered small hills. The elevation of the rift escarpments and ridges in the east and west ranges from 2000 to the maximum of 2940 m.a.m.s.l.

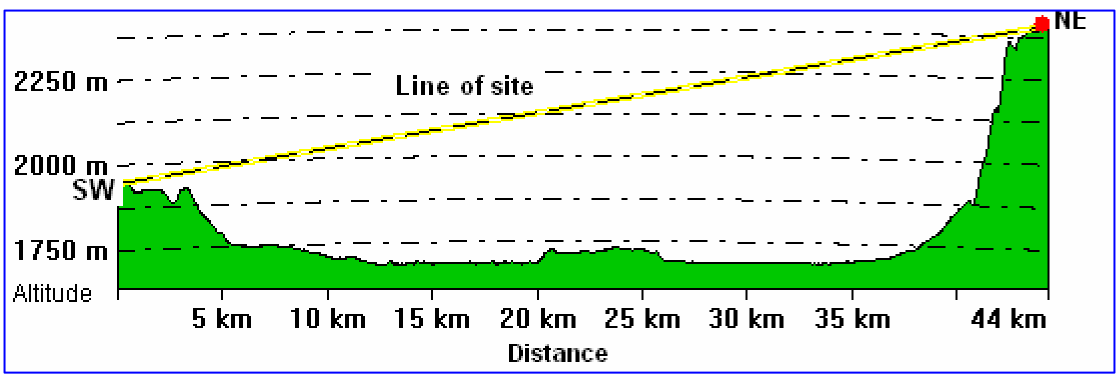


Fig. 3.3 Elevation range of the Awassa catchment

The drainage density and pattern mainly depend on climate, rock and soil formations, topography and surface and sub-surface fracture intensities. The highly eroded and most deforested western part of the catchment has relatively flat toped topography and is massive in nature made of coarse un-welded pumicious pyroclastic rocks has no significant drainage system. It is different from the eastern side, which is covered with fractured ignimbrites and tuffs. It can be seen from the drainage map that no interconnected and long river channel reaches the lake from the western uplands. This however necessarily does not mean that there is no run off from this side of the catchment. The overland flow is not channelized but it occurs in the form of dissipated overland flow. The flat laying thick and fertile agricultural land with slope range of 0-8% but dominantly 0-2% (W.W.C.S.E, 2001) composed of fine to medium texture soils infiltrates the dispersed overland flow from the highlands. The fact that most of the runoff produced from the South-western and North-western highlands ends up on the closed sub catchments of Muleti, 91.6 km2 and Wondokosha, 114 km2 due to the flatness of the plain agricultural land.

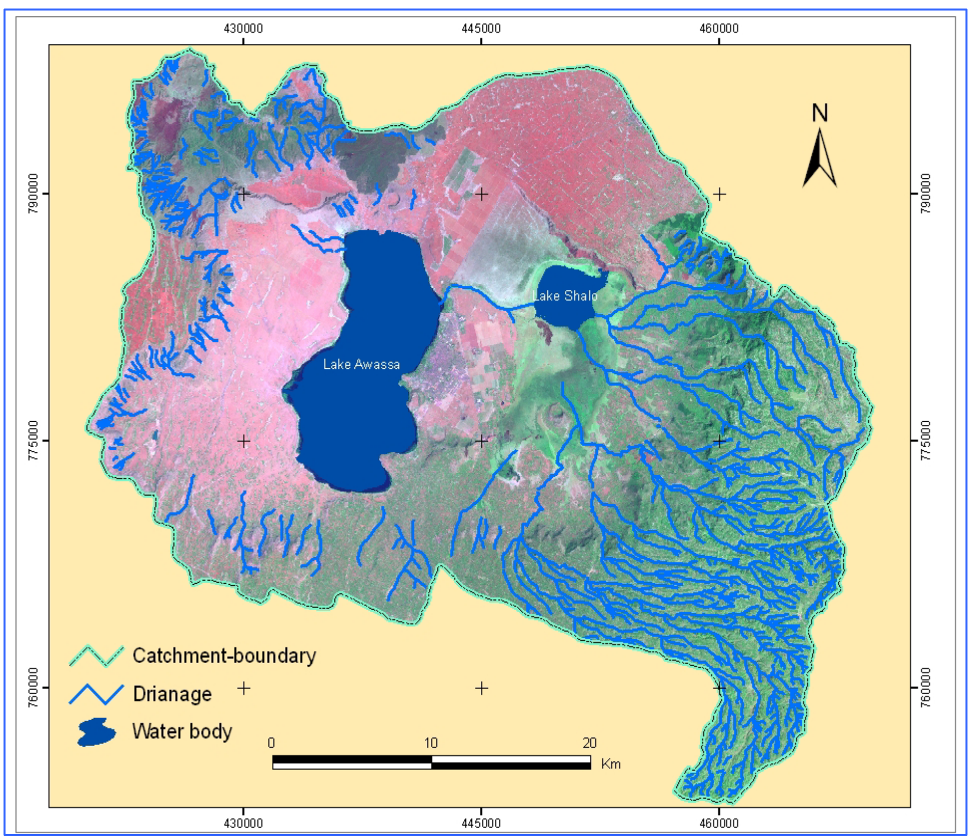


Fig.3.4 Drainage of the catchment

3.1.3 Climate

3.1.3.1 Rainfall

Ethiopia is located in the region where June through September is the main rainy season. Lake Awassa catchment however has even extended period of wet season (March-October with mean monthly rainfall varying from 85 to 133mm). The moisture for precipitation in the area originates from southwest equatorial air stream, which moves northwards with inter-tropical convergence zone (ITCZ), (W.W.D.S.E 2001). June to September rainfall contributes 44% to the mean annual precipitation in the catchment. The climate in the area is dry to sub-humid according to the Thornthwaite's system of defining climate or moisture regions, (Dessie 1995). The mean annual rainfall on bases of 12 to 30 years of record of 5 rainfall stations that contribute to the catchment is estimated to be 1038mm. Both the amount and seasonality of the rainfall shows some variability. The wettest months are April, May and September fig (3.4).

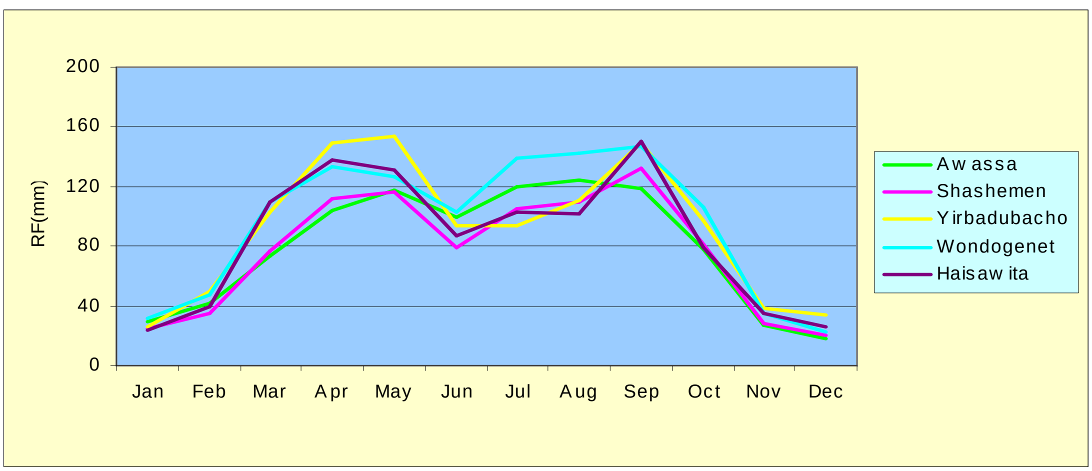


Fig.3. 5 Long-term mean monthly precipitation of different

3.1.3.2 Temperature

Though there is no other station in the catchment that records temperature to compare with, it can be concluded from Awassa station that the lowland part of the catchment annual temperature ranges from 9 to 29 ^{0}C, while mean monthly temperature is 19.7 ^{0}C.

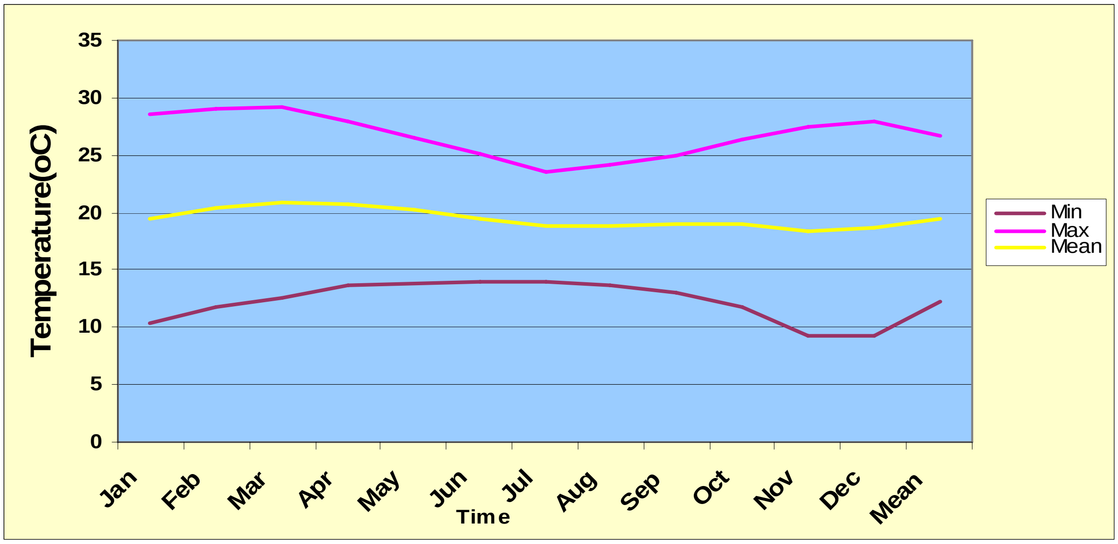


Fig.3. 6 Long-term mean monthly Min, Max and Average temperature

3.1.3.4 Relative humidity

At a station in Awassa town RH has been measured three times a day, since 1972. The Relative humidity records show the mean monthly value of 66.3% with mean minimum monthly of 53.9 in February and reaches maximum 77.3 in September. Long-term mean monthly values of climatic variables are presented in the following figure.

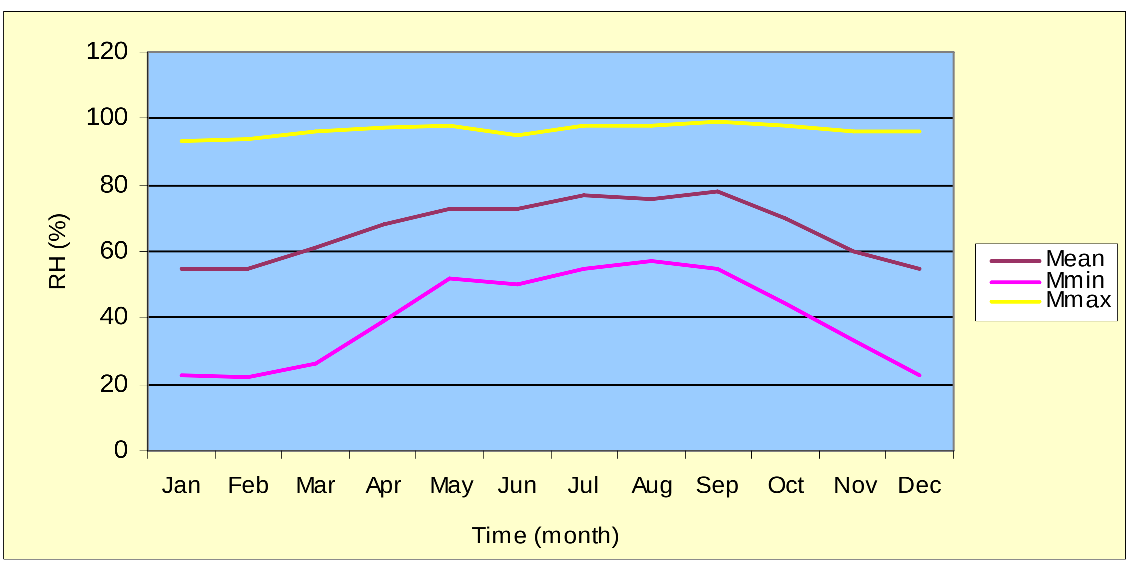


Fig. 3.7 Long-term mean monthly of RH (1972-2003)

3.1.3.3 Evaporation

Long-term pan evaporation data from NMSA at Awassa station is used and it was recorded using class A pan. From fig 3.8 it shows that high evaporation occurs during dry months while during the summer time decreases due to high rainfall and relatively increased humidity. Since pan evaporation is greater than evaporation from the catchment, pan coefficient of 0.8 is used in order to correct the various effects during evaporation from the pan. As a result the mean annual Potential evapotranspiration at Awassa is 1581mm.

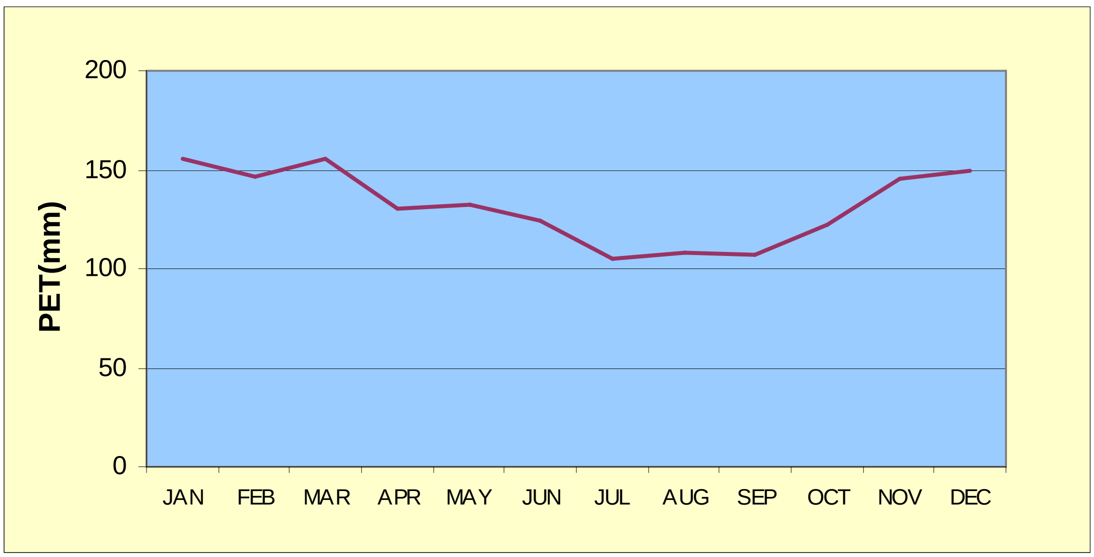


Fig.3.8 Long-term mean monthly PET

3.1.4 Soil of the Catchment

Water Works Design and Supervision Enterprise have classified the soil based on the physical and chemical characteristics. Depth, color, structural development, texture and evidence of profile development such as presence of diagnostic horizons, reaction to 10%HCl and P^H value are some of the classification criteria based on which soil map has been produced. Cambisols, Andosols, Vertic cambisols, Vertic luviosols, Regosols, Gleysols, Alisols, and Leptosols are some of the soil types described by W.W.D.S.E with respect to their position in a different relief intensity and slope. Generally based on their dominant characteristics these soils of the study area are classified in to four groups as clay loam, fine sand, fine sandy loam and silty loam.

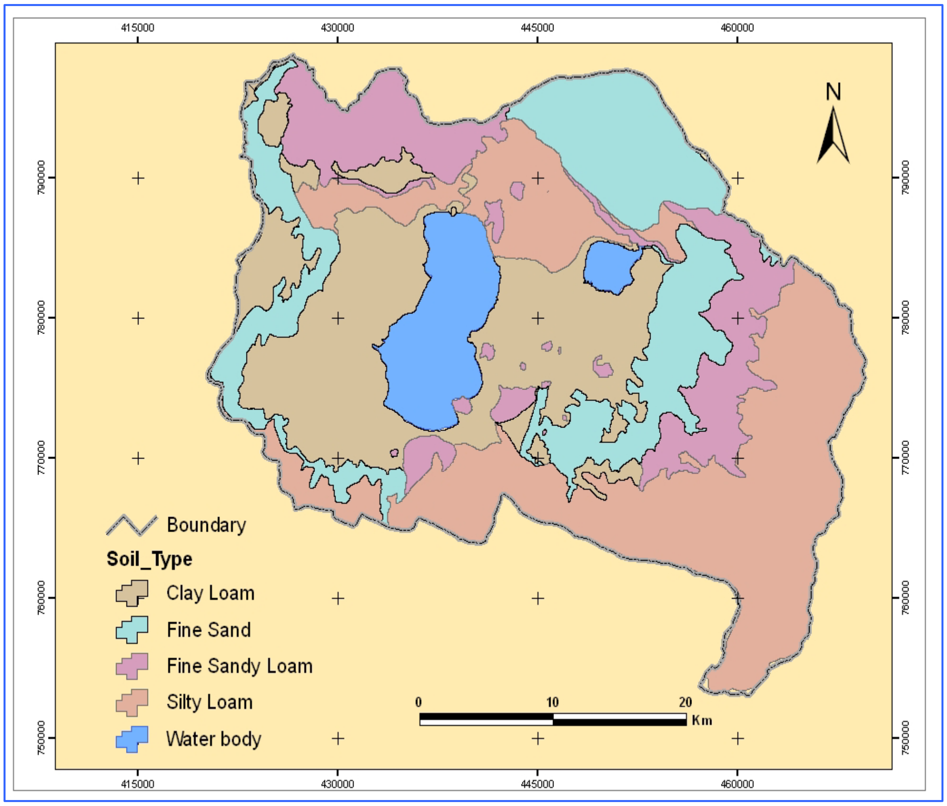


Fig.3.9 Soil map of the catchment (adopted from W.W.D.S.E 2001)

3.1.5 Land use and Vegetation

The land use of Lake Awassa catchment has been changed progressively due to extreme deforestation as a result of increase in population, which results in replacement of vegetation cover by cultivation land. Agriculture is the main land use practice in the catchment and occupies most of the floor of the catchment. Open bushy woodland with cultivated land found on the floor and southern part of the area; Cultivated land with exposed bare rock and soil found on southwest corner of the area; Open grassland covering the eastern escarpment western caldera rims; Open grassland with open bushy woodland on the volcanic hills are Landuse/Landcover condition of the area (as of 1998 surveyed by WWDSE).

As the deforestation of the natural vegetation cover continues soil loss due to erosion will result and it is aggravated where the slope is higher especially on the escarpments. This erosion could be one of the reasons for the rise of Lake Awassa water level and disappearance of Lake Cheleleka.

