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Department of Earth Sciences
Remote Sensing and GIS Stream

THE EFFECT OF LAND USE LAND COVER CHANGE ON HYDROLOGIC RESPONSE OF WUKRO-GENFEL CATCHMENT, TEKEZE BASIN, ETHIOPIA

By: Fitsum Melaku
Advisor: Dagnachew Legesse (PhD.)

A thesis submitted to the School of Graduate Studies of Addis Ababa University in Partial fulfillment of the requirements for the Degree of Master of Science in Remote Sensing and GIS

Addis Ababa, Ethiopia
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Approved By Board of Examiners:

Dr. Balemwal Atnafu ______________________

Chairman, Department

Graduate Committee

Dr. Dagnachew Legesse ______________________

Advisor

Prof. Tenalem Ayalew ______________________

Examiner

Dr. Bekele Abebe ______________________

Examiner

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Acronyms and Abbreviations

AMC	Antecedent Moisture Condition
ARS	Agricultural Research Service
ASTER	Advanced Space Born Thermal Emission and Reflection Radiometer
AVHRR	Advanced Very High Resolution Radiometer
CN	Curve Number
DEM	Digital Elevation Model
DIP	Digital Image Processing
DN	Digital Number
EMA	Ethiopian Mapping Agency
ESRI	Environmental Systems Research Institute
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agricultural Organization
FDRE	Federal Democratic Republic of Ethiopia
GCPs	Ground Control Points
GIS	Geographic Information Systems
GPS	Global Positioning System
GSE	Geological Survey of Ethiopia
HEC-HMS	Hydrologic Engineering Center-Hydrologic Modeling System
HSG	Hydrologic Soil Group
HSU	Hydrologic Similar Unit
HRG	High Resolution Geometric
MODIS	Moderate Resolution Imaging Spectroradiometer
MoWR	Ministry of Water Resources
NMA	National Metrological Agency
NRCS	Natural Resource Conservation Service
OIF	Optimum Index Factor
REST	Relief Society of Tigray
RMS	Root Mean Square
SCS-CN	Soil Conservation Service Curve Number
SLC-off	Scan Line Corrector-off

SLC-on	Scan Line Corrector-on
SPOT	Le Systeme Pour 1' Observation de la Terre
SRTM	Shuttle Radar Topographic Mapping
SWAT	Soil and Water Assessment Tool
TM	Thematic Mapper
USA	United States of America
USDA	United States Department of Agriculture
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VLIR	Vlaamse Interuniversitaire Raad

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Abstract

The environment of the northern Ethiopia highlands are seriously affected by land degradation, mainly caused by the combined effects of deforestation, overgrazing, expansion of cropland and unsustainable use of natural resources. These have also a potential effect on the runoff, infiltration, sedimentation and other hydrologic parameters. The main objectives of the current study are to assess land use land cover change that occurred during 1986-2007 and its effect on the hydrologic response of Wukro-Genfel catchment, in Tekeze river basin. The widely used Soil Conservation Service - Curve Number (SCS-CN) method was integrated with Remote Sensing and Geographical Information Systems (GIS) techniques. The analysis revealed an overall decrement of woodland, scrub and grassland by 2.9%, 2.2% and 4.7% respectively and increment of farmland, shrub and bareland by 8.6%, 3.1% and 2.3% respectively over the past twenty one years (1986-2007). Considering Antecedent Moisture Condition (AMC) II which is moderate soil moisture condition and taking 36mm of rainfall event, there was a decrement of runoff depth by 37.6% for shrub to woodland change, 6.1% for scrub to shrub change and 2.1% for scrub to farmland change with Hydrologic Soil Group (HSG) A, A and B respectively. On the other hand, there was an increment of runoff depth by 30.4% for woodland to farmland and by 3.7% for farmland to bareland with HSG B and C respectively. Out of the whole land use/cover classes, woodland plays significant role on runoff generation and its spatial distribution. Thus, Special attention should be given to sloppy river banks where high runoff is generated. The total volumetric runoff was decreased on average by 17.6% during the period 1986-2000 mainly due to the increment of woodland. An average increment in the total volumetric runoff was also observed by 13.5% for the period 2000-2007 caused by the depletion of woodland in the area.

Key Words: *Land use land cover, Runoff, SCS-CN, Hydrologic Soil Group (HSG), Remote Sensing, GIS*

Chapter 1
Introduction

1.1 Background and Justification

Nowadays, population growth and unwise utilization of natural resources are resulting in various environmental problems, out of which land use/cover change is a major one. Some even suggest that the consequences may outweigh those from climate change (Sala et al., 2000). According to FAO (2000), "Land cover is the observed biophysical cover on the earth's surface." The same document also defines land use as the arrangements, activities and inputs that people under-take on a certain land cover type. According to these definitions, land cover corresponds to the physical condition of the ground surface e.g. forest, grassland and concrete pavement while land use reflects human activities such as the use of the land like industrial zones, residential zones and agricultural fields. Therefore, anthropogenic effect plays significant role in causing and facilitating the environmental change.

Several previous studies indicate that the mismanagement of land use/cover has a potential effect on the runoff, infiltration, sedimentation and other hydrologic parameters. Identifying and quantifying the hydrological consequences of land-use/cover change are not trivial exercises and are complicated by; (1) the relatively short lengths of hydrological records (2) the relatively high natural variability of most hydrological systems (3) the difficulties in 'controlling' land use/cover changes in real catchments within which changes are occurring (4) the relatively small number of controlled small-scale experimental studies that have been performed and (5) the challenges involved in extrapolating or generalizing results from such studies to other systems (Defries and Eshleman, 2004). Since 1972, the use of Remote Sensing and Geographic Information Systems (GIS) techniques in combination with other hydrologic models is becoming an effective tool to assess the effect of land use/cover change on the hydrologic response. The advancement in Geospatial Technologies through Remote Sensing, Geographic Information Systems (GIS) and Global Positioning System (GPS) provide the capability of acquiring, analyzing and interpreting Geospatial data on various scales, time and least cost.

Due to the occurrences of quite steep rivers and some deep Gorges in the Tekeze basin, it is ideal for dam and hydropower construction. The basin has also a big potential for small and large scale irrigation. However, the drawbacks are high flows for the short rainy season only and the presence of high variability over year which is related to the land use change (MoWR, 2007). Therefore, identifying and quantifying the effect of land use/cover change on the hydrologic process is a crucial step and provide information on what action should be taken to overcome the drawbacks.

The ultimate goal of this research is to identify and quantify the effect of land use/cover change towards the hydrologic response of Wukro-Genfel catchment, Tekeze Basin. To evaluate the hydrologic response due to land use/cover change, the widely used SCS-CN method was integrated with Remote Sensing and GIS techniques.

1.2 Statement of the Problem

The environment of the northern Ethiopia highlands is seriously threatened by land degradation (Hurni, 1990). In addition to these, the area is known for its annual variability of river flow which is related with land use/cover change (MoWR, 2007). Descheemaeker et al. (2008) have determined Curve Number (CN) for vegetation in different restoration stages and related the CN to easily determinable variables such as vegetation cover and land use. The study also modified the standard SCS-CN table which was developed on the basis of a wide range of empirical data acquired from small agricultural watersheds of USA.

Even if Descheemaeker et al. (2008) determined the CN for rangelands and exclosures with vegetation in different restoration stages in the area, which is a very important variable in estimation of runoff generated from different land use/cover classes, there is no previous study conducted that relates and quantify the effect of land use/cover change on the hydrologic response of the area. Therefore, this study will fill the research gap that has been occurring for the past decades in relating the effect of land use/cover change with runoff in the area.

1.3 Objectives of the Study

1.3.1 General Objective

The general objective of the study is to assess the land use/cover changes in Wukro-Genfel catchment, Tekeze Basin and to provide an overall view on the effect of land use/cover change on the hydrologic response.

1.3.2 Specific Objectives

The specific objectives of the study are:-

- ✓ To study the land use/cover changes of the area for the periods (1986-2000) and (2000-2007)
- ✓ To identify the effect of land use/cover change on direct runoff and total volumetric runoff and
- ✓ To quantify the effect of land use/cover change on direct runoff and total volumetric runoff.

1.4 Significances of the Study

The study addresses the land use/cover dynamics of the area and its influence on the hydrologic response. The output of the research will be an input in planning and eradicating the problem of the area related to land degradation, erosion, flooding, water and soil conservation activities considering the land use/cover change occurring in the area. It will also help in planning environmental rehabilitation program, watershed management and hazard mitigation strategy in relation with the land use policy of the region. Moreover, this study tries to introduce the application of SCS-CN method in assessing the land use/cover changes in relation with direct runoff and total volumetric runoff generated from a given rainfall especially in semi-arid environment.

1.5 Scopes of the Study

- The experimental plots are in semi arid environments of northern Ethiopia and the findings of this study is mainly site specific.

- The coefficients and CN used in the study are mainly from experimental plots in the area conducted by Descheemaeker et al. (2008).
- The study assess only the effect of land use/cover change on direct runoff and total volumetric runoff excluding the runoff routing, channel processes etc.
- The Antecedent Moisture Condition (AMC) was assumed to be moderate (AMC II) and the corresponding CN for AMC II was used in the entire study.
- Data from experimental plots were taken as reliable information because there is data scarcity in the area to calibrate and validate the model.

1.6 Description of the Study Area

1.6.1 Location and Accessibility

Wukro-Genfel catchment is located within the Tekeze river basin and it is situated in the northern part of Ethiopia. Generally, Tekeze basin is bordered by the Mereb River basin and by Eritrea in the North, the Atbara River plains in Sudan in the West, the Abay River basin in the South and Danakil basin in the East. Even though the study area is irregular in shape, it can be bounded by the closest rectangle with geographic coordinates ranging from 561505 to 585684m Easting and from 1523020 to 1563964m Northing. It covers a total area of about 506 square km (See Figure 1-1). The area can be accessed by 781 Kms Addis Ababa to Mekelle and 42 Kms Mekelle to Wukro all weather road (asphalt road).

1.6.2 Topography and Climate

The relief of the area varies from lowland plains of 1990 masl to highland plateaus of around 2600 masl reaching to a maximum of 3065 masl around north of Idaga Dera. Some rugged topography occurs in the transition zone between lowlands and highlands which mainly characterize the North-South trending fault zone at the center of the study area.

The Agro-climatic map obtained from the Tekeze master plan study conducted by the Ministry of Water Resources (MoWR) separates the area into two zones. Majority of the Northern part is classified as Dega with mean annual temperature that varies from 11.28-26.49 °C. There is an erratic three month rainy season (June-August) with an annual rainfall that varies from 400-600 mm/yr. 67% of the total annual rainfall is contributed from these months (June-August) while the remaining rainfall is from April, May and September. The potential evapo-transpiration of this zone is around 1400-1500 mm/yr. The other Agro-climatic zone that characterizes the southern part of the area is Wayna Dega. This zone exhibit mean annual rainfall ranging from 500-800 mm/yr with the potential evapo-transpiration of around 1500-1700 mm/yr (MoWR, 1998).

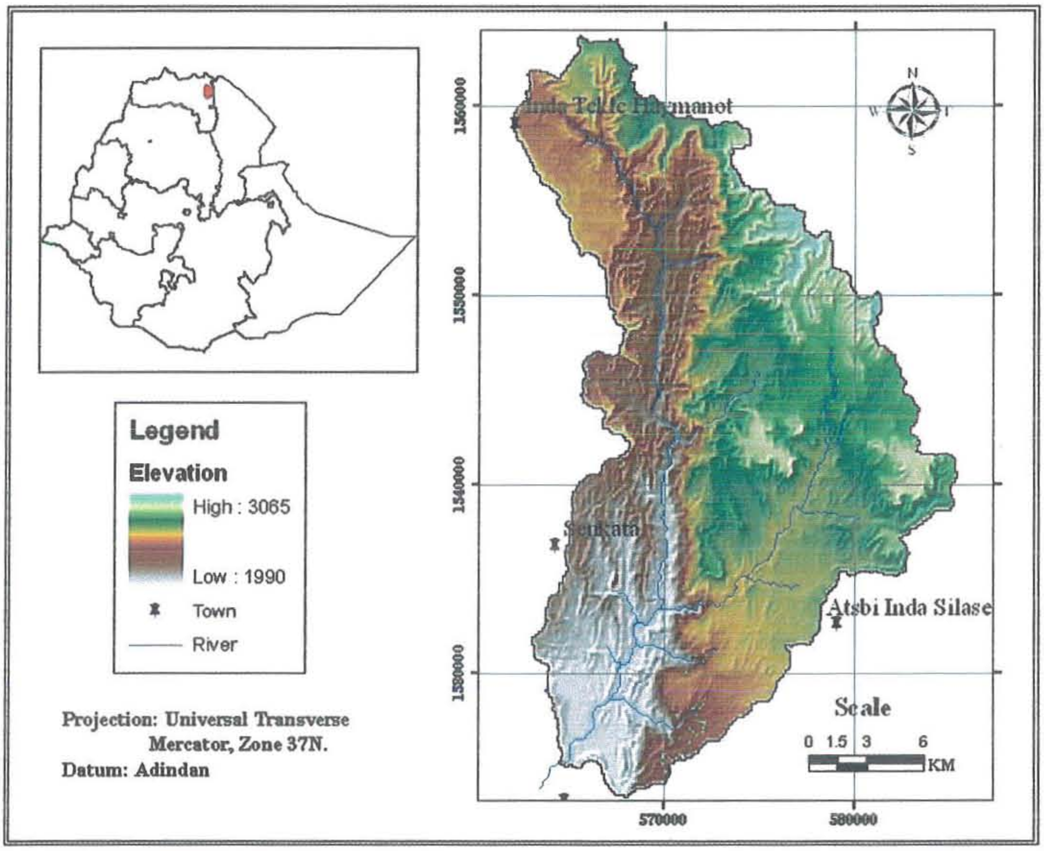

Figure 1-1 Location Map of the Study Area

1.6.3 Soil and Land Use/Cover

The dominant soil type covering about 62.21% of the total study area is Chromic Cambisols with clay texture and followed by the Chromic Luvisols which covers around 22.87 % of the total area. Almost Eastern half of the area is mainly characterized by Chromic Cambisols and the Western half which falls in the rugged topography is characterized by various soil types each covering relatively small area. Eutric Cambisols, Eutric Fluvisols, Eutric Gleysols, Leptosols and Eutric Cambisols are the minor soil types especially characterizing the Western part of the study area as shown on the Figure 1-2.

Concerning the general land use/cover of the Tekeze basin, it includes around 27% of cultivated land, 35% of shrubland, 0.3% of wooded grassland and 32.5% of bushy/open woodland, shrubby grassland, sparsely vegetated shrubland and exposed rock or soil. Most of the climax vegetation of the basin has disappeared and little of the original vegetation is evident while only little of the lowland woodlands and bush lands in the Western and Northern parts of the basin are nearer to climax. However, the Afro-alpine and sub Afro-alpine healthy vegetation lies between 3700 to 3900 masl around Simien Mountains (MoWR, 1998).

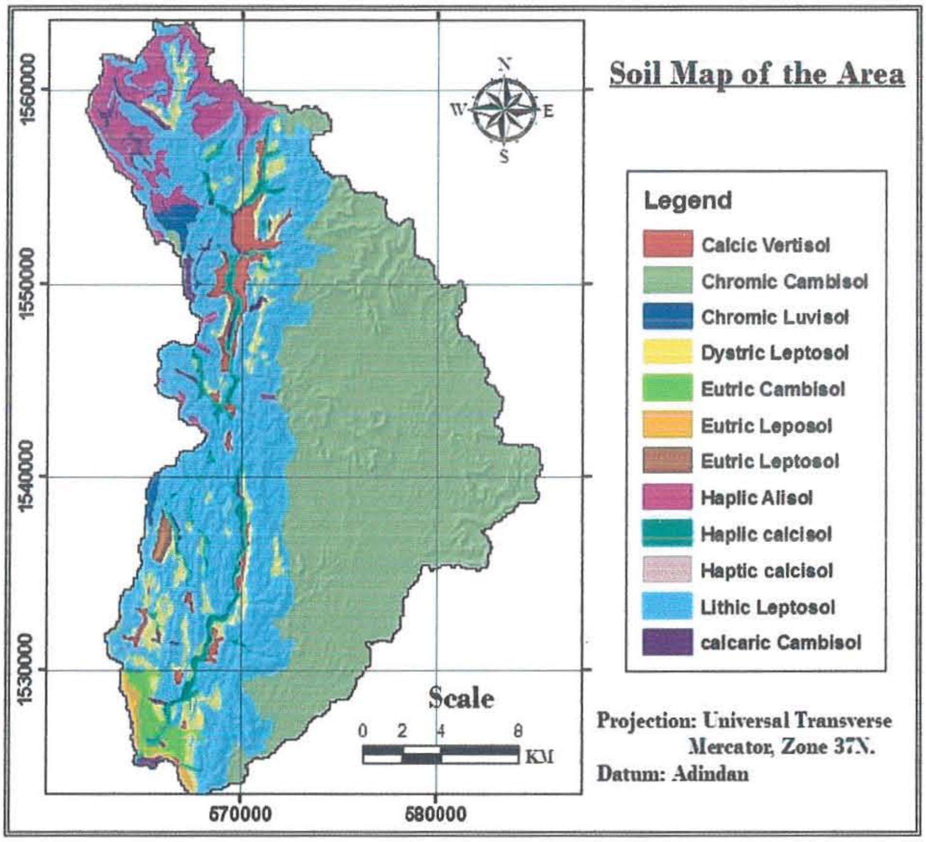

Figure 1-2 Soil Map of the Area
(Source: Ministry of Water Resources, Tekeze Basin Master Plan Study)

1.6.4 Geology

Concerning the Geology of the area, Tsaliet Metavolcanics, grouped under Tambien is a Precambrian, upper Proterozoic formation comprising of Greenschist originally agglomerate and tuffaceous sediments and quartzite originally rhyolitic lava gneiss, black limestone, dolerite and diorite, is the dominant unit and covers around 62% of the total area and mainly characterize the Eastern part of the area. The second dominant unit is Didikama formation within the same Tambien group which consists Detritic Dolomite (interbedded with slate, greywacke), Limestone, some calcareous slate and metavolcanics. The rest of the area is covered by Enticho sandstone, well bedded detrial limestone, Mareb granite, Adigrat sandstone etc.