3.1.6 Geology of the area

The main Ethiopian Rift Valley is divided based on structural features in to three geographic areas; represented by the northern (Fentale Nazret), Central (Nazret Awassa) and southern (Awassa-Konso) sectors. The central sector, where the Awassa lake catchment belongs to is a symmetric rift basin where both sides of the rift margins are fully defined except in the region between guraghe and Sodo of the western escarpment and the Shashemene area of the eastern margin (Tadesse and Zenaw, 2003). The closed catchment of the nested Awassa-Korbetti caldera complex is a giant elliptical depression 30-40kms wide.The Korbetii caldera, which is found northwest of Lake Awassa, is nested caldera with in Awassa caldera. It has two volcanic centers of Urgi and Chebbi. The Urgi centre is a source for the formation of pumice in the vicinity and Chebbi is a center of formation of obsidian, which covers the Chebbi Mountain. (Dessie 1995), stated the main formations in the area subdivided in to four lithologic units as follows;

1. Volcano lacustrine deposits, which cover most part of the floor of the depression, composed mostly of volcanic origin (tuff, pumice, ash) with small amount of diatomite.
2. Recent acidic volcanics, which covers large part of the north and north-western part of the catchment where glassy rhyolitic rocks superimposed and form massive domes and thick obsidian flows.
3. Basaltic lava flows, scoria and hyaloclastites, which are observed sprinkled on the flat catchment floor forming conical shapes.
4. Ignimbrite of the rift floor and the rift scarp, which is common rock type for the region and covers the east, southwest and the southern part of the catchment where the top few meters of the rock is weathered and fractured in places with columnar joints.

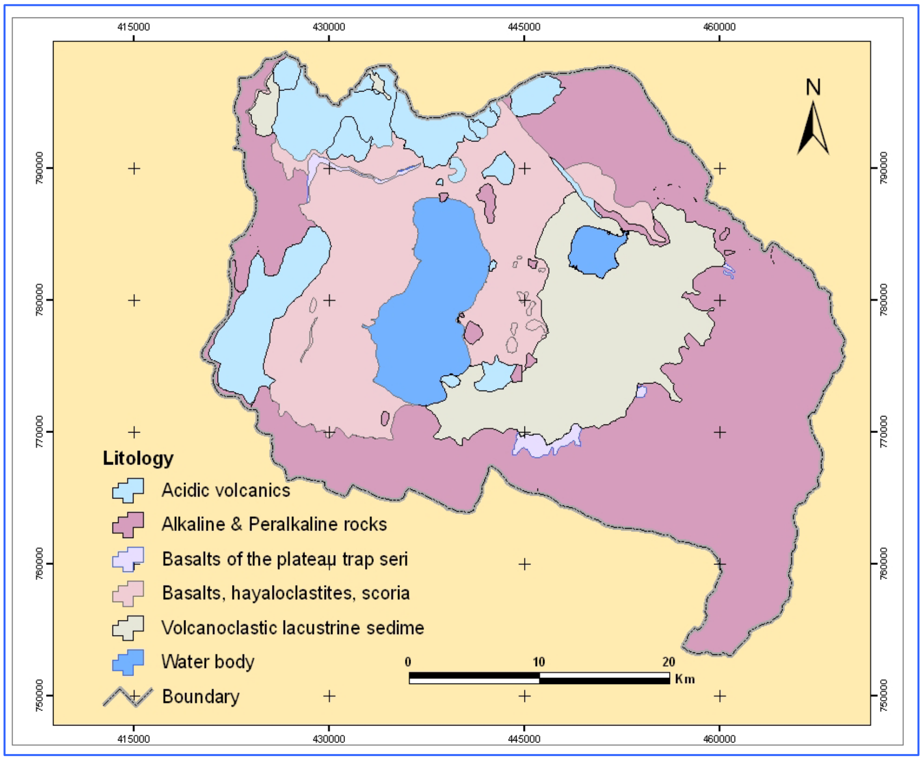


Fig.3.10 Lithological map (adopted from W.W.D.S.E 2001)

3.1 .7 Hydrology of the area

Lakes Awassa and Shallo (Cheleleka), situated in Awassa caldera, were united as a single lake last century (Tadesse and Zenaw 2003). However, recent terraces are much less preserved in the Awassa catchment than Ziway-Shalla lakes to the north, the reason may lay in the wetter climate of the Awassa region.

Lake Awassa is a Closed-catchment which is fed both by few ephemeral streams on the north-west and western side of the catchment and by the TikurWuha River, which is the only perennial river, enters Lake Awassa draining the Cheleleka swamp on the north-east side. Cheleleka swamp receives surface runoff from the headwaters of the eastern rift escarpment and from groundwater upstream. But now due to continuous erosion process on the eastern highlands have resulted on filling Cheleleka Lake with sediment load and transformed it to a swamp. Tall papyrus like grasses grow in the swampy area indicating that the deposition of transported sediment from the uplands has been in a continuous process of filling the natural reservoir of lake Cheleleka (W.W.D.S.E 2001).

3.2 Materials and data used

The following spatial (image) data and historic time series of hydrometeorological data have been collected and used in this study for the assessment of the impact of vegetation cove reduction on ground water recharge, using remote sensing and Geographical Information System (GIS) integrated with field survey:

Satellite image data and maps:

- Landsat MSS data of the year 1973 G. C. with four bands was used for Land use land cover mapping of the 1973.
- Landsat TM data of the year 1986 G. C. having seven bands was also used for time series analysis of the extent and rate of land use land cover change.
- Landsat ETM+ data of the year 2000 G. C. having eight bands was mostly used (it is the only latest available data for the area).
- SRTM (Shuttle Radar Topographic Mission) data of the year 2000 G. C. was used to produce 3D map of the catchment.
- Five topographic maps of year 1973 G. C., having a scale of 1:50,000: were used during field survey, digitization of road network, drainage network, and contour.
- 1965 Land use / land cover map of Awassa catchment prepared by (W.W.D.S.E. 2001) was used as a base map for land use / land cover mapping of the 1973 of the area.
- The Geology and Soil map of the area prepared by (W.W.D.S.E., 2001) 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.

Time series of hydro meteorological data:

- Mean daily and monthly discharge data of Tikur Wuha River gauged at Data station from 1981-1998.
- Monthly and annual precipitation data of 5 stations for 25-30.

- Mean monthly temperature and mean annual pan evaporation data from Awassa type A stations.
- Annual lake level data of lake Awassa for a period of 33 years

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, and the like of the study area. On top of this information GPS reading from the major LULC 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 be 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

1. ERDAS Imagine 8.6: used for geo-referencing and image sub-setting.
2. ENVI 4.2: used for visual interpretation and image analyses.
3. AcrGIS 9.1: used for GIS analysis and mapping.
4. Global mapper and Surfer: used to extract 3D map of the catchment.
5. GPS and digital camera

3.3 Methodology

3.3.1 GIS (Geographic information system) application

1-GIS mostly used in this research for: Digitizing base maps (geology, soil, drainage...)

2-Derivation of catchment physiographic characteristics (sub catchment, DEM, slope) using spatial overlaying techniques and thematic database queries.

3.3.2 Remote Sensing Application

Landsat MSS, TM and ETM+ satellite imagery have been used for:

1-Producion of land use/land cover map of 1973, 1986 and 2000, based on supervised classification methods using (field) checking, interviewing local people, old maps and visual interpretation techniques.

2- Determination of land use land cover changes from 1973 to 1986 and 1986 to 2000 using statistical change detection method.

3.3.3 Hydrological data analysis methods

In line with the present state-of-the-art in the assessment of hydrologic impacts of land use land cover transformation at the watershed scale, an attempt has been made to analyze changes in the hydrologic regime of the Awassa catchment in relation to changes in land use land cove and climate, which have taken place in the past 29 years. Historical time series data on stream flow, Lake level, rainfall, and evapotranspiration have been used in the analysis.

Daily and Monthly inflow data of Tukur wuha river were collected for the period of 1981 to 1998 gauged at dato village to determine the surface runoff and base flow of the catchment by extrapolating the gauged data to the entire catchment using hydrograph separation methods such as seasonal rescission method and timepolt method, in addition metrological data, which have a good relation with ground water recharge such as monthly rainfall data for a period of 25-30 years for 5 stations that area found in and around the catchment, Temperature and evaporation data of 23 year from Awassa type A meteorological station were collected from Ethiopia national metrological agency (ENMA) so as to examine the trend of the meteorological elements. Besides annual lake level data of Lake Awassa were collected from Ministry of Water resource for a period of 31 years to analyze its trend. After all the necessary data were collected the next step was data analysis, presenting results and discussion.

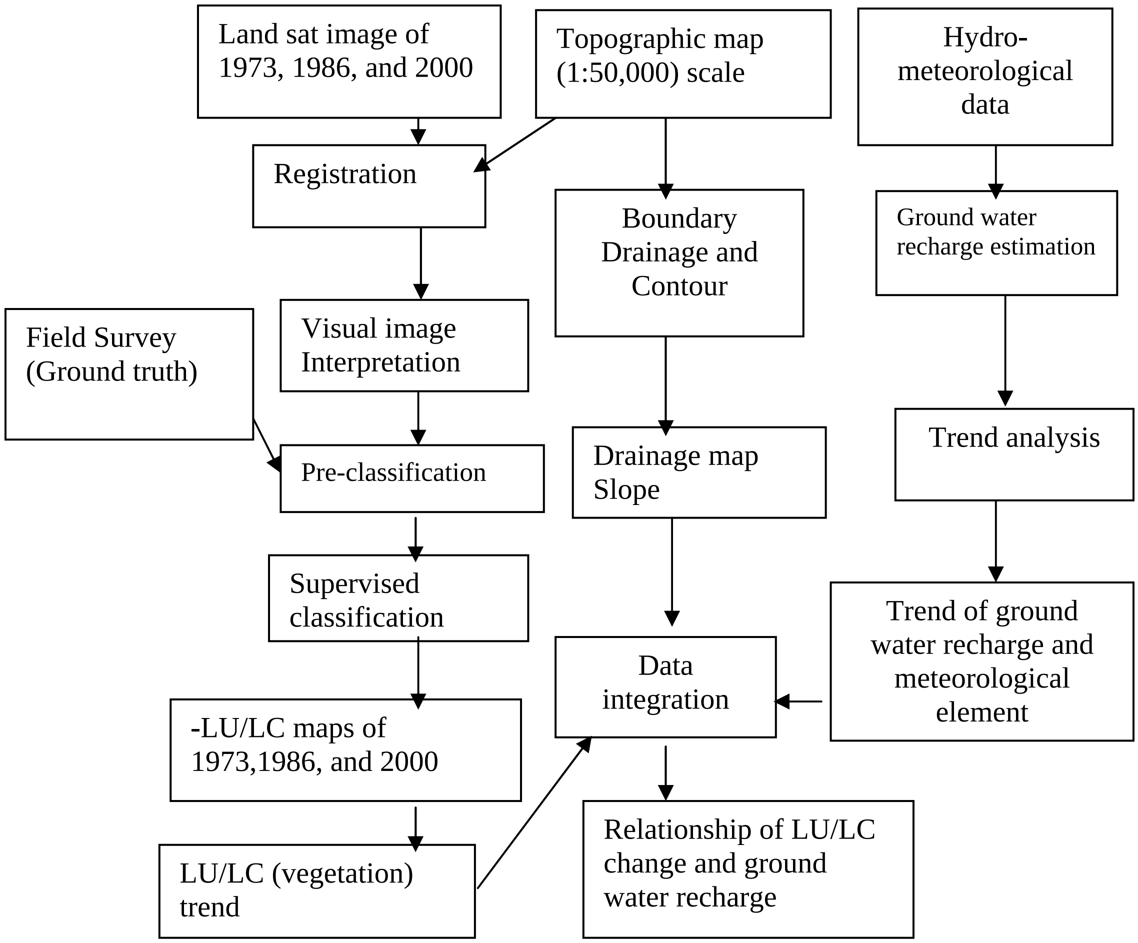


Chart.3.1 Flow chart showing the general methodology of the study

The first involves use of spatial technology tools, primarily the use of remote sensing data to obtain actual location, inventory and classification of different LU/LC spatially and change detection analysis. Secondly, 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's why it is used) and land use land cover factor (vegetation cover) to see the effect of the LU/LC changes on the hydrological regime in general and groundwater recharge in particular. Below all the analysis with their results to achieve the mentioned goals of the research are discussed one by one as separate sections.

4. LAND USE/ LAND COVER CLASSIFICATION

Remotely sensed images are vital in land use/land cover classification specially when dealing with large and inaccessible areas. The land use land cover study of the catchment was made based on Landsat MSS of 01-31-1973, 01-28-1986 TM, ETM+ of 01-27-2000 satellite images and field observations.

4.1 Procedures of land use and land cover classification

There are various steps and principles involved in mapping LU/LC from Satellite imageries however; presenting all the principles and steps is futile rather the most important ones are dealt here. Different approaches and techniques have been used in doing LU/LC mapping such as image restoration, enhancement and classification of the mentioned satellite imageries. These steps are described in the following Chart.4.1

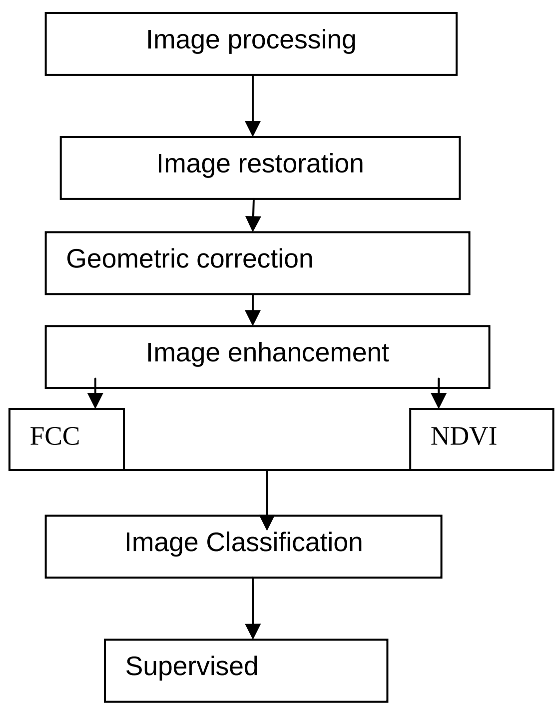


Chart 4.1 method of LULC classification

4.1.1 Image Restoration

Data received from satellites need to be corrected before use. Prior to any image classification atmosphere effects and geometric distortions should be removed. Similarly during the study the following pre-processing techniques were applied before actual image classification.

A) Geometric correction

When the images are obtained from the receiving station these are not georeferenced. In order to be able to work in a GIS environment (e.g. overlaying maps) the images must be linked to a co-ordinate system and a projection of the earth's globe. In this study the images (MSS 1976, TM 1988 and ETM 2002) have been georeferenced using the available topographic map to a *Universal Transverse Mercator* projection using 10 control points for each image. The points have been identified on the topographic map.

4.1.2 Image enhancement

Enhancement technique concerns the modification of an image to improve its quality as perceived by a viewer. 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:

A) Spatial resampling

As the images have different spatial resolution, it is 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 EnvI4.2 software by doing this the spatial resolution of all image becomes 28.5m by 28.5m which is important to perform change detection.

B) Normalized Difference Vegetation Index (NDVI)

NDVI is the most widely used of all vegetation indices. It only requires data from the red and near infrared portion of the electromagnetic spectrum, and it can be applied to virtually all-multispectral data types. NDVI has been used to differentiate vegetation from other land cover classes

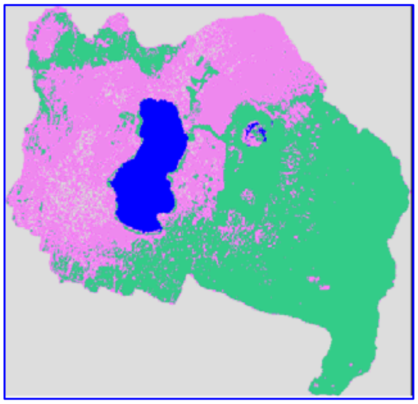
The Normalized Difference Vegetation Index (NDVI) is calculated from a TM-scene by taking the ratio of the difference of the near infrared and red reflection and the sum between these two bands using following formula:

NDVI= (4-3)/(4+3)

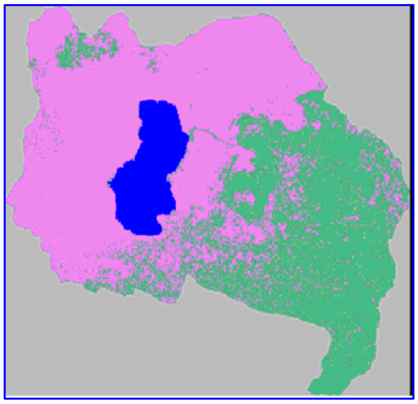
NDVI: Normalized Difference Vegetation Index

4: spectral band 4   3: spectral band 3

By applying all the formulas above the following NDVI images have been resulted which are help full to see how the vegetation cover of the catchment changes over the three periods, but during the NDVI analysis there was difficulty to distinguish between agricultural and vegetation cover so this analysis for the 1973 image gives some what exaggerated result but the rest period results are pretty much good. Based on this analysis the vegetation cover trend of the catchment can easily observed from this map.



1986



2000

Fig.4.1 NDVI images for the 1986 and 2000 periods

C) Band Selection for FCC (false color composite) image preparation

In this research band selection were made through the analyses of:

-Reflectance properties of objects or features, Correlation matrix of the image, and the histogram behavior of the bands. For the purpose of calculating the correlation matrix and the histogram of the Land-sat images the image processing software ENVI 4.2 and ERDAS IMAGINE 8.6 were used. ERDAS IMAGINE 8.6 was used to create the spectral profile of the different feature types.

- **Analyses of the Correlation Matrix**

Satellite data often show a degree of correlation, meaning that when the spectral values in one band are high the values in another band are expected to be high as well. Plotting values from highly correlated bands in a feature space will result in an ellipsoid denoting that the two bands contain dependent information. From a set of highly correlated bands only one adds real value while the other ones may be derived or estimated (Sotomayor, 20002). The correlation matrix of the spectral bands contains useful information about the redundancy of information and selection of optimal band combination for interpretation purpose. If the bands show strong correlation (value near to 1.000) this indicates that the bands usually contain similar information. When those bands are visualized the minimum variability among different feature would be noticed (Rahman et al, 2006).

Table 4.1 represents the correlation matrix of the sub scene that was clipped from the 1986 Landsat TM. From the table it can be observed that there exists high correlation among visible (band 1-3) and mid-infrared bands (band 5 & 7). It means that there is a high redundancy of Information within those bands in different feature types. Therefore, one band from the visible region, the near infrared and one from mid-infrared can be selected for the best variability in the vegetated areas using Landsat TM and ETM+ images but for the Land sat MSS bands 4-2-1 was used as it have only four bands. As it is common to use band 2 from the visible bands, band 4 from the near infrared and 7 from the mid-infrared bands the current study has also decided to do so. Therefore, bands 2, 4 and 7 were finally selected for the interpretation purpose.

Table 4.1 Correlation matrix of Land-sat TM image of 1986

Band	1	2	3	4	5	7
1	1.000	0.968	0.956	0.7256	0.867	0.8796
2	0.968	1.000	0.9156	0.8045	0.8971	0.9078
3	0.956	0.9156	1.000	0.6975	0.9178	0.8999
4	0.7256	0.8045	0.6975	1.000	0.7989	0.679
5	0.867	0.897	0.9178	0.7989	1.000	0.9330
7	0.8796	0.9078	0.8999	0.679	0.9330	1.000

- **Spectral reflectance properties of objects**

The basic premise of remote sensing (satellite images) is that different objects do have different reflectance properties at different EMS interacting with them since all objects vary with internal structure, morphology, and chemical composition. Based on this analysis band 4-2-1 and 7-4-2 were chosen for the Landsat Mss and Landsat TM and ETM+ respectively. The figure bellow clearly shows which wavelengths are more sensitive with which features.

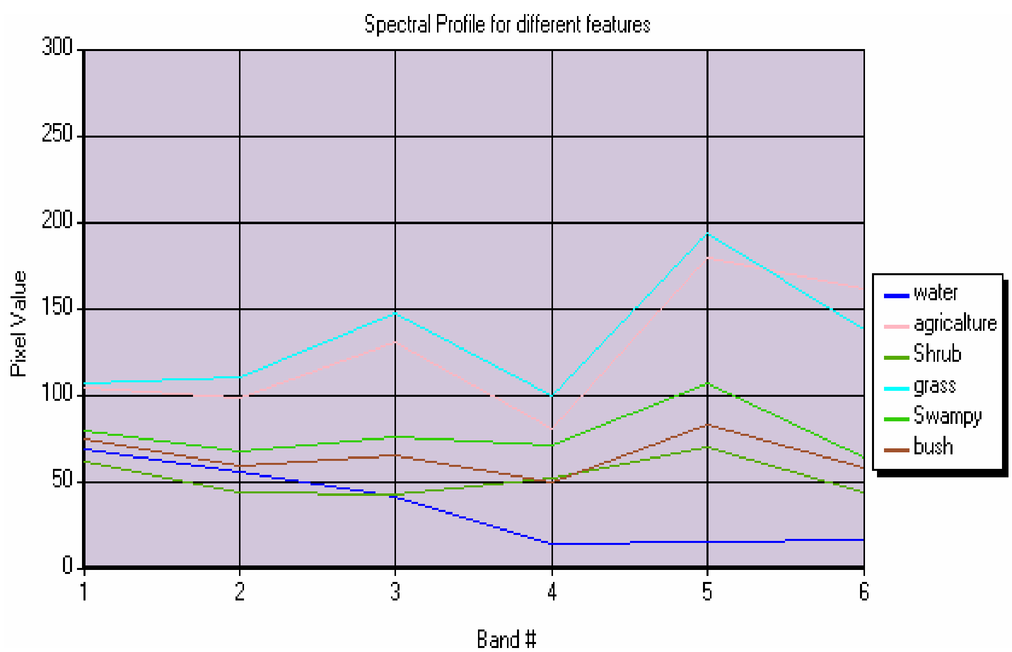


Fig 4.2 Spectral properties of different features

- **Histogram analysis**

According to the histogram behavior (refer to Figure 4.3) the bands 5 and 7 showed a normal distribution curve, both bands give the representative radiance range and this means more information, however the amplitude of the data in the band 7 is the highest, this is another reason for why the band 7 was chosen.

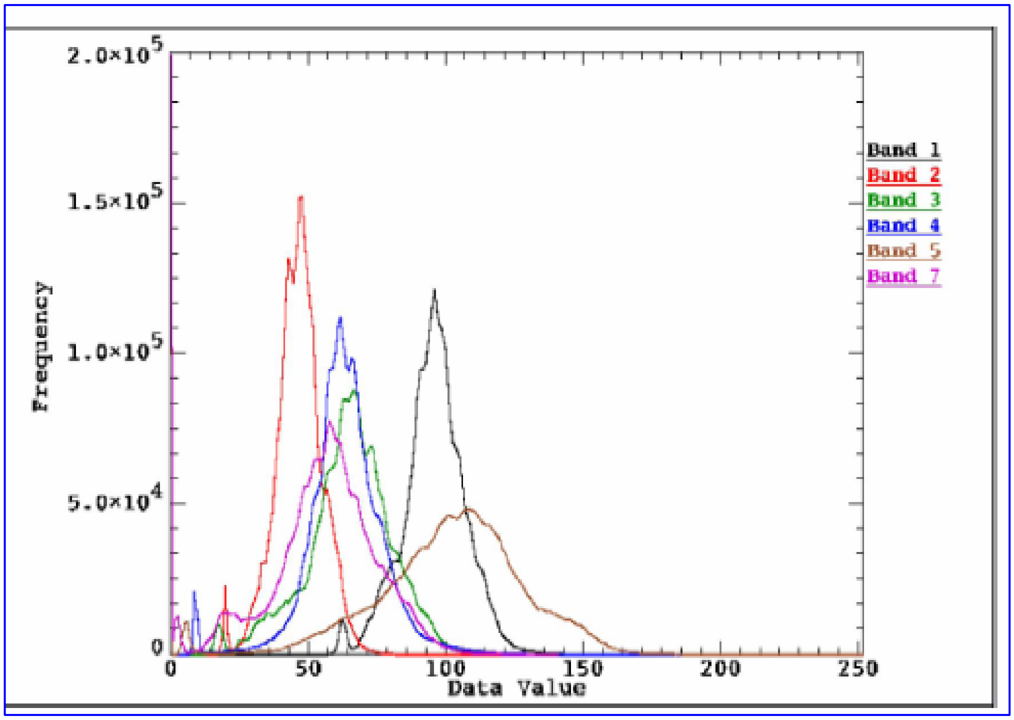


Fig 4.3 Histogram of different bands using 1986 landsat TM Image

D) False Color Composite (FCC) Image Preparation

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. In this research the false color composite image made using Landsat Mss bands 4-2-1(R-G-B), Land-sat TM bands 7-4-2(R-G-B) and ETM+ 7-4-2 (R-G-B) were found to be best for the identification of major land cover classes in the study area. In this band combination different types of area can be distinguished as shown in table 3.2

Table 4.2 colors of surface feature in FCC 7-4-2

Surface feature	Coloure
Water body	Dark blue
Agricultural area	Pink to red
Urban area	Light blue
Grass land	White to green

4.1.3 Image Classification

After all the required prepossessing techniques are done the last is to do the real classification of the LU/LC classes. The land use land cover study of the catchment was made based on Jan1973, 1986, 2000 satellite images and field observations. Satellite image classification can be done based two popular classification techniques namely supervised and unsupervised classification. Both methods have been tested in this research and the best one was selected.

- **Unsupervised classification**

In this type of classification, the computer produces spectral classes based on the digital numbers (DN) without any direction from the user. It gives preliminary information on the potential spectral clusters to be assigned to thematic classes. Therefore, subsets of the satellite data were first classified using unsupervised classification. This classification has been used as a guide in the selection of training sites for input into the supervised classification.

- **Supervised classification**

This method of classification unlike unsupervised ones needs a training points and the analyst should know the area before classification. Since it was difficult to identify all the land cover classes only by interpreting satellite images, ground truth data and old maps are important to verify the LULC classification, sample data from the major land use land cover classes and from those which are difficult to interpret from the image with in the boundary of the study area were collected. Water works construction supervision enterprise has also prepared a land use land cover map of 1965 based on 1965 aerial photograph interpretations and ground survey, and this map was used as abase for LULC classification of 1973 land sat TM image.

By interpreting the various FCC image and by making inter band comparisons and with the help of the above ancillary data about 25, 42, 38 sampling points were identified from the1973, 1986 and 2000 respectively. Hence based on this training point's supervised classification was performed by applying Maximum likelihood classifier algorithm using ENVI 4.2 software. Finally, 7-land use Land cover classes were extracted, mainly: *Water body, bush land, Shrubby woodland, Grassland, Agricultural land, urban area and Swampy area* but urban area is not include in the image classification rather masked as it disturbs the classification by having similar reflectance with the agricultural land. Finally it is extracted from the image as vector data and its areal extent is derived from the shape file.

Water bodies**:** areas, which are coved by open water.

Agricultural Land**:** areas of land, which are ploughed and/or prepared for growing crops.

Grassland**:** areas, which are coved with grasses.

Swampy area**:** areas where the water level is permanently or temporarily at (or very near) the land surface, typically covered in either herbaceous or woody vegetation cover.

Bush land**:** areas, which are covered with very short and bushy plants

Shrubby Woodland**:** areas which are coved with both shrub and woody plants

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

NOTE: The urban area is not included in land use/land cove classification rather it is masked since it affects the classification quality as its reflectance is highly similar with the agricultural land of the catchment and its areal change is directly generated by digitizing from the image as a polygon vector layer.

4.2 Accuracy assessment of LU/LC mapping

The result of a supervised classification usually has some percentage of misclassification, due to noise and unknown pixels. There fore it was necessary to test the accuracy of the classification by using field knowledge and other ancillary data. Accuracy assessment was done by comparing two sources of information: (i) remote-sensing derived classification data and (ii) reference test data (Jensen 1996). The relationship of the sample sets is summarized in an error matrix where columns represent the reference data while rows represent the classified data. 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 1973, 1986, and 2000 was performed. The following tables (Table 4.3-5), shows the result of accuracy of each land use and land cover classification based on Error/Confusion matrix. The Kappa coefficient lies typically on a scale between 0 and 1, where the latter indicates complete agreement, and is often multiplied by 100 to give a percentage measure of classification accuracy, Kappa values are also 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 (Rahman,et l.2006). Based on this all the LU/LC classification of this study lies on the kappa coefficient that show strong correlation as 0.8083, 0.9178 and 0.8966 for the period 1973,1986 and 2000 images classification respectively. The LU/LC map of the year 1973, 1986 and 2000 has been classified with an overall accuracy of 93.02%, 93.8% and 93.1% respectively. Of the LU/LC classes the water body has been classified with 100% accuracy but the least accuracy of mapping resulted on swampy LU/LC classes. The reason behind this is the swampy areas resemble with others LU/LC classes and results spectral confusion in classification.

The LU/LC classes are symbolized for presentation purpose as follow:

AL = Agriculture land GL=Grassland

SWL=Shrubby woodland SA=swampy area

BL=bush land WB = Water body

Table 4.3 Error matrix of, LU/LC image classification of 1973

	Ground Truth in %						
LULC class	WB	AL	GL	SA	BL	S WL	Total
Unclassified	0	0	0	0	0	0	0
WB	**100**	0	0	0	0	0	9.05
AL	0	**95.73**	0	0	1.12	0.13	3.04
GL	0	0	**100**	13.19	0	0.81	2.05
SA	0	0	0	**73.84**	0	6.19	7.83
BL	0	4.27	0	0	**98.88**	0.03	1.69
SWL	0	0	0	12.96	0	**92.84**	76.34
Total	100	100	100	100	100	100	100

Confusion Matrix : LU/LC-1973 (1742x1608x1)

Overall Accuracy = (10709/11512) **93.0247%**

Kappa Coefficient = 0.8083

Table 4.4 Error matrix of, LU/LC for 1986 image classification

	Ground Truth in %						
Class	WB	AL	GL	SA	BL	SWL	Total
Unclassified	0	0	0	2.39	0	0	0
WB	**100**	0	0	0	0	0	9.05
AL	0	**96.87**	0.68	1.79	1.65	2.74	3.04
GL	0	0.07	**92.82**	5.46	0	1.61	2.05
SA	0	0.04	5.84	**89.84**	0.69	1.79	7.83
BL	0	3	0	0	**94.74**	1.8	1.69
SWL	0	0.02	0.59	0.52	**2.93**	**92.05**	76.34
Total	100	100	100	100	100	100	100

Confusion Matrix : LULC-1986 (1742x1608x1)

Overall Accuracy = (26046/27749) **93.8628%**

Kappa Coefficient = 0.9178

Table 4.5 Error matrix of, LU/LC for 2000 image classification.

	Ground Truth in %						
Class	WB	AL	GL	SA	BL	SWL	Total
Unclassified	0	0	0	0	0	0	0
WB	**100**	0	0	0	0	0	9.05
AL	0	**88.7**	0	0	0.97	2.74	3.04
GL	0	0.06	**92.8**	0	0	1.61	2.05
SA	0	0.05	2.54	**100**	1.27	1.79	7.83
BL	0	8.26	3.77	0	**96.84**	1.8	1.69
SWL	0	2.94	0.9	0	0.92	**92.05**	76.34
Total	100	100	100	100	100	100	100

Confusion Matrix : LULC-2000 (1742x1608x1)

Overall Accuracy = (18768/20371) **92.1310%**

Kappa Coefficient = 0.8966

4.2.1 Land use land cover map of 1973

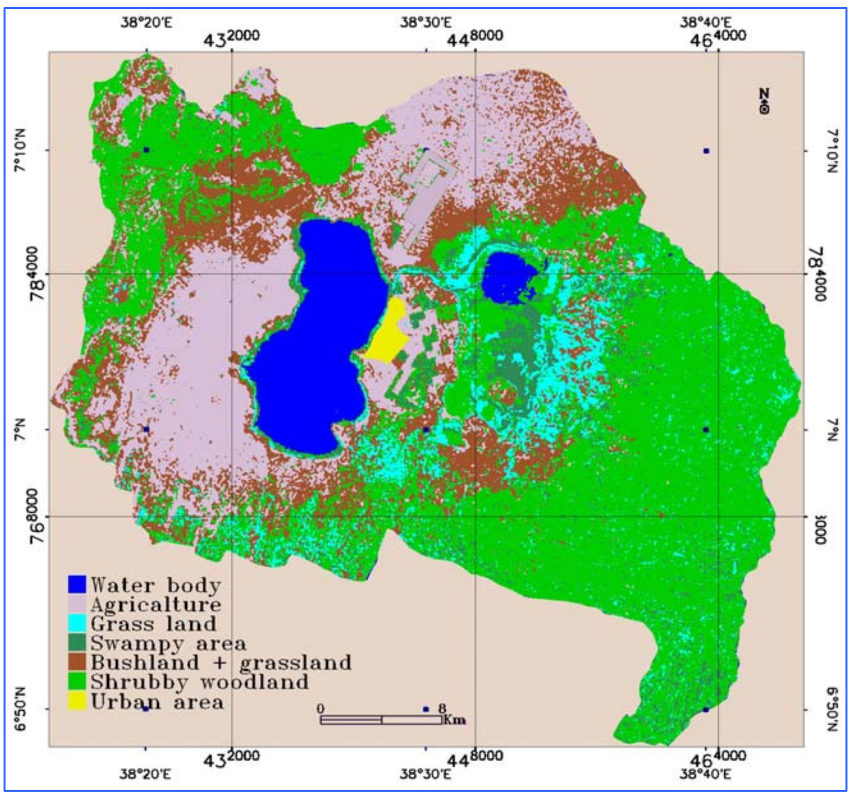


Fig.4.4 LU/LC map of 1973

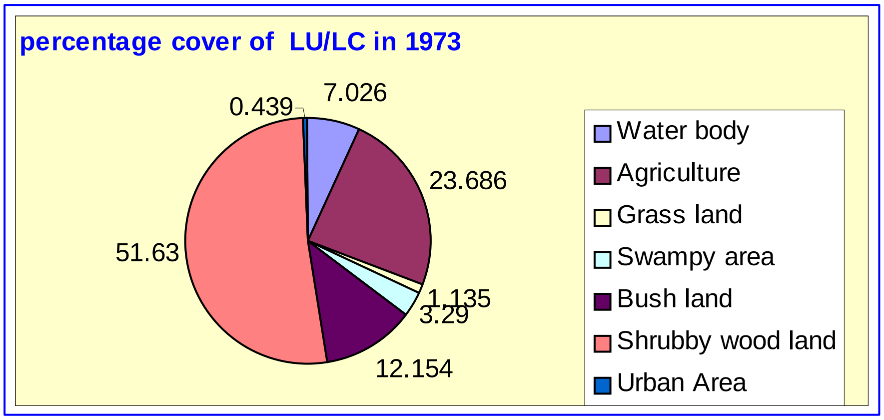


Chart 4.2 Percentage cover comparison of LU/LC classes 1973

The LU/LC percentage of this period indicates greater than half part of the area which accounts 51.63% was covered by shrubby woodland and even there was a significant Bush land about 12.15% that both dominates southern eastern and North western part of the catchment. And wetland area about 3.29% but the coverage of urban area is very much small in figure.