1.6.4.1 Tsaliet Group

The greater part of the basement is formed by a heterogeneous series of rocks with obvious volcanic associations. They are breccias, agglomerates, bedded tuffs and lavas, inter-bedded with marine clastics, rare limestones, tuffaceous slates, redeposited ash and greywacke composed partly of volcanic fragments. The maximum thickness is about 2000m (Kazmin, 1975). The rocks have been faulted and tightly folded to build anticlinoriums and anticlines but subjected to only low grade metamorphism. The dips are N40-55W; ranging 30-55 .The formation comprises acid metavolcanics, semi-green schist, shales and black quartzite. Only few exposures of acidic metavolcanics and some basic metavolcanics appear in the eastern part of Tigray (Levitte, 1975).

1.6.4.2 Tembien Group

The youngest Precambrian units that underline northern Ethiopia are dominantly clastics with subordinate carbonates. The Tembien group consists of thousands of meters thick mainly slate and limestone with inter-bedded phylites (Beyth and Shachnai, 1971). The upper unit of the Tembien group, consists of about 800 meters thick of black, massive, fine grained limestone, partly algal and oolitic commonly weathering into karstic topography and has thin inter-beds of dolomite and thinly bedded limestone.

1.6.4.3 Didkama Formation

This formation is typically developed in Tigray region. It overlies conformably the Tembien group in central and eastern Tigray. However in the west, where the Tambien group is not fully developed; it rests uncomfortably on older formations. The Didkama formation consists of creamish to white dolomite alternating with grey, black or variegated slates (Garland, 1980). The formation consists of yellowish, medium grained dolomite interbedded with grey, black or colored slate. It is 300 meters thick at its westernmost outcrop and over 1,500 meters thick at its central part around Gunda Gundi (Garland, 1980) the most eastern part of Tigray region. In the Sheraro area, at Negash syncline, it is unconformable overlapped by Matheos Formation, of youngest limestone (Kazmin, 1975; Garland, 1980).

1.6.4.4 Enticho sandstone

Two rock units assigned tentatively to the Paleozoic in the Mekelle area in the North of Ethiopia are the Enticho sandstone and the Edaga Arbi shales, silts and tilites. A glacial origin has been proposed for the latter. The Adigrat sandstone closely resembles these underlying formations, which it covers without the development of a significant unconformity (Kazmin, 1975).

The Enticho sandstone is widespread and takes its name from the town of Enticho on the Axum–Adigrat road (Garland, 1980). The Enticho sandstone is about 160m thick and composed of white, calcareous coarse grained ,cross bedded sandstone containing lenses of siltstone, grit and polymict conglomerate with subrounded to well rounded pebbles, cobbles and boulders, scattered erratically, mainly granite and gneiss are common in places. The position of the beds and completeness of the sequence vary from place to place and some units are seen to interfinger, thus being not stratigraphic horizons but facies of the same age. It is seen resting on the basement in many places is a white medium grained quartize with very angular grains, in a few places cemented by kaolin (Garland, 1980).

1.6.4.5 Adigrat Sandstone

This is name given by Blandford (1870) to the basal clastics in Tigray. It has a maximum thickness of 700 meters. It is gray or red, fine-grained, well sorted and very mature (practically quartize arenite), cross bedding is quite common and bioturbation of the silt-shale occurs frequently in the upper part of the section, where several red, ferruginous laterite beds occur. It rests uncomfortably on the Edaga Arbi glacial, on the Enticho sandstone and basement (Kazmin, 1975). The Adigrat sandstone is sub-horizontal with the dip usually only 2°-3° but higher in places where it has been tilted with block faulting of the rift escarpment, dips reaching up to 30° (Levitte, 1970).

Chapter 2

Review of Literatures

2.1 Land Use/Cover Change in Tigray

Our understanding of where, when and why land cover changes take place in tropical regions is seriously hampered by incomplete availability of quantitative data (Lambin, 1997). In most tropical regions, the common agricultural land use system is a smallholder farming system with agricultural production in small parcels for subsistence purposes with no or little external inputs. However, the small farm sizes are insufficient to provide for ever-increasing human populations (Shiferaw and Holden, 2000). In response to the increasing demands for food production, agricultural lands are expanding at the expense of natural vegetation and grasslands (Hartemink et al., 2008). Studies in the country indicate that intensity of land use has changed over time because of demographic, policy and natural factors (e.g. Tekle and Hedlund, 2000).

Like in other parts of Ethiopia, land use history in Tigray can be divided broadly into three eras: (i) Pre-1974 (ii) 1974-1991 and (iii) Post-1991, which correspond to the periods of the Imperial government, the military-socialist regime and the current government respectively (Abegaz, 2004). In the pre-1974 period, land was controlled by the state, the crown, the Orthodox Church, individuals and their families. Land use was characterized by traditional extensive agriculture, mostly without the use of fertilizers and pesticides. During the military-socialist regime (1974-1991), land was nationalized and distributed to farmers (about 1 ha per farm family) for indefinite use, but remained in public ownership (Griffin, 1992). The use of new cultivars and synthetic fertilizers were limited to demonstration plots and agricultural areas close to extension centers. This period is also known for its civil wars in the study area, which also resulted in vegetation degradation (Abegaz, 2004). The current government still keeps all land (rural and urban) under public ownership but allows land leasing and hiring although it prohibits land sale or purchase (FDRE, 1995). In the meantime, the use of improved cultivars and fertilizers has been promoted in agricultural extension package in most agricultural areas to increase crop production, but also farmers have started to return to their traditional farming practices.

Most of the land in Tigray is used for agriculture but the intensity varies from very low in areas dominated by shrubs and trees to moderately intensive with a mix of agriculture and natural habitat and to pure agriculture. Traditionally, the typical agricultural practice in the area has been a mixed crop-livestock smallholder farming system where cereal crops are planted in mixture and in rotation with pulses. Crops have traditionally been planted in between more or less densely spaced trees and shrubs but in recent years, trees have been removed especially close to towns (Kiros Meles, 2008). Land use/cover changes are caused by natural and human drivers, such as construction of human settlements, government policies, climate change or other biophysical drivers (Lambin et al., 2000). These changes caused by human-induced and natural drivers pose serious problem in the area. The existing land use system of Tigray exerts high pressure on the environment from the increasing human population density.

According to Kiros Meles (2008), shrubland was dominant in 1964 covering 46% of the area followed by woodland with coverage of 28% of the area. However, agriculture was dominant in both 1994 and 2005 covering 34% and 40% respectively. The next dominant land use/cover types in 1994 and 2005 were shrubland with coverage of 21% and 39% and scrubland with coverage of 30% and 16% respectively. The settlement class covered 1723 ha in 2005, an increase of 1624 ha over the 99 ha in 1964. Water bodies behind micro dams covered 15 ha in 2005. Grassland covered 238, 861 and 151 ha of the total 110819 ha area in 1964, 1994 and 2005 respectively. Over the whole study period (1964-2005) land cover changed substantially. For instance, 32.4 and 33.1% of shrubland was converted into combined agricultural land in 1964-1994 and 1994-2005 respectively. Moreover, 59.3 and 50.1% of grassland was converted into agricultural land in 1964-1994 and 1994-2005 respectively.