4.2.2 Land use land cover map of 1986

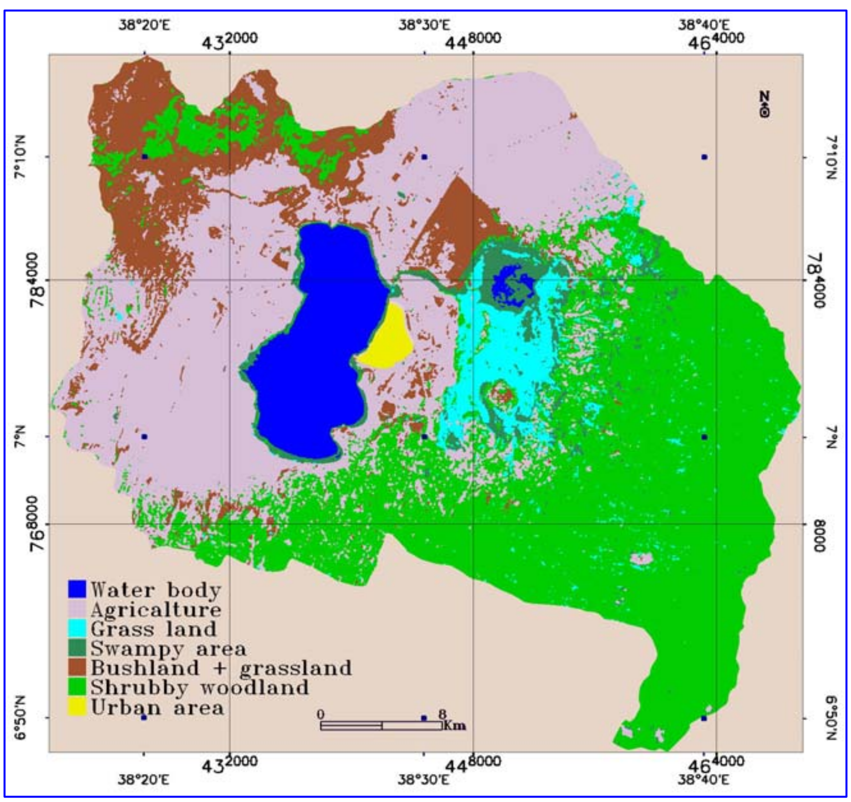


Fig.4.5 LU/LC map of 1986

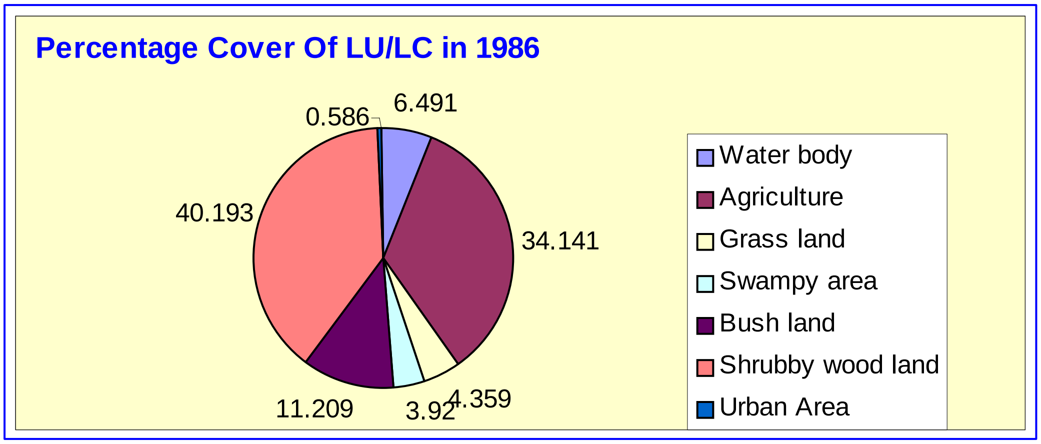


Chart 4.3 Percentage cover comparison of LU/LC classes in 1986

Shrubby woodlands have come to 40.19% from 51.63% around 10% decrement. This change is observed in the map on the North Western part of the catchment where extensive vegetation cover in 1973 map couldn't be seen in 1986 and Agricultural areas had been increased to 34.14% from 23.68%, which is nearly 10% increment.

4.2.3 Land use land cover map of 2000

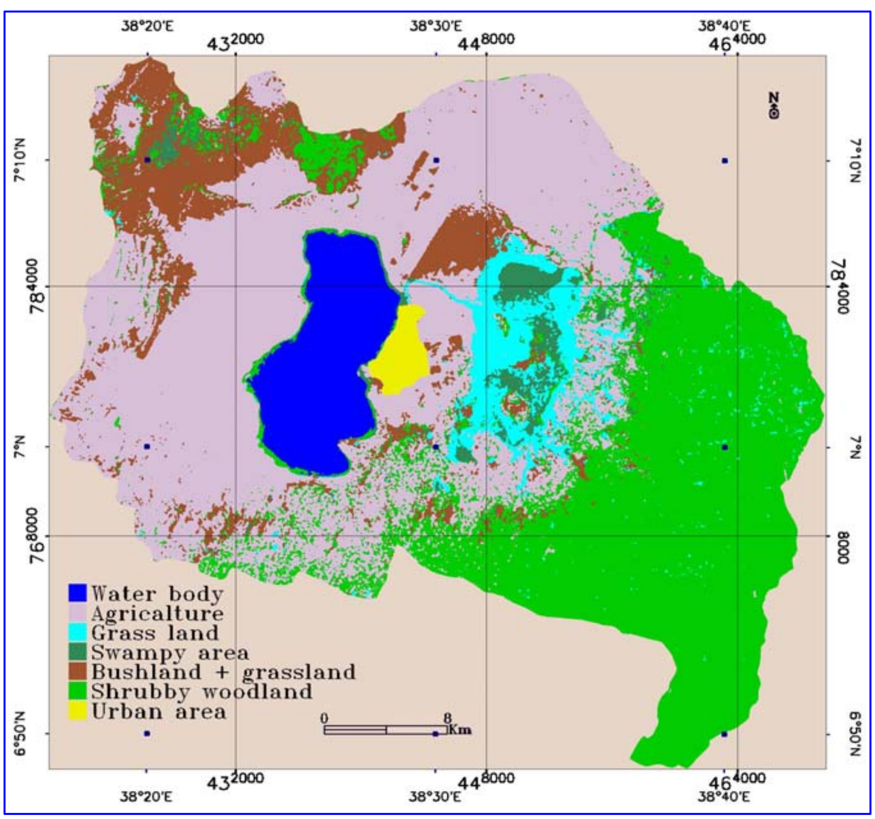


Fig.4.6 LULC map of 2000

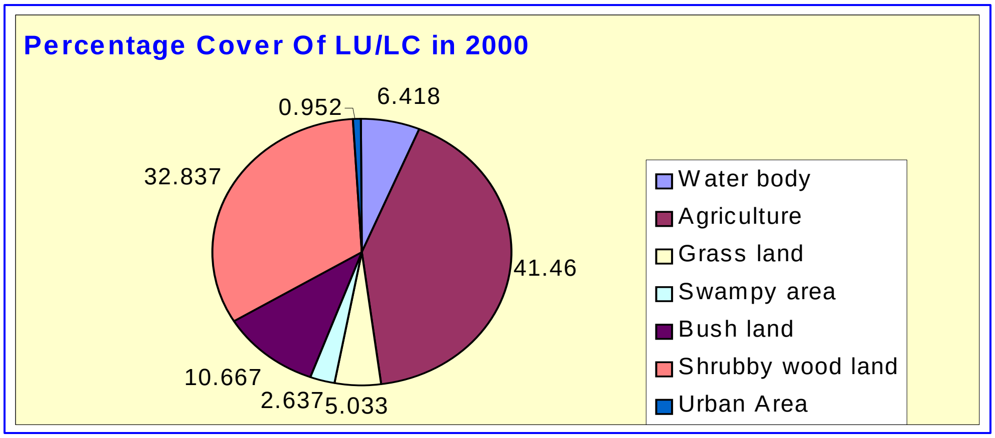


Chart 4.4 Percentage cover Comparison of LU/LC classes in 2000

In this period of satellite image analysis it could be possible to see even disappearance of a small lake in the eastern portion of the catchment locally called Cheleleka. On the contrary Agricultural land is increasing still this is at the expense of lake cheleleka and shrub woodland degradation. In the following section the change of each class with their direction of change is discussed in detailed.

Table 4.6 Summery of LU/LC classes of the periods with their area coverage

LU/LC Types	1973		1986		2000	
	In %	Km^2	In%	Km^2	In %	Km^2
Water body	7.026	95.9	6.491	88.6	6.418	87.6
Agriculture	23.686	323.3	34.141	466.2	41.46	565.9
Grass land	1.135	15.5	4.359	59.5	5.033	68.7
Swampy area	3.238	53. 6	3.923	44.2	2.637	36
Bush land	12.154	165.9	13.209	180.3	10.667	145.6
Shrubby wood land	51.63	704.7	40.193	548.6	32.837	448.2
Urban Area	0.439	6	0.586	8	0.952	13

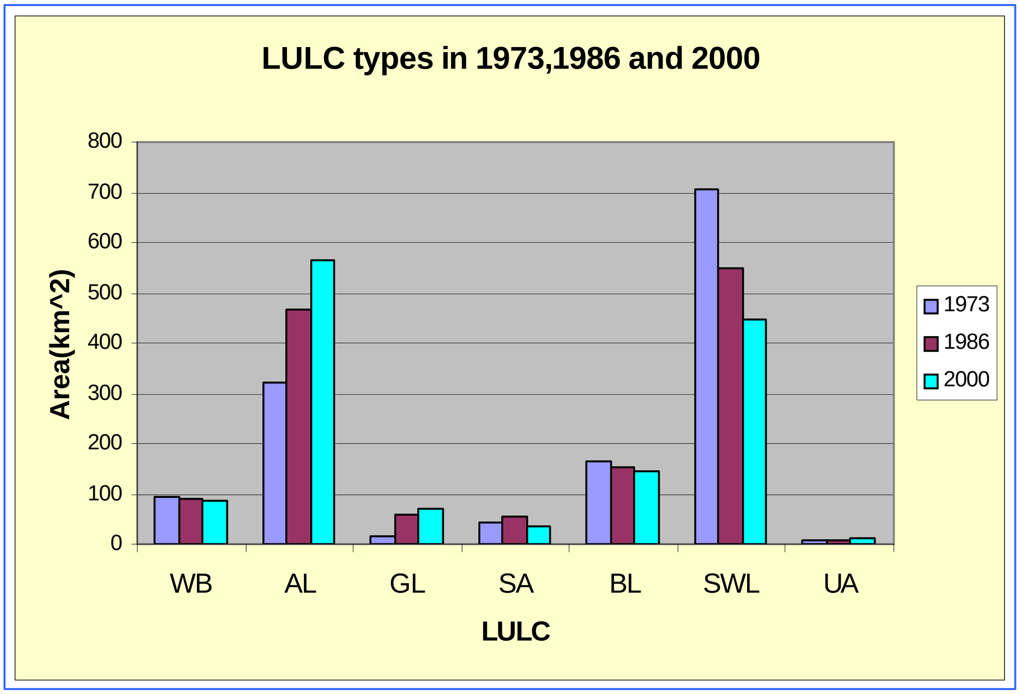


Fig. 4.7 LULC types of the different periods

4.3 Change detection analysis

Remotely sensed images are vital in land use/land cover change detection as it provides spatial and temporal information of the land use land cover condition of the catchment. In this research 14 year time span, and two phases change detection have been made one on 1973 to 1986, second 1986 to 2000, which is moderately enough in showing long history of land use and land cover. These time periods were chosen based on the availability of satellite image and other data in the catchment. The LU/LC change detection was assessed using post-classification cross-tabulation approach in ENVI 4.2 software.

Land use and land cover change detection method used in this study was post-classification comparison and multi-date composite image change detection. This method is widely used and easy to understand. The advantage of this method includes the detailed from-to information that can be extracted. Change detection was done for 1973 to 1986, and 1986-2000 to get the from-to information of changes in land use land cover and specially to see the trend of the vegetation cover which have great contribution in determining stream flow condition of the catchment. The chart below indicates the general procedure of change detection

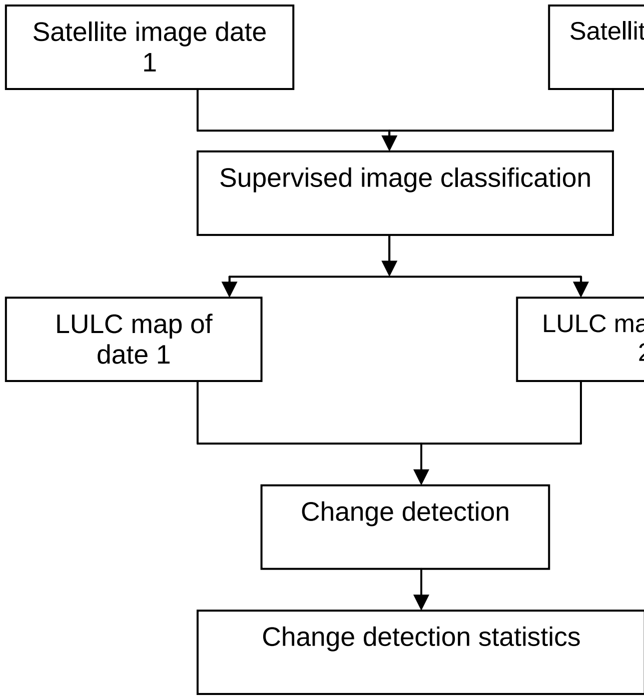


Chart 4.5 procedure of change detection

The tables, presented below, are the change detection matrix that depicts what is changed to what. The column of the table represents the initial stage and the row represents the final stage. In this regard image differencing was applied like wise from initial to final images. The diagonal values of the table depict the unchanged values, which are found in both times images. Unlike the diagonal values the class change tells the total changed image areas of each LU/LC of the initial stages. Where as the class total value of the column indicates the initial stage image total area of each LU/LC classes where as the row total represents the final stage area of LU/LC classes. The Image difference is the total net change of the two time images. The negative image change indicates a certain LU/LC is in a state of decrement and the positive value indicates increment.

Table 4.7 LU/LC change matrix of 1973-1986 (km2)

		LULC OF 1973							
		WB	AL	GL	SA	BL	SWL	Row Total	Class Total
	WB	85.71	0.11	0.06	0.69	0.04	1.9	88.5	88.5
	AL	0.33	258.83	0.36	12.47	103.31	78.66	453.96	458.48
LULC	GL	0.21	1.71	7.12	12.23	1.72	38.48	61.48	61.62
OF	SA	8.18	1.87	2.7	8.25	1.27	22.83	53.11	45.35
1986	BL	0.11	44.68	0.07	2.16	27.52	82.63	157.16	160.28
	SWL	1.31	13.11	5.04	16.84	30.67	469.61	536.58	543.11
	Class Total	95.91	323.33	15.54	45.54	165.94	704.68	0	0
	Class Changes	10.21	64.5	8.43	45.28	138.42	235.07	0	0
	Image Difference	-7.41	135.15	46.08	8.19	-5.66	-161.57	0	0

Table 4.8 LU/LC change matrix of 1986-2000 (km2)

		LULC OF 1986							
		WB	AL	GL	SA	BL	SWL	Row Total	Class Total
	WB	83.3	0.41	0.03	3.06	0.05	0.91	87.75	87.75
	AL	0.09	390.68	5.56	6.33	74.5	88.45	565.61	565.88
	GL	0.85	3.66	34.4	13.54	2.08	14.18	68.72	68.73
LULC OF 2000	SA	3.42	2.1	9.18	10.72	1.17	9.39	36	36
	BL	0.02	21.32	2.58	1.45	92.62	27.52	145.52	145.59
	SWL	0.88	13.3	7.69	9.01	8.84	407.57	447.29	448.49
	Class Total	88.55	436.19	59.46	53.15	180.32	548.62	0	0
	Class Changes	5.26	45.51	25.06	33.43	87.7	141.05	0	0
	Image Difference	-0.8	129.69	9.27	-8.15	-34.73	-100.13	0	0

4.3.1 Change detection on the periods of 1973 and 1986

From the figure below Water body, swampy area, Bush land, and Shrubby woodland have been changed by –7.41, -8.19, -5.66 and –161.57 km^2 area respectively. Where as Agricultural land and grasslands have been increased by 135.15 and 46.08 km^2 area respectively; From this it can be concluded that the vegetation cover is decreasing very dramatically which accounts about 167 km ^{2} cumulative area of both Bushy and shrubby lands area the main reason for the reduction is sever deforestation due to encroachment and improper fire wood collection (W.W.D.C.S.A, 2001). This intern increases the expansion of agricultural lands, which results an increment of 135.15 km^2 area.

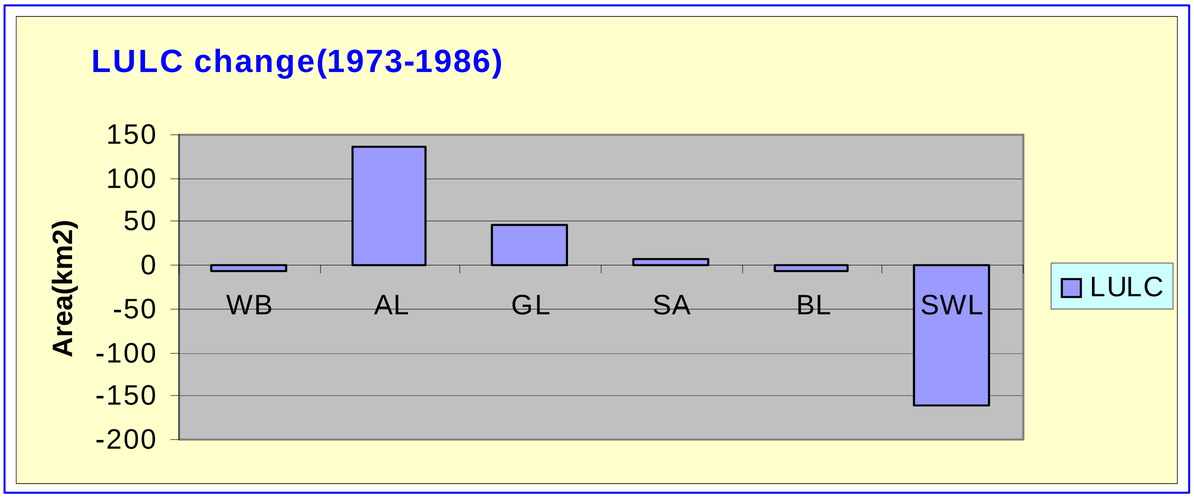


Fig. 4.8 LU/LC change (1973 and 1986)

The other most important Land cover, the lake, is under desiccation which accounts a decrement of –7.41 km^2 area . However this decrement was resulted from the extensive desiccation of the small lake named Cheleleka, which was directly affected by sedimentation problem due to extensive agricultural practices and deforestation on the upper catchment of the lake. In addition with the desiccation of the lake the wetlands around the lake has been under denudation due to the same reason mentioned above. In general this matrix explicitly shows the area of the LU/LC dynamics of the two image times.

As it is possible to see the direction of LU/LC change from the change matrix table 4.7, Agricultural areas are increasing at the expense of Shrubby woodlands and Bush lands which are showing negative image deference that indicates loss. This amount in this period is estimated from the table as103.31 from bush lands and 78.66 km^2 from Shrubby woodlands. The same works true for Lake (water body) in which the area coverage is reduced since Lake Cheleleka had been dramatically decreasing in this period.

4.3.2 Change detection on the periods of 1986 and 2000

In the second phase of detection (i.e. 1986-2000) the same LU/LC dynamics has been observed in all LU/LC classes the LU/LC which were under decrement are still decreasing (Water body, Swampy area, Bush land, and Shrubby woodland) and those which were increasing are still increasing (Agricultural lands and grass lands).

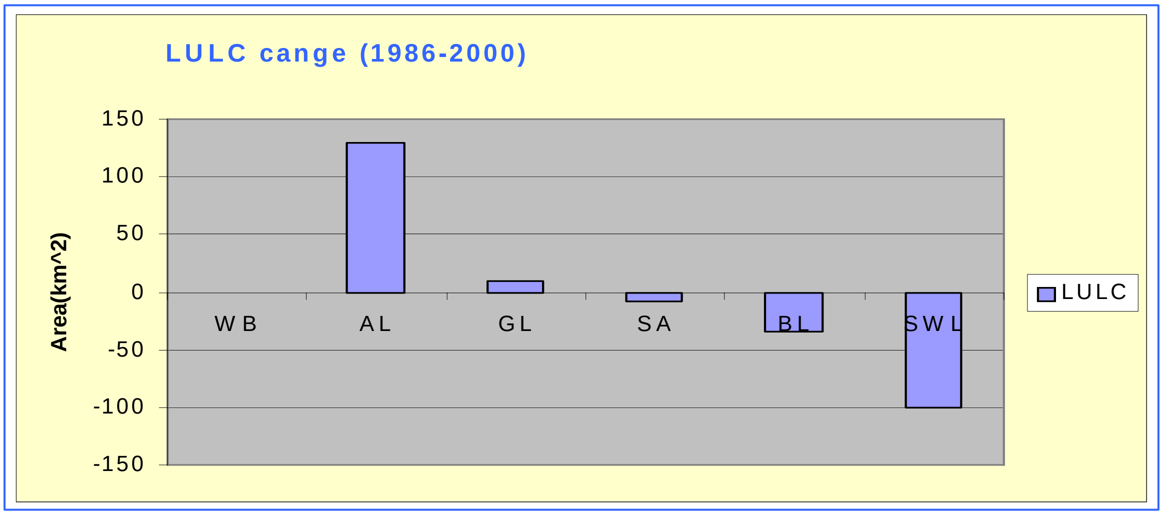


Fig. 4.9 LU/LC change (1986 and 2000)

However the extent of their change is some how different in acreage. The decrement of all the classes mentioned above has been found to be smaller in this phase of detection than the previous one especially the degradation rate of shrubby wood land has been reduced by half percent than before the reason behind this is due to intervention of different environmental and resource conservation in the catchments this is from informal interviewing with the inhabitants. Again except Agriculture and Grasslands the rest LU/LC classes are in decreasing situation. The secret of increasing of these classes is the conversion of Vegetation and swampy areas to agricultural area. From the table 4.8 like the previous ones depict 74.5 and 88.45 km^2 areas of Bush lands and Shrubby woodlands were changed to Agricultural areas.

Table 4.9 Summary of land use land cover change in 1973 and 1986 & 1986 and 2000 periods

LULC type	1973-1986		1986-2000	
	Km^2	%	Km^2	%
Water body	-7.41	7.7	-0.8	0.9
Agriculture	135.15	41.8	129.69	29.75
Grass land	46.08	25.4	9.27	15.6
Swampy area	8.19	15	-12.15	18.5
Bush land	-5.66	3.4	-34.73	19.3
Shrubby wood land	-161.57	23	-100.13	18.3
Urban area	2	33.3	5	62.5

4.3.3 Discussion on over all LU/LC changes in the catchment

Land use land cover changes like urbanization, change of shrubby woodland and bush land in to cultivated land and change of shallow Lake Cheleleka in to a swamp are found to be the major changes in the catchment. From the generalized map of the 1973, 1986 and 2000, it has been observed that aggregated area of bush land and shrubby woodland has been changing negatively on 1973 and 1986 change detection phase by 167.23 km^2 area and on 1986 and 2000 by 108.1 km^2 area and agricultural area has been changed positively on 1973 and 1986 by 143 km^2 and from 1986-2000 by 100 km^2, as it is occurred at the steeply slope area it highly affects infiltration condition of rain water which supply to the ground water by increasing surface runoff due to the reduction of vegetation cover which serves one as a barrier for reducing the speed of the runoff; second by adding organic mater to the soil which makes the soil spongy that improves both the water holding and infiltration capacity of the soil; thirdly 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 6 km^2 built up area of 1973 has grown to

$8km^2$ and 13k km^2 in 1986 and 2000 respectively which high increases surface runoff through creating compacted surface that hinder recharge. The amount of decline or increment of catchment runoff and ground water recharge varies with a land use land cover type.

The overall LU/LC mapping and change detection analysis is help full to know the LU/LC dynamics of the area which intern is important to understand the surface and subsurface hydrological condition of the catchments. In a general speaking the LU/LC dynamics of the Awassa catchments has under gone to very great change that enables to say there is a significant hydrological state change in the area. Nevertheless the factors governing the surface and subsurface hydrological conditions of a given catchmetn are not only controlled by the LU/LC dynamics rather many others evolved. In the next chapter all these factors with respect to ground water recharge would be discussed in detail.

5. HYDRO-METEOROLOGICAL DATA ANALYSIS

Any water resource study and planning without consideration of hydro meteorological data analysis will be futile; as these data are the major sources of information to tell about the hydrologic condition of a catchment. The most useful hydro metrological variables are stream discharge, lake level, precipitation, evapotranspiration, air temperature and relative humidity (Meyboom, 1961). But in this research of the meteorological elements Precipitation and evapotrancepiration were only analyzed as evaportanspiration is the reflection of various meteorological variables like temperature, wind speed and relative humidity.

5.1 Runoff analysis

Tikur wuha River is the main perennial river that drains the eastern escarpment and highland towards Lake Awassa witch covers about 625 km^2 area and it is the only gauged catchment. The rest 575 km^2 area is un-gauged. 18 years stream flow data gauged at Dato village was used to determine the total flow data of the catchment using Drainage area ratio and analog methods. Then the data was used in surface runoff and base flow analysis of the catchment.

5.1.1 Estimating total flow data of the catchment

(ii) Scaling up the stream flow values from the gauge to the size of the drainage area of catchment;

Scaling up was made by calculating the proportionality ratio (Drainage-Area Ratio) between the gauged sub-catchment drainage area and the drainage area of the total catchment.The estimation was made on consideration of the following conditions: climate patterns, soil characteristics, and land use land cover.

$$\mathbf{Q_{total} = (A_2/A_1)\, Q_{gauged}} \qquad (5.1)$$

$A_{1=}$ is the drainage area of the gauging station

$A_{2=}$ is total drainage area of catchment

$Q_{gauged=}$ is steam flow in m^3/sec of the gauged stream

$Q_{total=}$ is the total discharge in m^3/s

Applying this formula to the catchment results 2.6 multiplying factor to find the total discharge of the catchment. So to get the total flow of the catchment it is simply multimplying the gauged flow by 2.6.

Note:The monthly statistics of extrapolated flows is annexed in table-1.

(ii) Computation of total stream flow by the analogue method

When selecting the analogue catchment, particular attention has been paid to similarity of the catchments' under comparison in relation to physiographic features (topography, geology, climate, soils, vegetation), morphometeric features (drainage area, slope, etc) and other characteristics.

Since there is sufficient similarity between the catchments' under comparison in relation to the above characteristics, this provides a basis for transfer of discharge values from the base station to the un-gauged catchment.

If normal runoff and normal precipitation at the site with a short-term observation series are Q and P, and those for the analogue are Q_{an} and P_{an}, then:

$$\mathbf{Q = Q_{an} (P_{an}/P)} \qquad (5.2)$$

The analogue catchment is, in our case, a sub-catchment of the catchment under investigation, and the analogue precipitation is obtained from the nearby meteorology stations to the sub-catchment. The resultant flow values obtained from the above two methods are similar to each other and the values from the drainage area ratio was used for further analyses.

5.1.2 Recharge estimation

Ground-water recharge cannot be measured directly and is difficult to accurately estimate. Indirect recharge estimation can be subject to large errors and therefore, when possible, more than one method should be used to verify the estimates.

5.1.2.1 Hydrograph analysis

Hydrograph separation is the process of separating a plot of Runoff or discharge vs. time, known as a stream hydrograph, into base flow and surface runoff components. Base flow comprises the groundwater contribution to total stream flow, and a key starting assumption in performing a hydrograph separation is that base flow is a significant contributor to total stream flow in the selected stream. Clearly, it would be inappropriate to apply such a technique to an ephemeral stream fed only seasonally, or a stream that is only actively flowing after major precipitation events.

Hydrograph analysis is a useful technique in a variety of water-resource investigations. Separation of stream flow hydrographs into base-flow and surface-runoff components is used to estimate the ground-water contribution to stream flow. Hydrograph-separation techniques also have been used to quantify the ground-water component of hydrologic budgets and to aid in the estimation of recharge rates. In the next section these methods are discussed in detail to calculate ground water recharge (Meyboom, 1961).

A) Base flow: - This is a water or flow that is contributed to the river from Ground water. This flow sustains the river when there is no rainfall of course some streams have base flows all year round (Perennial stream) but in most cases base flows sustain the river for few days after rainy season and cease.

N.B. it does not mean that base flows occur only during dry seasons. It occurs in rainy season too. Extended rainfall duration, saturated soil and availability of water offer saturation are favorable conditions for deep percolation.

B) Surface runoff: - This is the part that flows above (on) the surface. So, it's the water that travels over the earth surface. This part occurs only when the precipitation rate is grater than the losses. So lower rate or amount of rainfall may not contribute anything to the surface runoff.

Daily and monthly flow data was used to determine the base flow and surface runoff of the catchment using the time-plot and seasonal recession methods since using of more than one method during ground water recharge estimation is very mandatory to improve the accuracy of the result because of the difficulty and susceptibility of the ground water recharge estimation to error so utilization of more than one method of estimation helps to reduce the error and to approach to the reality. As the seasonal recession method uses the average monthly data it generalizes some peak discharge, which can lead to error during the ground water recharge and surface runoff estimation so verifying the result again by using the time-plot, which uses the daily discharge, is important.

The separation of surface runoff and base flow has been made manually from extrapolated mean monthly flows and using a computer code known as Time-Plot, developed by Gabriel Parodi, which uses daily flow values and an attenuation coefficient that is controlled by the slope, land-use and land cover conditions of a watershed possessing a value in the range of **0.9-0.995**.

B) Method-1. Base flow Separation using time plot

There is much uncertainty for monthly flow volumes to be used for base flow separation purposes, as the information on short-term flow variability has been lost. While it can be concluded that it is possible to determine regionalized parameters from monthly data separation that includes short term flow variability. Hence base flow separation using time plot is important as it uses daily discharge data.

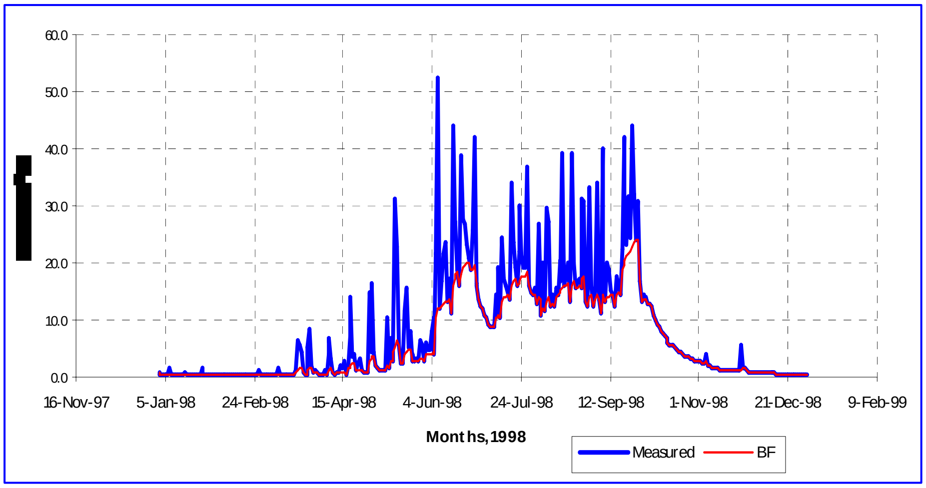


Fig 5.1 Base flow-surface runoff separations using Time-plot-1998

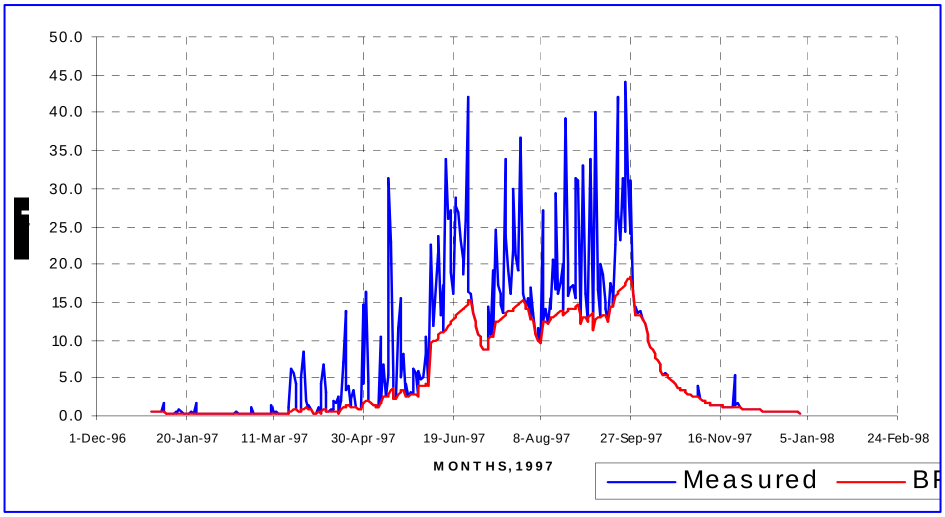


Fig 5.2 Base flow-surface runoff separations using Time-plot-1997

A) Method-2: Seasonal recession method

This method involves in the identification of one large recession trend and one large recharge trend in a semi-logarithmic seasonal hydrograph over a 12 month period for two or more consecutive years (Meyboom, 1961). If the exponentially decayed recession trend is plotted on a semi-logarithmic paper, it gives a straight line. The assumption is that the discharge of the stream during this large recession period below the recession trend line will be entirely due to the ground water contribution. Then, the total groundwater recharge is calculated by using the total potential groundwater discharge volume at the beginning of the recession minus the volume of potential groundwater discharge left at the end of the recession (Fetter, 1996) Based on the method,

$$V_{tp} = Q_0 t_1/2.3 \qquad (5.3)$$

Where V_{tp} = volume of the total potential groundwater discharge, m^3

Q_0 = the base flow at the start of the recession, m^3/sec

t_1 = the time that it takes the base flow to go from Q_0 to 0.1^*Q_0, sec

The remaining potential groundwater discharge at the end of a recession, V_t, is obtained by:

$$V_t = V_{tp}/10^{t/t1} \qquad (5.4)$$

Where t is time length from start of recession to end of the recession

The groundwater recharge, $R = V_{tp} - V_t$ (5.5)

Based on these methods, the groundwater recharge for consecutive 18 years was calculated and presented in appendix2.

5.1.2.2 Trend of base flow

Based on the result seen on fig.5.7 the general trend of the groundwater recharge of the catchment is significantly decreasing. So if conditions continue like this we can easily deduce that, what will be the fate of the ground water after some decades in the future. So to alleviate the problem of ground water recharge condition of the catchment it is very mandatory to examine the factors that have good relation with ground water recharge such as LU/LC change (especially vegetation cover change) and hydro meteorological elements (runoff, precipitation and evaporation), to do that temporal trend analysis of these factors were carried out, which helps to identify factor (parameter) that has significant influence on it,

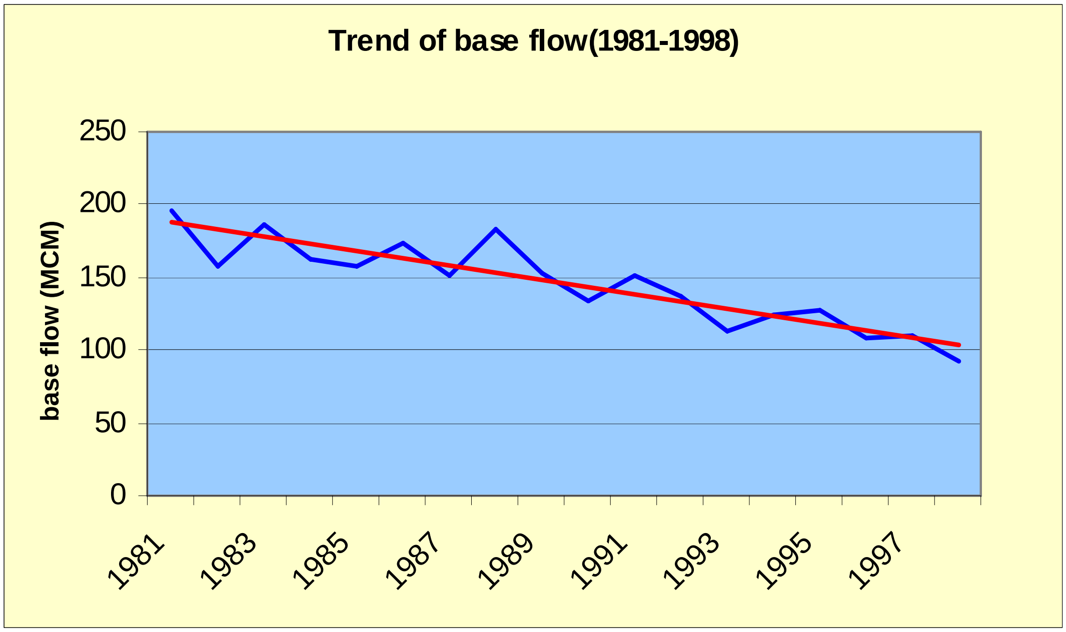


Fig. 5.3 Temporal trend of ground water recharge

5.1.2.3 Trend of Surface runoff

As it is seen in the fig below the surface runoff the cathment is increasing from time to time with some fluctuations in between.frow this we can easily understand that how the recharge condition of the catchment is reduced.