2.2 Effect of Land Use/Cover Change on Hydrologic Response

Human transformation of the Earth's land surface has multiple consequences for biophysical systems at all scales ranging from local urban heat islands and alterations in stream flow patterns (Rose and Peters, 2001) to altered patterns of global atmospheric circulation (Werth and Avissar, 2002) and long-term extinction of species (Pimm and Raven, 2000). Although the study of linkages between vegetative cover, hydrologic processes and water quality has a relatively long history based on modeling, experimental watersheds and measurements, the consequences of anthropogenic land use change for hydrology have received little attention in the study of land use change (Lambin et al., 2002). The consequences of land use change include: changes in water demands from changing land use practices such as irrigation and urbanization; changes in water supply from altered hydrological processes of infiltration, groundwater recharge and runoff and changes in water quality from agricultural runoff and suburban development (DeFries and Eshleman, 2004).

Identifying and quantifying the effect of land use change on hydrologic process is not as such an easy task especially in data scarce areas. In recent years, after technological advancement in data collection and computing capabilities, evaluating and predicting hydrological consequences of land use change at multiple scales is getting improvement at a rapid rate. Satellite remote sensing now has the potential to provide extensive coverage of key variables such as precipitation, soil moisture and flooding as well as many of the parameters such as vegetation cover, vegetation change and imperviousness that are important inputs to modern hydrological models. Research aimed towards explicit understanding of these interactions will provide necessary input to decisions that must balance trade-offs between the positive benefits of land-use change and potentially negative unintended consequences.

The implication of land use change for hydrology has been an area of intense interest to research hydrologists over the last 50 or more years. Issues of land use change affecting hydrology include increasing urbanization, changing vegetation cover, land drainage and changing agricultural practices. Since trees have effect on evaporation and interception rates, changes related to forestation and deforestation will affect the rainfall-Runoff process. In general Bosch and Hewlett (1982) concluded that the greater the amount of deforestation the larger the subsequent stream flows will be, but the actual amount is dependent on the vegetation type and precipitation amount. The high interception losses were experienced during small rainfall events and vice versa. Over all there is a high degree of variability in the amount of interception that is likely to occur. While it may be possible to say that in general a land use change that has increased tree cover will lead to a water loss, it is not easy to predict by how much that will be.

Fahey and Jackson (1997) concluded that with the loss of forest cover both runoff depth and peak flows increase. The peak flow response is a result of a generally wetter soil and a low interception loss during a storm when there is no forest canopy cover. The time to peak flow may also be affected, with a more sluggish response in a catchment with trees.

Tripathi et al. (2002) have conducted a runoff modeling of small watershed using satellite data and GIS. They used GIS to extract the hydrological parameters of the watershed from the remote sensing and field data. The land use classification was made from data of Indian remote sensing satellite (IRS-1B) LISS II to compute runoff Curve Number (CN), which they used to develop empirical models. They have concluded that the model can be applied for estimating runoff and evaluating its effect on structures of the Nogwan watershed.

Hisham and Abdalla (2007) used the SCS-CN method to estimate the runoff generated from rainfall events in Darfur as a first step in rainfall harvesting activities.

Purwanto and Donker (1991) proposed semi-distributed hydrologic modeling using SCS-CN method and assessed the effect of land use change for hypothetical cases of reforestation and deforestation conditions. When hypothetical case of 5% reforestation or deforestation conditions considered, the peak flow was reduced by 14 % for reforestation and increased by 12 % for deforestation case for hydrologic soil group C when compared to normal land use.

Schumann (1993) developed a conceptual semi-distributed hydrological model using GIS for a limited consideration of spatial heterogeneity described by area distribution function of the hydrological characteristics and successfully applied for estimation of model parameters.

2.3 Theoretical Background on Image Classification Process

Remote Sensing classification is a complex process and requires consideration of many factors. The major steps of image classification may include determination of a suitable classification system, selection of training samples, image preprocessing, feature extraction, selection of suitable classification approaches, post-classification processing and accuracy assessment. The user's need, scale of the study area, economic condition and analyst's skills are also important factors influencing the selection of remotely sensed data, the design of the classification procedure and the quality of the classification results (Lu and Weng, 2007).

2.3.1 Selection of Remotely Sensed Data

Remotely sensed data, including both airborne and space borne sensor data vary in spatial, radiometric, spectral and temporal resolutions. Understanding the strengths and weaknesses of different types of sensor data is essential for the selection of suitable remotely sensed data for image classification. The selection of suitable sensor data is the first important step for a successful classification for a specific purpose (Phinn et al., 2000). It requires considering such factors as user's need, the scale and characteristics of a study area, the availability of various image data and their characteristics, cost and time constraints and the analyst's experience in using the selected image. Scale, image resolution and the user's need are the most important factors affecting the selection of remotely sensed data. The user's need determines the nature of classification and the scale of the study area, thus affecting the selection of suitable spatial resolution of remotely sensed data.

In general, a fine-scale classification system is needed for a classification at a local level, thus high spatial resolution data such as IKONOS and SPOT 5 HRG data are helpful. At a regional scale, medium spatial resolution data such as Landsat TM/ETM+ and Terra ASTER are the most frequently used data. At a continental or global scale, coarse spatial resolution data such as AVHRR, MODIS and SPOT Vegetation are preferable. Another important factor influencing the selection of sensor data is the atmospheric condition. The frequent cloudy conditions in the moist tropical regions are often an obstacle for capturing high-quality optical sensor data. Therefore, different kinds of radar data serve as an important supplementary data source (Lu and Weng, 2007).

2.3.2 Selection of a Classification System and Training Samples

A suitable classification system and a sufficient number of training samples are prerequisites for a successful classification. Cingolani et al. (2004) identified three major problems when medium spatial resolution data are used for vegetation classifications: defining adequate hierarchical levels for mapping, defining discrete land cover units discernible by selected remote sensing data and selecting representative training sites. In general, a classification system is designed based on the user's need, spatial resolution of selected remotely sensed data, compatibility with previous work, time constraints, image processing and classification algorithms available (Lu and Weng, 2007).

A sufficient number of training samples and their representativeness are critical for image classifications (Chen and Stow, 2002). Training samples are usually collected from fieldwork or from fine spatial resolution aerial photographs and satellite imageries. Different collection strategies such as single pixel, seed and polygon may be used but they would influence classification results especially for classifications with fine spatial resolution image data (Chen and Stow, 2002).

When the landscape of a study area is complex and heterogeneous, selecting sufficient training samples becomes difficult. This problem would be complicated if medium or coarse spatial resolution data are used for classification because a large volume of mixed pixels may occur. Therefore, selection of training samples must consider the spatial resolution of the remote sensing data being used, availability of ground reference data and the complexity of landscapes in the study area (Lu and Weng, 2007).

2.3.3 Data Preprocessing

Image preprocessing may include the detection and restoration of bad lines, geometric rectification or image registration, radiometric calibration, atmospheric correction and topographic correction. If different ancillary data are used, data conversion among different sources or formats and quality evaluation of these data are also necessary before they can be incorporated into a classification procedure. Accurate geometric rectification or image registration of remotely sensed data is a prerequisite for a combination of different source data in a classification process. Topographic correction is another important aspect if the study area is located in rugged or mountainous regions (Gu and Gillespie, 1998).

2.3.4 Feature Extraction and Selection

Selecting suitable variables is a critical step for successfully implementing an image classification. Many potential variables may be used in image classification, including spectral signatures, vegetation indices, transformed imageries, textural or contextual information, multi-temporal imageries, multi-sensor imageries and ancillary data. Due to different capabilities in land cover separability, the use of too many variables in a classification procedure may decrease classification accuracy (Price et al., 2002). It is important to select only the variables that are most useful for separating land cover or vegetation classes, especially when hyper-spectral or multi-source data are employed. Many approaches such as principal component analysis, minimum noise fraction transformation, discriminant analysis, decision boundary feature extraction, non-parametric weighted feature extraction, wavelet transform and spectral mixture analysis can be used for feature extraction, in order to reduce the data redundancy inherent in remotely sensed data or to extract specific land cover information.

2.3.5 Selection of a Suitable Classification Method

Many factors such as spatial resolution of the remotely sensed data, different sources of data, a classification system and availability of classification software must be taken into account when selecting a classification method for use. Different classification methods have their own merits. The question of which classification approach is suitable for a specific study is not easy to answer. Different classification results can be obtained depending on the classifier(s) chosen (Lu and Weng, 2007).

2.3.6 Post-Classification Processing

Traditional per-pixel classifiers may lead to 'salt and pepper' effects in classification maps. A majority filter is often applied to reduce the noises. Most image classification is based on remotely sensed spectral responses. Due to the complexity of biophysical environments, spectral confusion is common among land cover classes. Thus, ancillary data are often used to modify the classified image based on established expert rules. Previous research has indicated that post-classification processing is an important step in improving the quality of classifications (Lu and Weng, 2007).

2.3.7 Evaluation of Classification Performance

Evaluation of classification results is an important process in the classification procedure. Different approaches may be employed, ranging from a qualitative evaluation based on expert knowledge to a quantitative accuracy assessment based on sampling strategies. To evaluate the performance of a classification method, Cihlar et al. (1998) proposed six criteria: accuracy, reproducibility, robustness, ability to fully use the information content of the data, uniform applicability and objectiveness. In reality, no classification algorithm can satisfy all these requirements nor be applicable to all studies, due to different environmental settings and datasets used.

2.3.8 Classification Accuracy Assessment

Before implementing a classification accuracy assessment, one needs to know the sources of errors (Congalton and Green, 1993). In addition to errors from the classification itself, other sources of errors such as position errors resulting from the registration, interpretation errors and poor quality of training or test samples, all affect classification accuracy. In the process of accuracy assessment, it is commonly assumed that the difference between an image classification result and the reference data is due to the classification error. However, in order to provide a reliable report on classification accuracy, non-image classification errors should also be examined, especially when reference data are not obtained from a field survey (Lu and Weng, 2007).

The error matrix approach is the one most widely used in accuracy assessment (Foody, 2002). After generation of an error matrix, other important accuracy assessment elements such as overall accuracy, omission error, commission error and kappa coefficient can be derived. Previous literature has defined the meanings and provided computation methods for these elements (Foody, 2002). Meanwhile, many authors have conducted reviews on classification accuracy assessment. They have assessed the status of accuracy assessment of image classification and discussed relevant issues.

The Kappa coefficient is a measure of overall statistical agreement of an error matrix, which takes non-diagonal elements into account. Whereas the error matrix approach is only suitable for 'hard' classification, assuming that the map categories are mutually exclusive and exhaustive and that each location belongs to a single category. This assumption is often violated, especially for classifications with coarse spatial resolution imagery. 'Soft' classifications have been performed to minimize the mixed pixel problem using a fuzzy logic. The traditional error matrix approach is not appropriate for evaluating these soft classification results (Lu and Weng, 2007).

2.4 Theoretical Survey on Curve Number Method

The Curve Number (CN) was initially developed to estimate the transformation of return period rainfall into return period runoff for traditional agricultural lands in the United States. However, the CN method is now being used worldwide and it is also commonly used as an abstraction term or loss model for both continuous and event simulations.

Technical Release No. 55 (TR-55) (USDA, 1986), a simplified NRCS method to estimate peak runoff rates using the CN and unit hydrographs, is now predominantly being used to model urban, pasture, meadow, and woodland areas. While the CN method was developed to compare the effect of land use/cover changes on runoff, some well-intentioned conservation groups, designers and State agencies are even using the CN array table values to estimate the impact of very specific land development designs despite its limitation. The Curve Number (CN) has a minimum recommended event size for use based on rainfall depth (mm/24-hr). Due to their ease of use, the method has gained wide acceptance not only among engineers and designers but also by regulators and land management agencies.

The Natural Resources Conservation Service (NRCS) and the Agricultural Research Service (ARS), both agencies of the U.S Department of Agriculture (USDA) formed a joint work group in 1990 to assess the state of the Curve Number (CN) method and to chart its future development. The work group recognized three distinctly different modes of application for Curve Numbers: 1) Determination of runoff volume of a given return period, given total event rainfall for that return period. 2) Determine the direct runoff for individual events. This acknowledges the variation between events and is the basis for the development. 3) Process models, an inferred application as an infiltration model or a soil moisture-CN relationship or as a source area distribution (Van Mullem, 1990). The first application is the most widely used in engineering and uses the Curve Number (CN) to transform the rainfall frequency distribution into a runoff frequency distribution. It was the reason for the development of the model. The runoff volume that is computed is often overlooked.

The second application, runoff from individual rainfall events, is the basis for the original development, the precipitation (P) vs runoff (Q) plots which led to the Curve Number (CN) concept. There is a wide variation of runoff from rainfalls of the same magnitude which forces us to acknowledge that CN varies between storms for a side range of reasons. The original handbook developed in large part for conditions in the humid east, south and mid-west designated "Antecedent Moisture Condition" or AMC as the most significant variable in explaining this. Average condition moisture was called AMC II and applied to the Curve Number (CN) when flooding occurs. Dry conditions (AMC I) applied to the low Curve Number and wet conditions (AMC III) applied to the high Curve Number (CN). This condition is most often determined by prior rainfall since soil moisture conditions are not frequently monitored. The work group also studied the effect of soil moisture on Curve Number (CN) by looking at infiltrometer studies (Van Mullem, 1992). Poor results are often obtained for small events and the CN model does not work well for small events, forcing the model user to increase CN or to devise some other scheme to increase runoff at certain times of the year. Over a wide range of rainfall depths, the direct runoff (Q) calculated by the equation is more sensitive to Curve Number (CN) than to rainfall depth (Hawkins, 1975).

Chapter 3
Materials and Methods

3.1 Materials

Most of the data used in the study were derived from raw remotely sensed data. Landsat imageries and 90m resolution SRTM digital elevation model (DEM) were used in generation of land use/cover, slope, elevation, hillshed, stream network (drainage), watershed, stream order, flow direction and flow accumulation. Concerning the soil data, the Tekeze basin master plan study database was received from Ministry of Water Resources (MoWR). For land use/cover map of the area, Landsat TM and ETM+ imageries of path 168 with row 050 captured at date 05/01/1986, 05/02/2000 and 24/02/2007 were utilized in supervised image classification. The Table below shows the different datasets used and their sources.

Table 3-1 Types of Data Used in the Study and Their Sources

Data	Type	Resolution/Scale	Source
DEM	SRTM	90m	USGS
Satellite Imageries	Landsat TM Landsat ETM+	30m	USGS REST
Soil Data	Geodatabase	____	MoWR
Geological Map	Map	1: 250,000	GSE
Topographic Map	Map	1: 50,000	EMA
Rainfall data	Tabular	Daily record	NMA

Regarding the professional soft wares used in the study, ArcGIS 9.2 was used both as host package for ArcCN Runoff Tool and in organizing spatial datasets. ArcCN Runoff tool is an extension of ESRI at ArcGIS software and can be applied to assign Curve Number (CN) and to calculate runoff for a given rainfall event in a watershed. For the image classification analysis ERDAS IMAGINE 9.1 and ENVI 4.2 were utilized. Garmin hand held GPS was also the only means in determining the position of the sample points and in navigating the pre-selected observation site during pre-field work.

3.2 Methods

To achieve the above mentioned objectives Remote Sensing and GIS techniques were integrated with SCS-CN method. The general methodology is illustrated in Figure 3-3 and Figure 3-4. The figures show the procedures followed from generating the various datasets to the final output.

3.2.1 Remote Sensing Data Analysis

Remote Sensing is the science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in physical contact with the object, area or phenomenon under investigation (Lillesand and Kiefer, 2000). This technique also enables acquisition of data with both spatial and temporal variation. For the current research, remotely sensed Landsat TM and ETM+ were mainly used in extracting information about the land use/cover conditions of the area in the year 1986, 2000 and 2007.

3.2.1.1 Preprocessing

Preprocessing operations are activities which ought to be performed before image enhancement and classification with the objectives of correcting geometric and radiometric distortions. Some of the distortions related with variation of flight altitude, earth curvature, velocity of the platform and others were solved at the satellite data receiving station. However, the following data preparation techniques were performed after layer stacking, re-projecting to appropriate coordinates system (UTM, Adindan and Zone 37N), sub setting the images by the catchment boundary and selecting the most informative band combination.

3.2.1.1.1 Geometric Correction

The 1986 and 2000 images were originally Ortho-rectified by the supplying company and checked for its reliability using Ground Control Points (GCPs) collected during field work and additional point selected from Topographic map like river intersections, road intersections and natural features. But the 2007 image shows some shifting when it is overlaid with the rest of the images and when it is checked for the GCPs. Therefore image to image geometric correction was performed using ERDAS IMAGINE package until acceptable Root Mean Square (RMS) was achieved.

3.2.1.1.2 Radiometric Correction

At the time of image acquisition by the satellite, there could be noise introduced into the image due to detector malfunctioning or by atmospheric scattering and these defects could be corrected by restoring periodic line dropout, striping and atmospheric haze (Dagnachew, 2005). Since May, 31 2003 Landsat 7 has been facing a problem of striping caused by the malfunctioning of a device called Scan Line Corrector (SLC). SLC is an electromechanical device that compensates for the forward motion of the satellite within the ETM+ image scanning. This causes individual scan lines to alternately overlap and then leave large gaps at the edges of the image. While it is not possible to correct for this missing data, it is possible to modify the processing algorithms to produce imagery containing roughly 80% of the expected pixels.