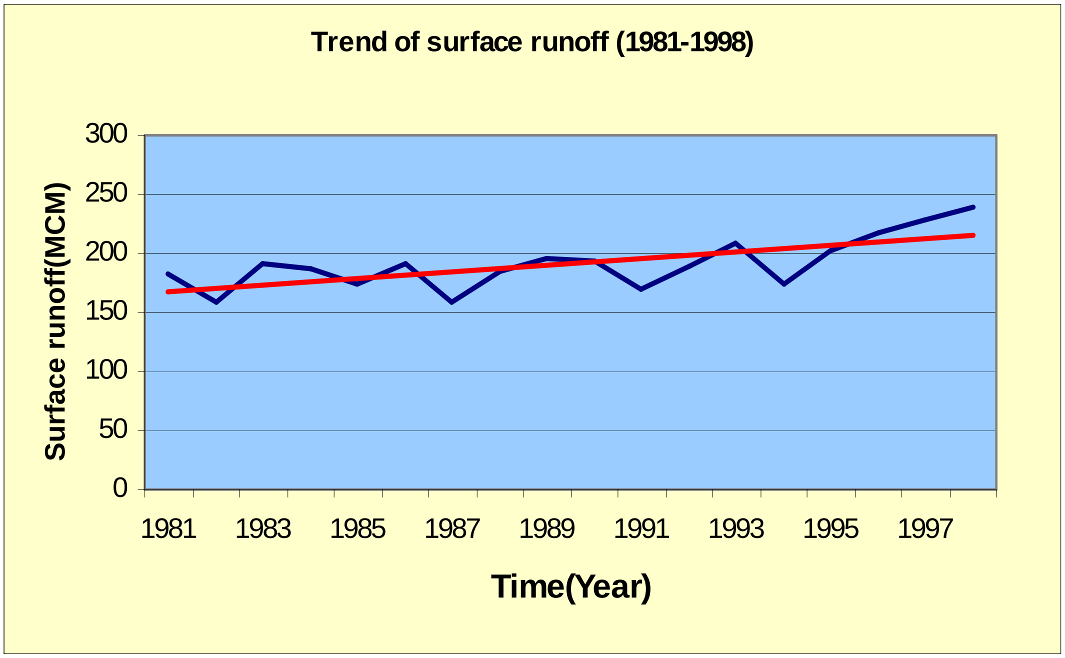


Fig. 5.4 Temporal trend of surface runoff

5.2 Lake level analysis:

The study area is a closed catchment with out surface connection with the surrounding basins. There is no surface water that enter out of the catchment or leaves out the catchment. Lake Awassa is the main water body in the area, following Lake cheleleka, which at present becomes a swampy area. 32 years annual lake level data of Lake Awassa were used to analyze the trend (see fig.5.5) of the lake level, which indirectly tells about the hydrologic condition of the catchment.

5.2.1 Trend of Awassa Lake Level

Based on the trend analysis the lake level shows generally increasing trend with some fluctuation in between, which is the main problem of the people settled around the lake due to flooding incidence. The reasons for increasing of the lake level are 1) the increment of surface runoff that inter to the lake but the contribution of ground water recharge to the lake is insignificant as stated by (Yemane, 2004), 2) the disappearance of Lake Cheleleka which serves as a regulator for Lake Awassa due to sedimentation results from excessive deforestation of the eastern highlands that produce high runoff to the lowlands shortly after individual storms (W.W.D.S.E 2001). As a result of losing its function as sediment trap, water and sediment load to Tikurwuha is now directly going in to Lake Awassa so due to these reasons the general trend of the lake level is increasing with some fluctuation in between.

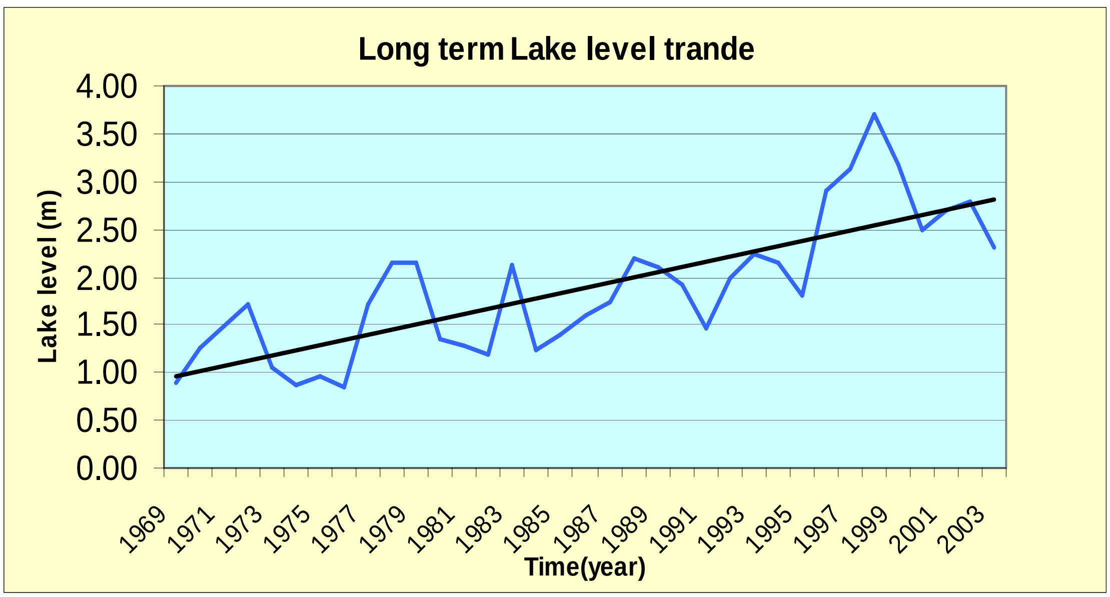


Fig. 5.5 Stage increment of Awassa Lake level

5.3 Meteorological data analysis

This topic focuses on the analysis of rainfall and evaporation characteristics of the catchment. Since rainfall is 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. There fore analysis of these factors are very important to know their effect on ground water recharge.

5.3.1 Annual rainfall depth over the catchments

The rainfall measurement at a point observation may not be used as a representative for catchments. Therefore point measurements have to be averaged over the area for hydrological study that needs knowledge of geographical distribution of a point rainfall records. The mean rainfall depth analysis over the catchments is estimated or calculated using Thiessen polygon method. Long-term annual rainfall records for five stations were taken from National Meteorological Service Agency (NMSA) in order to analyze the temporal variations in precipitation with in the catchment. All of the stations are located in the catchment, where three of them are near the water divide (The mean monthly data are listed in appendix 4).

Thiessen polygon method

This method gives good results when rain gauges are not evenly distributed with in the catchments in both flat and hilly terrain (Tenalem and Tamiru, 2001, Jaya rami, 1996). To compute the average rainfall depth over the area using this method, five stations found in the catchments were used. Aerial depth of precipitation obtained using this method was presented in (table5. 1, and fig.5.6). From the result shown in table 5.1, the total annual precipitation over the catchment is 1038mm.

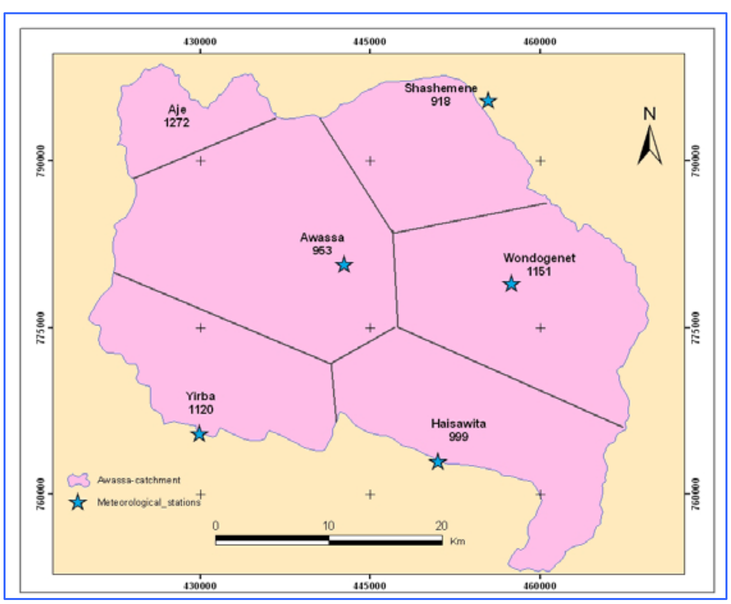


Fig.5.6 Theissen polygon of the catchment

Table.5.1 Theissen mean annual rainfall

Stations	Mean annual rainfall (mm)	AREA	Area (%)	Theissen mean
Haisawita	999.00	229.5	16.68	166.6
Wendogenet	1151	282	20.49	235.9
Shashemene	918	147.6	10.73	98.5
Yirba	1120.00	178.5	12.97	145.3
Aje	1272.00	79.4	5.77	73.4
Awassa	953.00	459	33.36	318
	Total area	1376		1037.7

5.3.2 Trend of Annual Rainfall

One of the determinant factors of hydrologic condition of a catchment is the rain falling on the cathcment area. 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 last 18-29 year's annual rainfall trend of the stations found in and around catchment area has been analyzed and presented in figure 5.7 From this result the trend of rainfall doesn't show clear change except fluctuation along the mean. Therefore based on this it is possible to say the rainfall has no significant impact for the reduction of the recharge so there should be another factor. Hence analysis of the other meteorological element, which is evapotranspiration that has great influence on the recharge, is mandatory.

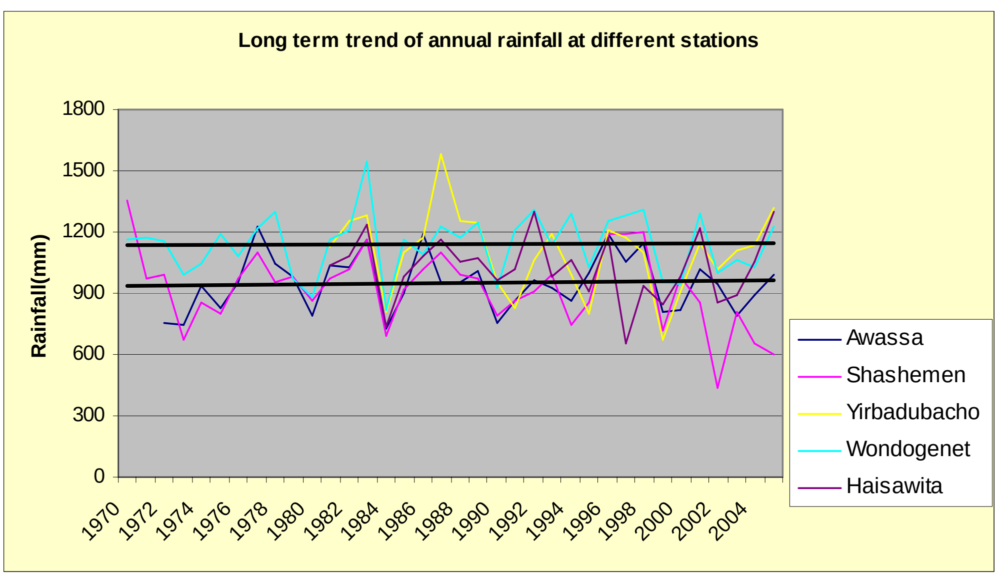


Fig.5.7 Trend of annual rainfall

5.3.3 Evapotranspiration

To estimate reliable evapotranspiration values in the study area, there is lack of enough data stations except Awassa where class A recording station is available. Others have only rainfall recorders. There fore an attempt is made to estimate the catchment ET (evapotranspiration) from available station records.
The station has 19 years Pan Evaporation recorded data. Hence this data is used for calculation of potential Evapotranspiration of the catchment using penman method.

Evapotranspiration involves both processes of water evaporation from soil surface and transpiration by growing plants. To measure evaporation and transpiration separately is very difficult. Therefore, these are generally grouped together in one term. Transpiration is the process where by water is brought up through the plant root, circulated throughout the plant structure and finally returned (transpirated) to the atmosphere.

Potential Evapotranspiration

PET is the maximum amount of water that could be evaporated by vegetation assuming an unlimited supply of water in the ground. There are several methods for calculation of potential evapotranspiration such as: Blaney–Craiddle, Penman, etc. In this study Pan Method is used for calculation of ETP.

Pan evaporation approach, penman 1, 1950a

The method relates potential evapotranspiration from a vegetated land surface to the evaporation from open water, (penman,1950a). Pans provide an observation of effects of radiation, wind, temperature and humidity on evaporation; all integrated together from an open surface the response of plants are in the same fashion. But heat storage, reflectivity, air turbulence, temperature and humidity of the plant and pan vary widely. All these factors are included in the pan coefficients from many observational researches on the effect of climate on crop evapo-transpiration (UNESCO, 1987).

ETo = Kp * Epan (5.6)

Where

Kp =Pan coefficient
Epan =Pan evaporation

The appropriate value of pan coefficient was selected based on the ground cover of the pan station and its surroundings and general wind and humidity conditions (FAO, 1977). Accordingly, for the mean relative humidity range of 40-70% (medium), mean speed of 24 hour wind ranging from 175-425 km/day (moderate), and pan station surrounded to a distance of 10 -100m by green crop in the wind ward side, the pan coefficient, f, is determined to be 0.8 (FAO, 1977). Based on this method, PET of the study area is calculated to see its trend.

5.3.3.1 Trend of potentialevapotranspiration

The other factor, next to rainfall, that influences hydrologic condition is evapotranspiration, which is dependent on the temperature, wind and relative humidity of the area. In this regard 19-year pan-evaporation data of the area was used to determine PET of the study area. Therefore this data is used to analyze the trend of evapotraspiration of the catchment over the past 19 years of period. Based on this the potential evapotranspiration of the area shows a decreasing trend that favors the recharge (base flow) but still the base flow of the catchment shows decreasing trend so there mast be another factor that highly affects the base flow (recharge) that is land use land cover change (vegetation cover reduction). Long-term PET calculated from pan evaporation data is presented in the fig below.

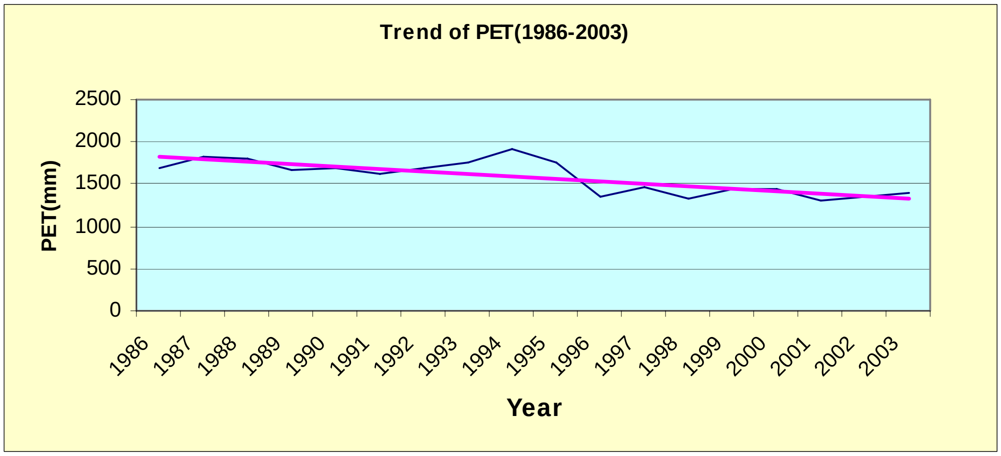


Fig. 5.8 Annual trend of PET from pan evaporation

Understanding of ground water recharge with respect to evaporation in this context depicts there is no effect of evaporation on the area as it is generally in decreasing trend rather favors the ground water recharge but still the recharge is decreasing.

Analysis of the Meteorological factors which control base flow and surface runoff shows a favor since evapotranspiration is in a decreasing trend that favors recharge. And rainfall shows no clear change that could reduce the base flow of the catchment. Generally all the meteorological factor have no significant effect on the ground water recharge but something else reduce ground water recharge other than the meteorological elements. In the next section, relation between vegetation cover change and ground water recharge is going to be discussed.

6. COMPARISON OF GROUND WATER RECHARGE AND VEGETATION DYNAMICS

It has been observed that the ground water recharge is progressively declining in substantial rate. The decline in rate of recharge has been treated by analyzing the temporal trend patterns of some of the hydro meteorological elements that have a good relationship with groundwater recharge. Based on the result observed in the previous section and the fig.below these factors don't shows any significant impact rather trend of some factor (evapotranspitation) shows fevor to recharge however the recharge is still in a decreasing trend. Therefore analyzing the relation between recharge and LULC change of the catchment especially vegetation cover is necessary to see if this change has an impact on the recharge similarly comparing their temporal trend does this.

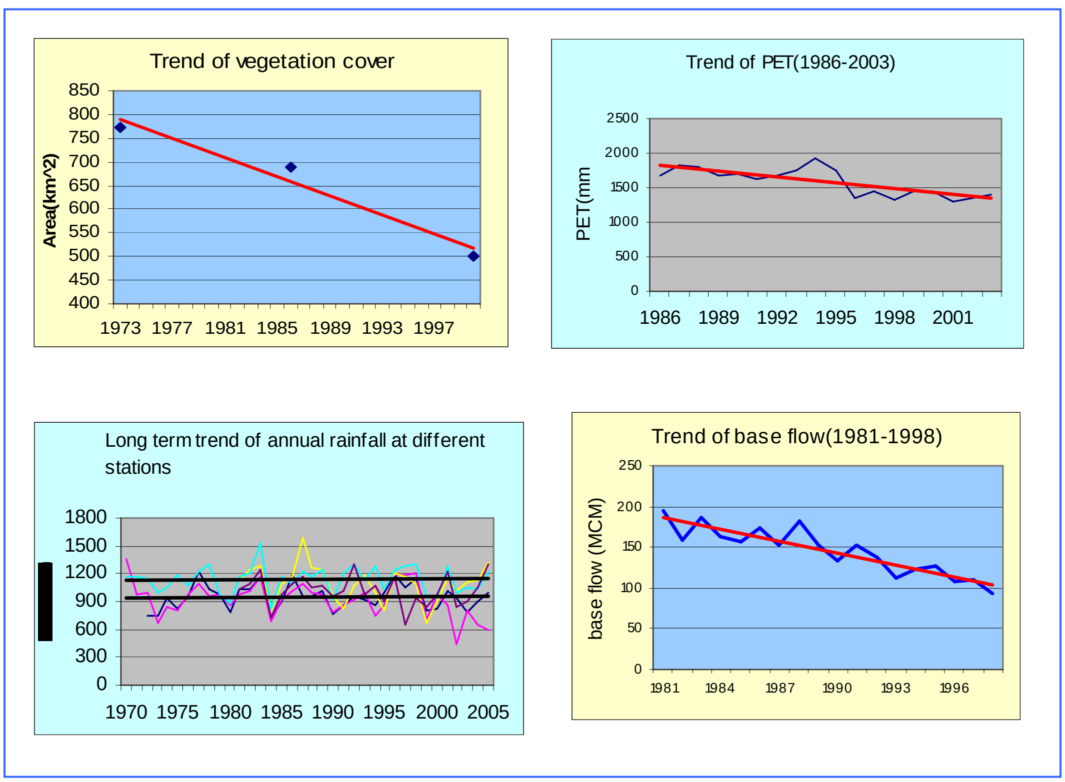


Fig.6.1 trend of ground water recharge and the different factors

Based on the figure below ground water recharge and vegetation cover change moves in a similar fashion so from this it can be concluded that the main factor for the reduction of recharge is the excessive deforestation takes place in the catchment.