David et al. (2003) conducted a comparison study on SLC-off Landsat image with respect to measurement and mapping of land use/cover change detection by analyzing the problem using three approaches. The first approach was performing standard processing as it is and two additional post-classification corrections were performed. These were a post-classification majority filter on the SLC-off derived product and by compositing of a recent good SLC-on derived product with the SLC-off derived product. The second approach was performing Fourier transformation of the SLC-off image as it is and re-composite the transformed and original SLC-off images. The third approach was compositing adjacent multi-temporal SLC-off images and previous SLC-on images. The comparison indicated around 90% of information was obtained (10% loss) when compared to the recent SCL-on image and there is no significant variations observed among approaches (David et al., 2003). Other studies also report around 80% of the information can be obtained by compositing adjacent multi-temporal scenes and interpolation depending on the scale of mapping. Especially the SCL-off Landsat data are still useful in global, regional and medium scale mapping like this study. On the other hand, the usefulness of SLC-off data in large scale study is still controversial.

The 2007 Landsat ETM+ image was radiometrically corrected by the supplying company for striping (See Appendix E) by compensating the gap through mosaicing adjacent scenes, replacing the pixel using multi-temporal scenes and by conducting various transformation and interpolation techniques. Atmospheric haze correction was conducted on 1986, 2000 and 2007 images by subtracting the Digital Number (DN) values obtained from selected shadowed area. Deep clear water body and shadowed areas are assumed to have zero DN value. If the values are above zero, it is assumed to be the effect of haze. The values subtracted from each band of the images are presented in Table 3-2.

Table 3-2 DN Values Subtracted during Haze Correction

	1986	2000	2007
Band 2	16	33	21
Band 3	15	26	16
Band 4	7	15	12

3.2.1.1.3 Topographic Normalization

Use of remotely sensed data from mountainous regions generally requires additional pre-processing, including corrections for relief displacement and solar illumination differences. Specifically, variations in illumination affect land cover discrimination as the same land cover will have different spectral responses among shadowed and non-shadowed areas. The correction of illumination variations is referred to as Topographic Normalization or Topographic Correction. Techniques are grouped into two major categories, (1) band ratios and (2) modeling of illumination conditions. Band ratio techniques assume that the spectral response is distorted (increased or decreased) in the same way across all bands. Therefore, the proportion between them will compensate for topographic effects. Their drawback is the loss of spectral resolution. Techniques under group (2) model illumination to compute the flat-normalized radiance of each pixel. They are grouped into two additional subcategories, Lambertian and non-Lambertian, depending on whether they assume a Lambertian or non-Lambertian surface behavior. For this study, Topographic Normalize function in ERDAS Image Interpreter was used and it is a Lambertian Reflectance model to normalize topographic effect in Visible/Infrared imagery.

The model uses the following formula.

$$\mathbf{BV_N = BV_o \ / \cos i}$$

Where $\mathbf{BV_N}$ = normalized brightness values

$\mathbf{BV_o}$ = observed brightness values

$\mathbf{\cos i}$ = cosine of the incidence angle

3.2.1.1.4 Band Selection

In order to avoiding the redundancy of information and to increase visual interpretability of the image, spectral bands combination having the most information contents should be selected. Optimum Index Factor (OIF), which is a statistical method was used and visually inspected to check whether band combinations with high OIF value gives more information than the combination with low value. The OIF is a statistical calculation of every possible 3-band combination, based on total variance within bands and correlation coefficient between bands. It is based on the following relation.

$$OIF = \frac{\sum_{i=1}^{3} SDi}{\sum_{j=1}^{3} ABS(CCj)}$$

SDi is the standard deviation of band i and

ABS(CCj) is the absolute value of the correlation coefficient between any two of the possible three pairs.

After Calculating Optimum Index Factors (OIF) for the possible band combinations and ranking based on their value, selection was done between the first five combinations using visual observation. The selected band combinations for the three imageries were Band 2, Band 3 and Band 4. The OIF values are included in the Appendix B.

3.2.1.2 Image Enhancement

The goal of image enhancement is to improve the visual interpretability of an image by increasing the apparent distinction between features in the scene. The following image enhancements were conducted on the geometrically and radiometrically corrected images.

3.2.1.2.1 Histogram Equalization

Histogram Equalization is a non-linear stretch that redistributes pixel values so that there is approximately the same number of pixels with each value within a range. This is a stretching where the original range of DN is sub-divided into a series of equal spacing and the stretching is performed by forcing the number of pixels in each sub-division to be equal. This stretching method takes the frequencies of DN's into account. The result approximates a flat histogram. Therefore, contrast is increased at the peaks of the histogram and lessened at the tails.

3.2.1.2.2 Spatial Frequency Filtering

Spatial frequency refers to the "roughness" of the tonal variations occurring in the image (Dagnachew, 2005). Image areas with high frequency features are tonally "rough" and those areas with low spatial frequency are tonally "smooth" where grey levels vary only gradually over a relatively large number of pixels. Spatial filters emphasize or deemphasize image data of variable frequencies that refer to the "roughness" of the total variation. The process involves matrix operations and the kernel size play an influential role. In this study, low frequency filter of 3*3 kernel on the histogram equalized images were applied to emphasize low frequency features and suppress the high frequency features. This process also helps to remove noise in an image.

3.2.1.2.3 Normalized Different Vegetation Index (NDVI)

Normalized Difference Vegetation Index (NDVI) is preferred to the simple index for global vegetation monitoring because NDVI help to compensate for changing illumination condition, surface slope, aspect and other extraneous factors. It is mainly helpful in mapping healthy and densely vegetated areas.

$$\mathbf{NDVI= (NIR-R) / (NIR+R)}$$

Where **NIR** is Near Infrared Band and **R** is Red Band

3.2.1.3 Image Classification

Image Classification is the process of sorting pixels in to a finite number of individual classes or categories of data based on their data values. There are two types of image classification. Namely: - Unsupervised image classification and Supervised image classification

Unsupervised Classification is used to cluster pixels in a dataset based on statistics only, without any user-defined training classes. Although the method requires no user input to create the classified image, the output tends to require a great deal of post classification operations to make the results more meaningful. Unsupervised classification was first conducted as preliminary assessment of the land use/cover condition of the area by integrating previous studies and used in identifying the possible land use/cover classes and in selecting field observation points. The unsupervised classification was performed taking 20 ISODATA clusters and finally merged together according to their similarity.

Supervised Classification is the process of using a known identity of specific sites (through a combination of fieldwork, analysis of aerial photography, maps and personal experience) in the remotely sensed data, which represent homogenous examples of land use/cover types to classify the remainder of the image. These areas are commonly referred to as training areas.

3.2.1.3.1 Training Areas

Training areas are samples of the earth's surface with known properties and the statistics of the imaged data within the area are used to determine decision boundaries in image classification (Dagnachew, 2005). One hundred ten ground truth data were collected using hand held GPS during field work and used for delineating sample training area and validating the classification for the year 2007 and additional information were added by interviewing local elders to understand the land use/cover situation during 1986 and 2000 (See Figure 3-1). The spectral signature obtained from the training areas were used in image classification.

3.2.1.3.2 Maximum-Likelihood Classifier

Supervised image classification was conducted using Maximum-Likelihood classifier method with the help of spectral signatures obtained from training areas. The Maximum-Likelihood classifier is one of the most popular methods of classification in remote sensing and assigns a pixel with maximum likelihood into a corresponding class (See Figure 3-3). The classification was done according to the land use/cover classification of the Tigray Bureau of Agriculture and Natural Resources (BoNAR, 2000) except here the three sub-classes of cultivated land are merged and named as farmland to simplify the change analysis (Table 3-3).

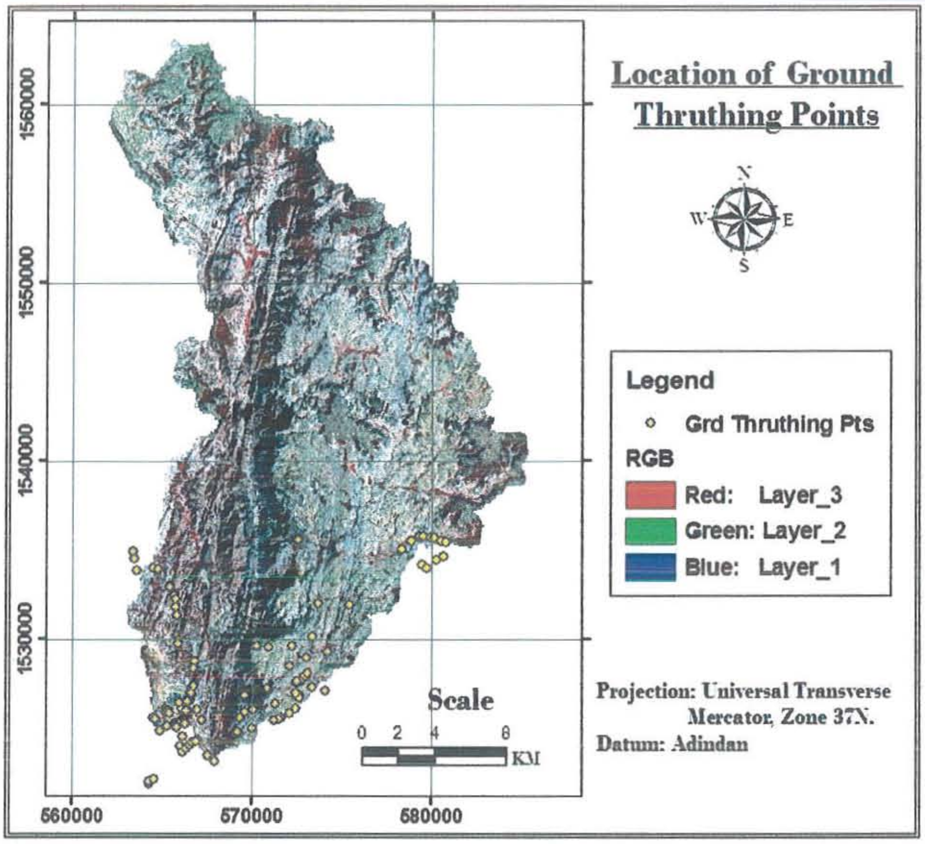

Figure 3-1 Ground Thruthing Points

3.2.1.4 Post Image Classification

Classified data often manifest a salt and pepper appearance due to the inherent spectral variability encountered by a classifier (Lillesand and Kiefer, 2000) and it is often desirable to smooth the classified output to show only the dominant class. Moreover, classified imageries often suffer from a lack of spatial coherency (speckle or holes in classified areas). To overcome this problem majority filter analyses were applied using a kernel size of 3*3 pixels in ERDAS IMAGINE 9.1.

Table 3-3 Land Use/Cover Classes Classification of Tigray Bureau of Agriculture and Natural Resources (BoNAR, 2000)

Class Name	Description
Woodland (Wd)	Land covered by trees, bushes, shrubs and herbs. Canopy cover is estimated to be 65% and the remaining (35%) is covered either by grasses, herbs or bareland.
Shrubland (Sh)	Land supporting stands of shrubs, usually not exceeding 3m in height, with a canopy cover of more than 30% while the remaining may be covered by grasses, herbs (plant without woody stem) or bare
Scrubland (Sc)	Land covered by strata of shrubs and grasses or herbs growing here and there.
Sparsely Cultivated land (SCu)	It is classified as sparsely cultivated (only 20 – 40%) of the entire mapping unit is under cultivation while the remaining area can be covered by trees, shrubs or herbs.
Moderately Cultivated land (MCu)	It is estimated that of this mapping unit 40 – 70% of the land is under annual and perennial crop while the remaining area can be covered by covered by trees, shrubs or herbs.
Intensively Cultivated land (ICu)	It is estimated that of this mapping unit over 70% of the land is under annual and perennial crops while the remaining area can be covered by trees, shrubs or herbs.
Grassland (Gr)	Open grassland with some shrubs and occasional trees.
Water body (W)	Water in micro dams.
Settlement (Se)	Residential and industrial areas.

3.2.1.5 Accuracy Assessment

The accuracy of the classification was determined from two measures: a confusion matrix, which lists in tabular form the percent of correctly and incorrectly classified pixels based on ground truth input and the Kappa coefficient, which is a measure of overall statistical agreement of an error matrix, which takes non-diagonal elements into account. Around seventy two ground truth input data were used to measure the percent of error or to see how much the output is reliable.

3.2.2 GIS Techniques

Concerning GIS application, it is a powerful tool for capturing, storing, checking, integrating, manipulating, analyzing and displaying data which are spatially referenced. It also provides a means of extracting many different kinds of information, processing it into compatible datasets, combining it, querying and displaying the results on a map. Different GIS analysis were conducted in derivation of watershed physiographic characteristics (i.e. sub-basin, main river length, slope, aspect etc) using hydrological analysis extension, generation of Hydrological Similar Units (HSUs) in terms of their land use/cover class and Hydrologic Soil Group (HSG) through overlay analysis, assigning the appropriate CN for the HSUs, calculating both the direct runoff and volumetric runoff for the watershed using ArcCN Runoff tool and presenting the final output of the study in tabular, graphic and thematic format (See Figure 3-4).

3.2.3 Hydrological Method

To predict the direct runoff from catchments covered by different land use/cover types and to assess the effect of land use/cover on hydrologic response, many hydrological models make use of the Soil Conservation-Curve Number (SCS-CN) method. Especially in areas where there is lack of continuous hydro-meteorological data. The USA Soil Conservation Service (now called the Natural Resources Conservation Service), division of the USDA (USA Department of Agriculture) has worked for decades developing equations and conducting experiments to determine reliable models for predicting direct runoff generated from a given rainfall. The SCS-CN method is based on Curve Number which is a hydrologic parameter used to describe the storm water runoff potential for a watershed and is a function of land use, soil type, and soil moisture or CN is an index developed by the Soil Conservation Service (SCS) to represent the potential for storm water runoff within a watershed area. In calculating the amount of direct runoff from watershed, the Curve Number is a major input to determine the amount of precipitation excess that results from a rainfall event over the watershed. This methodology is a standard hydrologic analysis technique that has been applied in a variety of different settings throughout the United States. The development and application of the Curve Number is well adopted in many part of the world with slight modification considering the change in environmental setting. The method was developed based on rainfall and runoff data from small agricultural watersheds in the USA and became a widely used method to predict runoff in catchments ranging in size from 0.25 ha to 1000 km^2 (Boughton, 1989). Also data obtained from smaller runoff plots can be used for Curve Number (CN) determination

(Hawkins and Ward, 1998) and in modification of the standard SCS-CN table. Semi-arid areas are underrepresented in the hydrological scientific literature and SCS-CN applies even more to rangelands and areas with (semi) natural vegetation in these regions (Descroix et al., 2002). Because it is a function of the soil and land use/cover type of the watershed area, estimation of a Curve Number requires mapping of soil and land use/cover within the watershed area and specification of unique soil types and unique land use/cover categories.

The SCS-CN method is based on the empirical formula expressed in the following equation (USDA, 1986):

$$Q = \frac{(P - Ia)^2}{(P - Ia + S)} \quad \text{, for P > Ia}$$

$$Q = 0 \quad \text{, for P} \leq \text{Ia}$$

Where Q = runoff (mm)

P = rainfall (mm)

Ia = initial abstraction (mm)

S = potential maximum retention after runoff begins (mm)

Based on a Curve Number, the potential maximum retention after runoff begins (S) can be calculated using the formula (USDA, 1986):

$$S = (25400/CN) - 254 \quad \text{where, CN is Curve Number value}$$

Subsequently, the initial abstraction (Ia) can be obtained from the following formula (USDA, 1986):

$$Ia = \lambda \times S \quad \text{where, } \lambda \text{ is Abstraction Ratio}$$

For the evaluation of land use/cover change on direct runoff, the CN plays an important role in determination of the runoff change due to the land use/cover change. Therefore, any change on the land use/cover returns a change in the CN which result a change on the runoff. Figure 3-4 shows the general methodology adopted in the study.

3.2.3.1 Model Parameter

3.2.3.1.1 Curve Number (CN)

When there is sufficient hydro-meteorological data, the CN for different land use/cover classes can be determined from model calibration and validation. However, in areas where there is no sufficient hydro-meteorological data, CN can be determined from experimental plot. Since there is no continuous hydro-meteorological data in the area, for the current study CN table generated by Descheemaeker et al. (2008) in collaboration with Mekelle University, department of land resources management and VLIR was adopted. The experimental plots used in the CN generation by Descheemaeker et al. (2008) are close to the current study area and are reasonably in similar environmental setting. The study was done by constructing around 26 experimental plots of different land use/cover classes, HSG, slope gradient and antecedent moisture condition (AMC). The precipitation and runoff data was collected for two rainy seasons and the data was treated statistical using least square fitting procedures (see Appendix C). During the determination of the local CN, the effects of antecedent moisture condition (AMC) on runoff production were considered and the recorded data were split into three groups based on the rainfall in the previous 5 days (P5).

$$\text{AMCI if } P5 < 12.5 \text{ mm}$$
$$\text{AMCII if } 12.5 \text{ mm} < P5 < 27.5 \text{ mm}$$
$$\text{AMCIII if } P5 > 27.5 \text{ mm}$$

In this study, the AMC was assumed to be moderate (AMC II) and CN with high standard error was rejected prior to averaging CN which have the same land use/cover class, HSG and Slope (See Table 3-4).