6.1 Impact of LU/LC change on the hydrological condition

It has been known for many decades that water in the hydrological cycle is in a continuum between the various parts of the cycle, and development or contamination of one component will affect the other parts of the cycle. In the catchment Vegetation cover has changed dramatically in the past 28 years due to high demand of forest products like firewood, charcoal, and timber for furniture and house construction (W.W.D.S.E., 2001). These changes have in turn affected the hydrological condition of the catchment by enhancing surface runoff and reducing ground water recharge. Vegetation cover reduction reduces recharge through the following ways:

Infiltration is the process by which water moves through the soil surface into the soil matrix and percolation is the process by which it moves down through the profile and into the underlying weathered rock. Vegetation has a significant impact on infiltration both by providing canopy and litter cover to protect the soil surface from raindrop impacts and by producing organic matter, which binds soil particles and increases its porosity (SCOTT DF and Le MAITRE DC, 1998).

Litter on the ground surface tends to retain more water than bare soil and improves conditions for infiltration into the soil. Infiltration rates are positively related to litter and grass basal cover, being up to 9 times faster with 100% litter cover than for bare soil (O'Connor, 1985). There fore the higher infiltration rates in area covered by vegetation were related to lower bulk density, lower penetration resistance and a greater litter mass (organic matter input). But in caltivated or bare land area the condition is the reverse i.e. there is high bulk density, high penetration resistance due to compacted surface and low organic mater input. Roots may provide channels for the preferential flow of water through the unsaturated zone to the water table, particularly in low-permeability soils, thereby increasing recharge. Hence the reduction in vegetation cove affects this process and enhances surface runoff rather than recharge.

7. CONCLUSION AND RECOMMENDATIONS

The application of RS and GIS based methodology for assessment of the effects of land use land cover change on the hydrologic regime of the Awassa catchment, has led to the following conclusions and recommendation.

7.1 Conclusion

Based on the over all of the researches work, it is possible to conclude the following points. Remotely sensed images are vital in land use/land cover change detection as it provides spatial and temporal information of the land use land cover condition of the catchment.

Land use and land cover change detection method used in this study was post-classification comparison and multi-date composite image change detection, which is very important in knowing the from- to change.

The multitemporal analysis of satellite image data clearly indicate, Land use changes like urbanization, change of shrubby woodland and bush land in to cultivated land and change of shallow Lake Chelelekа in to a swamp are found to be the major changes in the catchment.

To put the change figuratively the aggregative vegetation cover has been changing negatively from 1973-1986 by 168.7 km^2area and from 1986-2000 by 108.1 km^2 area, and agricultural area has been changed positively from 1973-1986 by 143 km^2 and from 1986-2000 by 100 km^2. Similarly 6 km^2 built up area of 1973 has grown to 8 km^2 and 13 km^2in 1986 and 2000 respectively that aggravate surface runoff by creating compacted surface which hinder infiltration. To segregate the effects of land use land cover change from climate variability over the catchment hydrological data were analyzed independently in the study.

Analysis of the meteorological factors which supposed to control ground water recharge shows insignificant effect on ground water recharge since rainfall doesn’t show clear change and evapotranspiration is in decreasing trend that favor recharge but something else reduce ground water recharge other than the meteorological elements that is vegetation cover reduction due to excessive deforestation on the recharge zone of the catchment.

Based on the trend analysis both ground water recharge and vegetation cover change showed similar trend. The research not only understands the ground water recharge but also the lake level fluctuation of lake Awassa, and concluded that the lake level is increasing from time to time and this is due to the runoff volume increment due to vegetation degradation.

From this result the study concluded that the significant change in ground water recharge (see fig.5.3) is due to land use and land cover change (especially vegetation cover reduction) in the catchment for the last three decides which bring about change in the runoff generation and recharge reduction by the reasons mentioned in subtopic 6.1.

7.2 Recommendation

- ❖ As it is possible to conclude that, decrease in ground water recharge is brought from the extensive deforestation in the catchment which intern yield high runoff than recharge, is due to poor land use planning and improper land use managment; Therefore to safeguard the ground water existence in the area there should be enforceable land use polices and alternative energy source for the surrounding people that depend on forest product as source of energy.
- ❖ Creating awareness on the surrounding people to use the forest resource properly and to practice off-farm activities that serves, as alternative source of income (developing cooperative that involve in different business activities, introducing micro finance, etc) then by doing that the

deforestation activity by the surrounding people will decrease by reducing their dependency on the forest product.

- ❖ The over all result of the research warn that there is a significant ground water scarcity in the near future if conditions goes like this; and this needs an immediate action to reinstate the normal situation. Hence in this regard it is highly recommended to protect the remaining patch of vegetations in the area and to apply both physical and biological conservation measure to reclaim the degraded area.

- ❖ The research not only understands the ground water recharge but also the lake level fluctuation of lake Awassa, which concluded that the lake level is increasing from time to time. This put the town under threat of flooding; the reason behind this is excess runoff production on the catchment especially on the eastern part of the catchment due to deforestation. Therefore, the research out put again warns the lake level rise will continue unless some protection measures which reduce the runoff entering to the lake is put in to action. Like allowing to reclaiming the eastern part of the catchment from which almost all of the runoff receive the lake. By doing this it is possible to reduce risk of flooding as the lake Awassa and Cheleleka are found almost on similar elevation range which helps the lake Awassa to flow back to the chelelka during high lake level rising.

7.3 Future research

This study needs to be continued to include more time series data. The next stages of development should focus on a GIS modeling approach in order to simulate the catchment dynamics for different land use scenarios. Assessing the effect of land use changes on water quality and sediment yield is another need for sustainable management of the Awassa catchment.

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APPENDICES

Appendix-1

Modified Monthly flow of tikurwuha River at Dato Village (Mm3)

Y/M	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1981	3.12	2.08	1.72	7.85	8.84	5.80	8.55	26.70	69.43	41.91	24.00	3.33
1982	1.48	1.33	1.25	2.37	6.03	5.98	19.81	19.34	50.29	34.42	15.65	11.83
1983	5.72	2.37	1.87	2.70	24.62	35.39	16.77	23.63	61.45	41.24	26.05	13.31
1984	8.37	5.02	3.48	2.65	3.20	7.28	10.71	15.78	41.03	17.08	4.16	2.34
1985	1.48	0.88	0.44	0.10	5.64	11.60	5.56	11.18	29.07	29.69	5.30	2.03
1986	5.20	1.01	1.38	2.16	6.92	36.43	33.80	36.19	94.10	35.18	24.00	16.41
1987	2.65	1.30	2.37	7.38	24.26	28.99	13.75	9.67	25.15	17.81	10.14	5.49
1988	3.56	2.57	2.96	2.94	4.13	7.70	18.67	37.23	96.80	39.08	24.28	12.66
1989	9.57	6.97	6.76	7.07	9.72	19.24	15.60	16.43	42.72	31.17	17.47	11.60
1990	10.14	8.53	20.20	35.72	24.41	12.92	12.90	18.33	47.66	41.18	29.25	7.88
1991	5.90	3.80	3.15	8.27	24.52	9.00	17.42	25.77	66.99	36.11	23.17	13.73
1992	5.41	1.98	1.61	2.16	7.93	11.08	15.08	20.67	53.74	56.08	37.83	12.97
1993	7.57	4.81	3.51	2.83	9.85	24.44	30.99	29.95	77.88	41.11	30.58	26.73
1994	15.16	4.16	2.34	4.21	6.99	11.31	19.60	38.53	100.18	28.13	19.08	15.39
1995	12.14	9.05	2.86	6.45	11.44	16.59	19.71	25.27	65.71	33.28	40.56	47.81
1996	11.70	8.32	7.80	11.49	26.00	38.53	41.11	40.90	106.33	53.40	42.35	33.41
1997	22.91	16.22	14.98	11.60	15.34	15.89	14.12	16.07	41.78	27.51	33.88	42.02
1998	47.84	41.60	27.82	11.70	24.44	47.84	48.88	39.78	103.43	55.90	36.14	24.96

Appendix-3

REGION: SIDAMO	
STATION: AWASSA	
ELEMENT: MONTHLY TOTAL PAN EVAPORATION IN MM	

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	average annual evaporation
1986	230.50	211.70	240.90	176.60	113.20	140.20	124.40	146.90	162.60	172.40	192.50	188.10	2100.00
1987	239.80	200.10	179.90	179.90	190.70	173.80	173.50	172.20	154.50	175.10	208.00	230.50	2278.00
1988	212.90	203.30	243.20	192.10	206.30	171.40	110.20	146.60	140.20	164.50	273.50	193.00	2257.20
1989	196.40	126.30	227.60	155.40	219.60	183.50	129.40	153.70	166.60	179.70	189.10	158.60	2085.90
1990	180.50	143.60	167.20	173.90	187.00	187.70	149.70	143.20	158.40	198.60	198.50	224.20	2112.50
1991	222.30	191.00	178.10	154.60	153.00	159.10	120.60	142.10	149.40	183.60	178.50	188.10	2020.40
1992	152.50	120.90	254.40	216.20	182.00	185.60	178.40	160.70	135.30	155.50	177.60	184.40	2103.50
1993	182.70	163.60	237.10	170.00	200.10	161.50	153.20	161.70	148.20	169.70	212.30	234.80	2194.90
1994	250.10	242.90	235.30	195.10	179.70	179.70	121.60	141.50	162.40	206.10	231.30	248.90	2394.60
1995	267.20	242.50	240.00	182.00	202.90	198.80	122.60	107.50	118.50	139.20	158.50	202.60	2182.30
1996	148.10	183.00	159.10	140.30	129.40	109.40	108.30	118.00	103.20	149.90	164.80	176.54	1690.04
1997	169.60	211.90	203.10	126.60	169.00	143.90	146.30	153.90	114.30	128.10	110.20	139.90	1816.80
1998	207.60	129.80	149.30	152.50	143.50	141.20	113.80	103.80	110.70	93.40	144.90	170.30	1660.80
1999	177.80	196.80	150.30	162.00	160.10	152.40	128.90	133.50	109.80	103.30	153.80	171.80	1800.50
2000	201.50	201.80	205.20	158.20	131.20	142.40	127.60	117.10	113.00	113.90	139.00	158.80	1809.70
2001	156.40	172.70	137.90	144.20	130.30	105.30	104.70	114.10	109.50	120.90	154.50	170.30	1620.80
2002	153.80	164.20	149.60	144.70	136.50	131.50	147.30	103.80	111.50	136.40	183.60	138.50	1701.40
2003	160.30	174.00	149.30	109.90	145.40	130.20	96.80	117.50	129.50	156.60	190.40	183.00	1742.90

Appendix-4

Lake level of lake awassa (m.a.m.s.l)

Y/M	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1969	-	-	-	-	-	-	-	-	-	1679.7	1679.6	1679.5
1970	1679.3	1679.3	1679.3	1679.3	1679.3	1679.3	1679.3	1679.4	1679.6	1679.9	1680.0	1679.8
1971	1679.7	1679.5	1679.4	1679.3	1679.4	1679.5	1679.6	1679.8	1679.9	1680.0	1680.1	1680.0
1972	1679.9	1679.9	1679.8	1679.8	1679.9	1680.0	1680.0	1680.2	1680.4	1680.5	1680.4	1680.3
1973	1680.1	1680.0	1679.8	1679.6	1679.6	1679.6	1679.6	1679.7	1679.8	1679.9	1679.8	1679.6
1974	1679.5	1679.3	1679.2	1679.2	1679.2	1679.2	1679.2	1679.3	1679.4	1679.7	1679.6	1679.4
1975	1679.3	1679.1	1679.0	1678.9	1678.9	1678.9	1678.9	1679.2	1679.4	1679.7	1679.7	1679.5
1976	1679.4	1679.2	1679.1	1679.0	1679.0	1679.0	1679.0	1679.1	1679.3	1679.4	1679.5	1679.4
1977	1679.4	1679.3	1679.3	1679.2	1679.2	1679.3	1679.3	1679.5	1679.6	1679.8	1680.2	1680.3
1978	1680.2	1680.0	1680.0	1679.9	1679.9	1680.0	1680.0	1680.2	1680.4	1680.7	1680.8	1680.7
1979	1680.6	1680.6	1680.5	1680.5	1680.4	1680.4	1680.5	1680.6	1680.7	1680.8	1680.8	1680.7
1980	1680.6	1680.4	1680.3	1680.2	1680.2	1680.1	1680.1	1680.1	1680.1	1680.1	1680.1	1679.9
1981	1679.7	1679.5	1679.5	1679.6	1679.6	1679.5	1679.5	1679.6	1679.8	1680.0	1680.0	1679.8
1982	1679.7	1679.6	1679.5	1679.5	1679.4	1679.4	1679.4	1679.5	1679.6	1679.7	1679.7	1679.7
1983	1679.6	1679.6	1679.5	1679.4	1679.5	1679.9	1680.0	1680.1	1680.4	1680.7	1680.7	1680.7
1984	1680.5	1680.3	1680.2	1680.0	1680.0	1680.0	1680.0	1680.0	1680.0	1680.0	1680.0	1679.8
1985	1679.6	1679.5	1679.3	1679.3	1679.4	1679.5	1679.5	1679.7	1679.8	1679.9	1680.0	1680.0
1986	1679.7	1679.5	1679.4	1679.3	1679.3	1679.5	1679.7	1679.8	1680.0	1680.3	1680.3	1680.2
1987	1680.0	1679.8	1679.7	1679.7	1679.8	1680.2	1680.3	1680.3	1680.4	1680.5	1680.4	1680.3
1988	1680.1	1680.0	1679.9	1679.7	1679.7	1679.7	1679.8	1680.0	1680.4	1680.8	1680.9	1680.8
1989	1680.6	1680.5	1680.4	1680.4	1680.4	1680.5	1680.5	1680.5	1680.6	1680.7	1680.7	1680.7
1990	1680.6	1680.5	1680.5	1680.6	1680.7	1680.7	1680.6	1680.7	1680.7	1680.7	1680.7	1680.5
1991	1680.3	1680.2	1680.2	1680.1	1680.1	1680.1	1680.1	1680.2	1680.2	1680.3	1680.2	1680.0
1992	1679.9	1679.8	1679.7	1679.7	1679.6	1679.6	1679.7	1679.8	1680.0	1680.4	1680.6	1680.6
1993	1680.5	1680.5	1680.4	1680.3	1680.4	1680.5	1680.5	1680.6	1680.7	1680.8	1680.9	1680.8
1994	1680.6	1680.5	1680.3	1680.2	1680.3	1680.3	1680.3	1680.6	1680.9	1680.9	1680.9	1680.7
1995	1680.5	1680.4	1680.3	1680.3	1680.3	1680.2	1680.2	1680.3	1680.5	1680.6	1680.4	1680.4
1996	1680.3	1680.1	1680.0	1680.1	1680.2	1680.5	1680.8	1681.1	1681.4	1681.6	1681.6	1681.5
1997	1681.4	1681.1	1681.0	1680.9	1680.9	1680.9	1681.0	1681.1	1681.2	1681.3	1681.6	1681.7
1998	1681.7	1681.6	1681.7	1681.6	1681.6	1681.6	1681.7	1681.8	1681.9	1682.2	1682.4	1682.2
1999	1682.1	1681.9	1681.8	1681.7	1681.6	1681.6	1681.6	1681.6	1681.6	1681.8	1681.9	1681.7
2000	1680.3	1680.2	1680.4	1680.6	1681.1	1681.0	1681.0	1680.9	1681.0	1681.2	1681.3	1680.0
2001	1680.0	1680.5	1680.2	1680.8	1680.8	1681.0	1681.1	1681.2	1681.4	1681.6	1681.7	1681.6
2002	1681.4	1681.3	1681.2	1681.2	1681.2	1681.2	1681.1	1681.2	1681.3	1681.3	1681.2	1681.0
2003	1680.9	1680.8	1680.7	1680.6	1680.7							

Appendix-5 **Mean Monthly Rainfall for different station**

Mean Monthly Rainfall in mm Awassa Station

Y/M	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1972	13	15	75	65	116	78	70.6	143.4	123.7	17.4	8.5	31.1	756.7
1973	17.9	7.4	0	65.9	148.2	83.4	116.4	181.5	82	33.9	0.7	6.2	744
1974	7.7	28.3	97.9	6.8	106.5	118.3	210	159.3	163.9	37.5	0	3.3	940
1975	10.2	36.5	34.2	103.6	98.4	88.4	175	119.7	107.8	46.7	5.7	0	826
1976	6.5	33	78	42.1	171	70.4	161.2	134.2	112.6	79.1	47.1	18.2	953
1977	87.1	53.2	37.9	94.7	113.6	108.1	123.5	120.7	130.4	222.9	122	12.1	1226
1978	3.3	164.9	23.9	96.8	118.9	85.7	74.7	118.2	199.1	58.9	57.1	41.4	1043
1979	65.9	37	53.3	99	121.5	66.6	126.3	136.4	158.8	86.1	0	27.3	978
1980	13.8	15.5	38.3	110.6	112.5	73.8	88.3	127.7	40.2	139.1	34	0	794
1981	0	25	198.7	135.9	48.3	127.2	132.9	155.9	157.3	52.4	7	0	1040.6
1982	49.6	46.6	99.9	92.1	70.8	121.1	166.3	117.1	72.7	95.9	84.4	12.4	1028.9
1983	60.5	47.9	56.3	186.2	239.4	76.2	102.8	125.9	153.9	90.6	14.2	6.4	1160.3
1984	0	0	36.5	17.4	170.2	70.7	96.1	92.7	165.7	27.4	34.5	13.3	724.5
1985	9.2	0	75.7	201.9	93.3	106.9	146.1	80.7	116.4	50.2	12.8	8.3	901.5
1986	0	34.7	69.6	109.8	167.2	193	153.3	194.2	171.8	57.3	22.8	18.4	1192.1
1987	0.1	11.8	151.4	127.8	230.8	58	97.3	108.1	68.8	100.1	0.4	4.1	958.7
1988	25.8	68.5	17.5	80.9	100.1	110.9	117.7	138.8	205	83.9	1.3	6.6	957
1989	38.8	49.9	62.8	191.8	95.2	123.8	78.1	86.4	166.3	44.7	22.3	50.2	1010.3
1990	10.5	93.7	121.1	89.9	85.3	44.4	139.5	39.5	94.1	27.3	7.6	3.8	756.7
1991	12.3	90.6	87.4	48	129.5	116.7	109.2	90.6	104	21.6	12.2	44.8	866.9
1992	23.4	83.2	73	109	60.5	83	92.8	123.6	74.5	142.3	80.1	16.6	962
1993	101.6	109.1	22.3	104.9	165.3	46.7	54.7	130.8	47.8	130.8	10.5	3.9	928.4
1994	0	4.7	56.8	108.7	80.8	146.2	195.7	118.9	68.9	58.8	19.1	2.9	861.5
1995	0.8	21.4	61.8	156.1	43.6	118.7	175.7	134.7	166.8	22.3	18.3	84.2	1004.4
1996	78.4	36.9	89.6	113.8	161.5	243.3	121.2	108.7	145	69.6	19.7	1.4	1189.1
1997	23.4	1.7	75.1	125	73	111.2	98.6	113.9	118.9	157.1	132.2	24	1054.1
1998	92	140	90.8	86.4	88.4	56	172.9	108.3	109.6	193.3	10.6	0	1148.3
1999	19.8	0.4	105.5	27.1	64.7	99.8	135.1	83.8	115.4	120.4	20.1	16.8	808.9
2000	1.1	0	11	132	145.1	36.4	80	179.3	87.6	110.7	29	9.3	821.5
2001	1.8	39.9	122.7	67	233.7	137.5	93.5	131.7	89.7	80.2	2.6	21.3	1021.6
2002	52.5	2.4	127.7	119.6	85.2	118.4	76.6	190.4	82.2	37.2	0	51.5	943.7
2003	30.4	2	78.2	179.1	40.4	110.5	74.5	76.1	85.7	56.4	6.2	51.8	791.3
2004	46.2	94.2	42.0	83.1	81.5	75.7	75.4	182.8	113.0	57.1	26.8	15.2	893.0
2005	81.1	7.7	120.9	156.0	144.5	73.2	140.9	61.3	122.2	28.4	46.0	10.4	992.6
Mean	28.96	41.268	73.318	103.94	117.79	99.3588	119.79	123.979	118.288	77.576	26.935	18.153	

Mean Monthly Rainfall in mm Shashemene Station

Y/M	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1970	52.7	44.3	128.1	174.6	56.5	107.9	66	245.8	340.8	133.7	0	0	1350
1971	0.1	2.8	38.2	81.2	94	83.7	67.3	185.9	108.7	121.5	**105**	88.5	977
1972	26.2	110.8	66.8	132	76.7	88	144.6	100.2	174.5	57.9	7	3.4	988
1973	8	0	0	99.4	142.1	51.9	129	86.2	80.2	61	4	7	669
1974	15	15	191.4	21	146.1	47	137.2	105.5	124.9	48.9	0	0	852
1975	21	31	81	105	120	65	108	101	87.3	77.6	2.7	0	800
1976	9.3	22.1	88.6	73.7	117.2	59	109.4	121.5	142.2	134.9	75.4	16.5	970
1977	86.2	25.3	59.1	55.6	137.9	69.2	117.9	91.9	133.6	258.8	37.3	24.1	1097
1978	3.5	123	29.6	63	157.4	62	87.9	215.1	119.7	54	35.3	3.6	954
1979	68.7	60.2	64.2	57.1	144.1	59.8	86.2	165.2	126.6	58.5	32.6	57.7	981
1980	66.1	71	49.9	136	101.4	123.7	82	71.4	90.7	61.6	7.8	0	862
1981	1.5	18.9	205.7	124	48.3	69.1	106.2	117	156.1	88.5	28.4	12.7	976.4
1982	58	33.6	72.3	81.8	113.9	93.7	109.8	91.8	110.2	80.7	114.4	61.8	1022
1983	30.2	47.9	75.6	180.7	194.2	80	104.2	139.5	124.2	108.7	76.6	3.9	1165.7
1984	0	0	41.4	27.9	159.7	66.7	77.1	90.4	147	27	42.5	12.1	691.8
1985	5	1.3	60.4	219.9	155.7	88.7	120.1	81.9	129.9	39.7	8.8	11	922.4
1986	0.2	45.9	69	115.5	129.7	163.3	98.5	153.8	159.9	52.6	14.7	17.3	1020.4
1987	1.4	27.3	155.8	124.4	276.4	83.1	70.3	113.6	102.3	122.9	9.8	9.9	1097.2
1988	24.5	55.5	47.8	128	76.8	105.5	144	125	175	97.4	0.4	8.9	988.8
1989	24.1	56.8	82.3	151.5	67.3	117.9	78.9	80.5	135.2	68.5	25.3	84	972.3
1990	15.1	99.2	109.5	109.3	80.4	55.1	99.6	58.5	87.9	29.3	23.6	26	793.5
1991	17.2	83.3	132	78.9	116.1	68.6	89.3	90.1	113.6	23.2	17.2	33.3	862.8
1992	55.1	44.3	29.3	114.3	117.6	125.6	96.4	99.9	124.6	27.4	36.6	41.5	912.6
1993	61.2	43.7	0	137	75.8	23	162.8	112.8	243.8	131.5	0	0	991.6
1994	0	0	59.5	112.6	65.8	40.5	192	64.2	185.5	1.3	20.9	0	742.3
1995	0	23	135.8	184.8	76.2	68.5	65.1	102.9	130.4	35.8	5.2	24.9	852.6
1996	16	0	108.5	135.9	187.2	107.6	209.2	128.8	170.5	82	33.7	7.9	1187.3
1997	52.5	0	96.1	169.8	120.4	106.2	91	184	58.3	167.2	140.7	2.2	1188.4
1998	48.6	96.1	113.2	76.6	126	73.5	162.4	149.9	156.1	186	12.9	0	1201.3
1999	14.5	0	50.3	37.5	122.3	119.1	119.2	10.1	162.7	70.7	4.3	6.5	717.2
2000	0	0	3	257	244.7	45.6	92.3	52.3	105.4	150.8	21	13.9	986
2001	0	6.8	151.1	37.6	89.9	92.9	102.4	110.7	113	115.8	8.2	23.9	852.3
2002	54.8	8	14	41.1	88.9	33.5	18.5	60.5	67.9	9.5	0	39.8	436.5
2003	7.3	22.3	68.3	131.9	32.1	101.5	86.9	110.1	134.7	56.3	16.2	45.6	813.2
2004	34.8	29.5	25.9	116.2	70.1	80.4	93.6	97.7	49.6	48.3	5.3	3.3	654.7
2005	34.7	3.2	66.2	129.3	71	7.3	72.7	46.3	66.4	39.6	37.8	23	597.5
Mean	25.38	34.781	76.942	111.73	116.66	78.725	105.5	110.05	131.65	81.364	28.1	19.839	

Mean Monthly Rainfall in mm Yirbadubacho Station

Y/M	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1981	5.1	30.9	306.4	112.6	40.8	52.2	96.5	107.3	196.1	105	68	3.4	1124.3
1982	50.2	33.9	56.7	108.2	177.3	81.9	99.2	75.2	193.1	63.4	177.1	137.6	1253.8
1983	22.1	39.4	117.6	182.1	191.1	106.4	92.6	188	150.7	151.6	39	5.3	1285.9
1984	0	0	36.8	48.3	213.5	55	65.5	118.6	180.3	21	65.9	8.1	813
1985	6	0.6	65.9	294.6	196.8	108.5	121.3	77.6	160.7	51.8	8.3	3.9	1096
1986	0.8	112.6	90.9	148.6	138.1	128.8	83.4	165.8	198.7	53.4	20.3	32.6	1174
1987	4	42.7	199.2	174.4	415.8	129	100.2	119.3	159.2	183.6	34.1	23.6	1585.1
1988	9.6	40.7	99	235.2	111.4	136.9	157.1	156.8	185.6	115.3	0	10.9	1258.5
1989	9.2	67.7	139.2	226.7	77.6	154.1	82.6	130.7	145.3	100.3	19	92.6	1245
1990	6.3	220	119.3	74.1	97.4	51.8	60.5	76.9	75.5	45.1	34.9	97	958.8
1991	20.5	99.3	153.2	64.7	138.3	81.7	21.2	59.4	134.6	16	20.1	15.9	824.9
1992	36.3	34.3	71.3	100.8	183.9	80.1	87.7	93.8	165	115.1	59.6	36.4	1064.3
1993	87.3	87.8	20.5	223.2	216.9	55.4	47.2	115.5	111.9	206.1	9.1	13.8	1194.7
1994	0.2	7.3	42.9	128.6	119.6	115.6	235	157.7	135.4	17.7	26.8	4.1	990.9
1995	0	32.8	91	214.5	52.8	72.3	74.4	59.9	80.8	64.7	14.3	43	800.5
1996	46.3	35.4	113.1	201.8	234.2	170.8	88.6	96.6	178.1	40.1	6	2.4	1213.4
1997	46.2	2.9	119	131.4	133	86.8	128	144.3	94.5	159.5	125.3	2.9	1173.8
1998	93.7	114.5	76.7	99.9	129.2	82.8	80.3	81.5	94.1	224.2	20.6	1.7	1099.2
1999	4.1	2.7	95.7	57.6	121.9	86.4	110.9	4.7	155.9	9.3	14.6	10.6	674.4
2000	0.4	1.7	13.4	95.2	188.5	33.3	104.6	123.1	136.4	121.9	62	24.2	904.7
2001	7	14.8	105.2	97	144.7	167.8	118.1	97.3	146.2	184.5	6.2	54.1	1142.9
2002	72.7	37.5	181.3	92.1	93.6	54.9	50.7	128.5	146.1	49.8	0	112.3	1019.5
2003	12.4	7.4	112.8	174.3	41.3	119.9	103.9	199.7	194.4	59	25.7	54.9	1105.7
2004	79.5	138.8	51.2	222.2	115.9	34.7	49.8	81	158.9	138.5	47.6	18.6	1136.7
2005	37.7	31.2	105.1	223.3	276.6	85	93	102	148	135	45	34	1315.9
Mean	26.304	49.476	103.3	149.3	154	93.284	94.092	110.4	149	97.28	37.98	33.76	

Mean Monthly Rainfall in mm Wondogenet Station

Y/M	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1970	106.9	52.5	169.7	68.6	65.1	50.5	177.1	145.1	153.9	161.6	0.1	9.3	1160
1971	0.3	7.3	118.5	95	134.3	161.4	83.5	132.5	137.8	200.9	65.7	34.2	1171
1972	21	161.6	85	196.7	104.3	72.8	186.7	130.5	147.6	22.3	20.6	8.1	1157
1973	30.1	0.6	31.6	62.6	154.9	81.2	222.9	179	92.1	137.9	0	1.9	995
1974	8.8	36.5	171.8	23.2	119.5	86.3	190	195.4	146.1	63	0.4	3.3	1044
1975	14.8	12.2	46.3	73.4	85.5	215.8	213.9	273.7	140	102	3.7	12.5	1194
1976	14.5	61.2	107.8	117.7	127.5	61.2	124.3	187.5	148	106	5.8	20.3	1082
1977	13.5	49	108	95	117.4	81.8	137.3	140.1	134.5	248.3	61.6	35.7	1222
1978	10	102	129.9	85.4	106.1	119.3	178.6	228.1	200.1	86.7	48.9	8.3	1303
1979	87.2	49	134.7	53.2	117	54.2	104.6	172.3	131.1	11.4	34.2	21.5	970
1980	41.6	43.3	61.9	121.6	100.3	118.6	142.5	55.5	92	94.6	14.3	0	886
1981	0.1	7.3	197.9	173.4	76.4	45.4	128.6	129.3	179.7	152.5	25.9	42.9	1159.4
1982	100.4	31.7	85.6	77	149.1	112.2	99	116.8	117.1	114.1	134.8	69.9	1207.7
1983	14.8	76.7	87.7	248.8	224.9	91.4	161.7	165.3	113.7	132.5	222.4	1.2	1541.1
1984	0	0	69.5	31.5	159.6	102	98.6	96.8	152.6	44.1	46.3	19.9	820.9
1985	0.9	4.2	61.7	258.1	254.6	83.8	138.1	122.3	169.5	31.3	8.3	26.3	1159.1
1986	0	10.8	75.1	137.2	130.7	231.6	89.3	157.8	173.5	68.1	5.4	7.7	1087.2
1987	0.9	41.9	182.6	121.6	305.6	101.6	37	162.1	127.6	140.3	0.6	7	1228.8
1988	48.5	78.4	52.1	129.2	45.8	111.3	223.1	128.6	201.8	136.5	0	13.5	1168.8
1989	38.3	71.3	111.7	208.2	54.9	160.5	108.7	77.6	197.3	111.8	29.9	71	1241.2
1990	17.8	112.2	137.6	160.2	72.6	50.4	137	63.2	105.2	52	13.3	6.9	928.4
1991	25.9	138.9	182.4	181.8	93.1	101.1	159	95.2	141.7	39	6.1	40.5	1204.7
1992	46.6	93.7	54.5	134.8	114	67.7	146.1	164.3	136.2	213	99.6	36.9	1307.4
1993	77.8	96.4	35.1	207.3	157.3	99.4	71.2	96.9	144.4	137	13.4	1.9	1138.1
1994	0.7	0.8	130.2	126.4	116.7	141.6	408.6	171.5	147.9	16.4	28.5	2.2	1291.5
1995	0	21.7	104	212.1	97.1	68.1	134.7	187.6	134.1	19.2	1	45.3	1024.9
1996	38.9	19.4	102.8	179.2	105.4	155.9	183.1	246.4	153.3	41.3	19.2	8.2	1253.1
1997	39.5	6.5	54.1	252.6	76.2	192	92.4	158.7	109.9	153.5	141.4	4.7	1281.5
1998	91.3	157	175.1	75.5	155.1	108.1	131.9	99.8	120.9	181.1	9.1	0	1304.9
1999	7.7	0	127.6	53.3	97.4	62.8	112.1	151.5	130.7	180.9	5.7	23.4	953.1
2000	0	0	6.9	114.6	104.6	29.7	83	83.4	204.2	226.8	63.7	26.6	943.5
2001	0	58.5	183.2	87.3	235.3	139.5	100.2	169.1	198.7	106.3	1.3	11.2	1290.6
2002	84.7	15.8	204.4	103.6	146.4	93.4	65.1	93.6	83.6	31.7	0	75.7	998
2003	26.9	55.2	98.1	165.7	31.6	102	133.9	141	163.6	68.4	19.7	55.4	1061.5
2004	65.7	16.4	145.4	98.7	127.2	94.5	89.9	139	217.8	69.4	41.9	24.6	1030.5
2005	75.2	9.6	132	255.7	179.6	33.2	94.4	77.1	147.3	130.6	73	21.7	1229.7
Mean	31.981	47.21	110.1	132.9	126.2	102.29	138.56	142.6	147.1	106.5	35.16	22.21	

Mean Monthly Rainfall in mm Haisawita Station

Y/M	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1981	1.5	20.1	218.4	131.7	51.3	73.4	112.8	124.3	165.8	94	30.2	13.5	1037
1982	61.6	35.7	76.8	86.9	121	99.5	116.7	97.5	117	85.7	121.5	65.6	1085.5
1983	32.1	50.9	80.3	191.9	206.3	85	110.7	148.2	131.9	115.4	81.4	4.2	1238.3
1984	0	0	44	29.6	169.7	70.9	81.9	96	156.2	28.7	45.2	12.9	735.1
1985	5.3	1.4	64.1	233.6	165.4	94.2	127.5	87	138	42.1	9.4	11.7	979.7
1986	0.2	48.8	73.3	122.7	137.8	173.5	104.6	163.4	169.9	55.8	15.6	18.4	1084
1987	1.5	29	165.5	132.1	293.6	88.3	74.7	120.6	108.6	130.6	10.4	10.5	1165.4
1988	26	59	50.7	135.9	81.6	112	153	132.8	185.9	103.5	0.5	9.5	1050.4
1989	13.9	31.3	83.2	169.6	127.2	189.1	84.2	50.3	155.7	49.1	26.9	91.4	1071.9
1990	35	116.7	161.8	161.6	86.5	59	110.4	52	115.2	2.4	52.2	14	966.8
1991	18.2	88.5	153.6	153.7	108.9	50.6	114.4	104.6	119.5	43	32.7	32.8	1020.5
1992	31.3	96.6	107.8	113	118.6	133.6	131.4	141	184.9	137.7	77.5	27.3	1300.7
1993	24.8	89.8	43	174.5	174.6	16.3	78.4	66.3	123.4	156.2	10.4	25.9	983.6
1994	6.6	23.8	137.2	113.8	109.4	56.2	236.9	190.4	120.8	7.3	63.2	1.1	1066.7
1995	0	16.4	99.7	202.8	99.2	35.6	113.1	133.2	144.8	25.7	0	37.4	907.9
1996	53.7	56.4	179.6	135.2	146.5	126.2	116.8	122.2	134.6	69.3	24.1	12.2	1176.8
1997	39.6	0	56.8	136.7	102.6	88.5	23.5	38.8	62.2	59.5	46.9	0	655.1
1998	16.6	75.6	163.9	122.5	119.7	82.5	110.6	11	192.4	12.5	25.2	0	932.5
1999	7.1	7.9	128.1	90.6	79.5	73.9	68.8	124.2	134.2	89.8	3.1	41.4	848.6
2000	1.6	0	5.6	175.4	131.9	36	76	138.9	134.5	214.1	45.3	23.8	983.1
2001	2.6	36.9	150.4	81.5	246.5	106.4	108.2	76	166	176.4	19.1	52.3	1222.3
2002	62.6	15.4	125.7	97.3	121.5	72.2	47.7	76.8	141.4	27	0	63.8	851.4
2003	20	19.6	93.7	140	34.1	107.8	92.3	116.9	143	59.8	17.2	48.4	892.8
2004	83.1	62.6	77.3	126.7	39.1	53.5	97.1	88.3	284.3	96.3	33.3	13.8	1055.4
2005	53.2	12	213.4	199.8	205.5	83.3	89.2	48.7	230	85.4	72.2	7.9	1300.6
Mean	23.924	39.776	110.2	138.4	131.1	86.7	103.24	102	150.4	78.69	34.54	25.59	

Appendix. 6 Profile of Satellite imageries used for LU/LC mapping

Sensors (Instrument)	Scale	Satellite_ Name	Path and row	Date of acquisition	Spatial Resolution (m)	Spectral Resolution Bands Name	Wavelength (μm)
Landsat MSS	**1:50,000**	**Landsat_1**	**P_181_r_55**	01-31-73	**57.00**	**1 (**MSS_BAND_4)	0.50-0.60
						2 (MSS_BAND_5)	0.60-0.70
						3 (MSS_BAND_6)	0.70-0.80
						4 (MSS_BAND_7)	0.80-1.10
LandSat TM	**1:50,000**	**Landsat_5**	**P_168_r_55**	01-28-86	28.50	TM_BAND_1	0.45,0.52
						TM_BAND_2	0.52,0.60
						TM_BAND_3	0.63,0.69
						TM_BAND_4	0.76,0.90
						TM_BAND_5	1.55,1.75
						TM_BAND_6	10.40,12.50
						TM_BAND_7	2.08,2.35
Landsat ETM+	**1:50,000**	Landsat_7	**P_168_r_55**	01-27-2000	28.00	TM_BAND_1	0.45,0.52
						TM_BAND_2	0.52,0.60
						TM_BAND_3	0.63,0.69
						TM_BAND_4	0.76,0.90
						TM_BAND_5	1.55,1.75
						TM_BAND_6	10.40,12.50
						TM_BAND_7	2.08,2.35
					14.25	TM_BAND_8	