3.2.3.1.2 Initial Abstraction Ratio (λ)

In the original development of the CN method, the initial abstraction ratio (Ia/S or λ) is assumed to have a value of 0.2 and in most studies; λ is simply set to this value. Optimum values obtained by Deschmaeker et al. (2008) in the least squares fitting procedure were around 0.05 for most experimental plots, which was also observed by Hawkins et al. (2002). For this study λ was set 0.05 in all calculations which is recommended by Deschmaeker et al. (2008) for the northern highlands of Ethiopia.

Table 3-4 Land Use/Cover Class and Their CN Values Used in the Study for AMC II

Land Use/Cover Class	HSG		
	A	B	C
Water body	0	0	0
Woodland	30	45	60
Shrub	59	74	81
Farmland (crop C + T)	66	74	80
Scrub	67	78	84
Grassland	68	79	86
Bare (fallow)	74	83	88
Rock outcrop	98	98	98

3.2.3.1.3 Rainfall Data

One of the data required to estimate the direct runoff generated is rainfall data. Rainfall records from four weather stations, which are within and nearby to the study area, were received from National Meteorological Agency of Ethiopia (NMA) and used to calculate the daily aerial depth of precipitation using the Thiessen polygon approach. The weather stations are at Wukro, Hawzen, Senkata and Edaga Hamus (Figure 3-2). The method attempts to define the area represented by each gauges in order to weigh the effects of non-uniform rainfall distribution. The procedure of the method is first to connect the gauging stations by drawing straight lines, then the perpendicular bisectors of the connecting lines is drawn. After that, the area of each polygon (A_i) derived from the intersection of the study area boundary and the lines drawn are determined. Finally, the daily aerial depth of the area is calculated using the formula below.

$$\bar{P} = \frac{\Sigma A_i P_i}{A} = \sum_{i=1}^{n} \left(\frac{A_i}{A} \right) P_i = \sum_{i=1}^{n} a_i P_i$$

Where P = the daily aerial depth of rainfall

P_i = the rainfall at gauging station n

A = the total area of the study area

A_i = the area of polygon i

n = number of gauging stations

Since there were no enough Meteorological stations before 2000 and also for stations established before 2000 lack continuous recording, the rainfall records from 2000 up to 2008 were utilized in calculating the daily aerial depth of precipitation, average daily precipitation and average maximum precipitation for the selected August records. Generally, the area is known for scarcity of past historical records. But, after 2000, there are relatively continuous records after the establishment of some new stations.

3.2.3.1.4 Slope

The 90m SRTM digital elevation model were used to derive the slope gradient data layer of the area in the spatial analyst extension of ARCGIS 9.2.

3.2.3.1.5 Hydrologic Soil Group (HSG)

Soils are classified into hydrologic soil groups (HSGs) to indicate the minimum rate of infiltration obtained for bare soil after prolonged wetting. The Hydrologic Soil Group (HSG) is produced mainly based on the soil infiltration rate and soil textural class (Table 3-5). For this study, the semi detail soil survey conducted by Ministry of Water Resources was used as reliable soil data. To overcome the problem of some missing soil data, additional information from FAO and Ethio-GIS Geodatabases were used in deciding the textural class and drainage class of the various soil units. Once the above data was reorganized, the soil map was classified into Hydrologic Soil Group (HSG) based on textural class and infiltration rate (Figure 4-16).

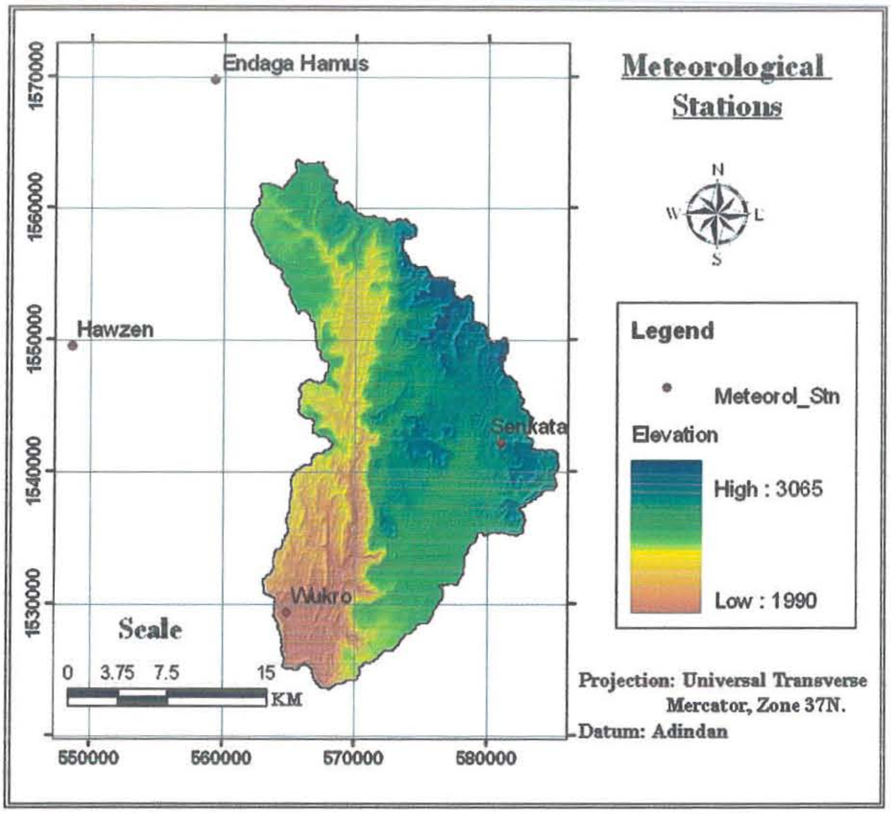

Figure 3-2 Meteorological Stations

3.2.3.2 ArcCN Runoff Tool

For the current study ArcCN Runoff tool, an ArcGIS extension script which is used to calculate the direct runoff and volumetric runoff generated from a given rainfall based on SCS-CN method considering the spatial variability in terms of land use/cover and soil type were selected and used because of its advantages in the types of input data it requires and its simplicity in running the method specially in data scarce areas. The script was downloaded from ESRI web site (http://arcscripts.esri.com/details.asp?dbid=13311) and adopted for the current study.

Once the land use/cover data layer for the years 1986, 2000 and 2007 were generated and converted to vector format using the ArcGIS conversion function, the other inputs necessary were the hydrologic soil group (HSG) and CN database in dbf format. The first step was to overlay the land use/cover vector data with the hydrological soil group (HSG) layer using the intersection operator included in the ArcCN Runoff tool or in ArcGIS extension. This results polygons with similar land use/cover and HSG then additional information attribute columns will be added to prepare space for the CN, Runoff and Volumetric Runoff that will be calculated later for a given rainfall. Next, the land use/cover overlaid with HSG and the CN dbf file is added to the display or table of content. In the CN-Runoff-Volume interface of ArcCN Runoff tool, the LULC/HSG layer is given, and then get CN value box will be checked. Next the column name from which it takes the land use/cover type and HSG type is selected form the combo list. Subsequently, the CN dbf will be inserted from which it matches the CN for each polygon. The next step is matching, the land use/cover class of the LULC/HSG layer with that of the CN table. Then, check the box in front of get Runoff value and give the precipitation in millimeter (mm) then after if the volumetric runoff is necessary check the box in front of get RunoffVol. Value and select the unit of the result. Finally click ok. After it has finished calculating, go to the attribute table and observe the CN, Runoff and RunoffV_M column for each polygon. The value for each polygon is automatically calculated and entered into the columns. These steps will be repeated to calculate for different precipitations and land use/cover conditions.

3.2.4 Limitation of the Method

Even if the method is entrenched in runoff prediction practice and is acceptable to regulatory agencies and professional bodies, it has some considerable limitations. To mention some of the limitation:-

- No consideration is given to rainfall intensity or duration.
- No guidance given about the watershed size to which the method is applicable, except that the empirical relations were established for 'small' watersheds.
- Orographic influences on rainfall also have an effect on predicted runoff volumes.

Table 3-5 Characteristics of Hydrologic Soil Groups (USDA, 1986)

Soil Grp.	Characteristics
A	Sand, loamy sand or sandy loam types of soils. It has low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission.
B	Silt loam or loam. It has a moderate infiltration rate when thoroughly wetted and consists chiefly or moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.
C	Sandy clay loam. They have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine structure.
D	Clay loam, silty clay loam, sandy clay, silty clay or clay. This HSG has the highest runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with high swelling potential, soils with a permanent high water table and shallow soils over nearly impervious material.

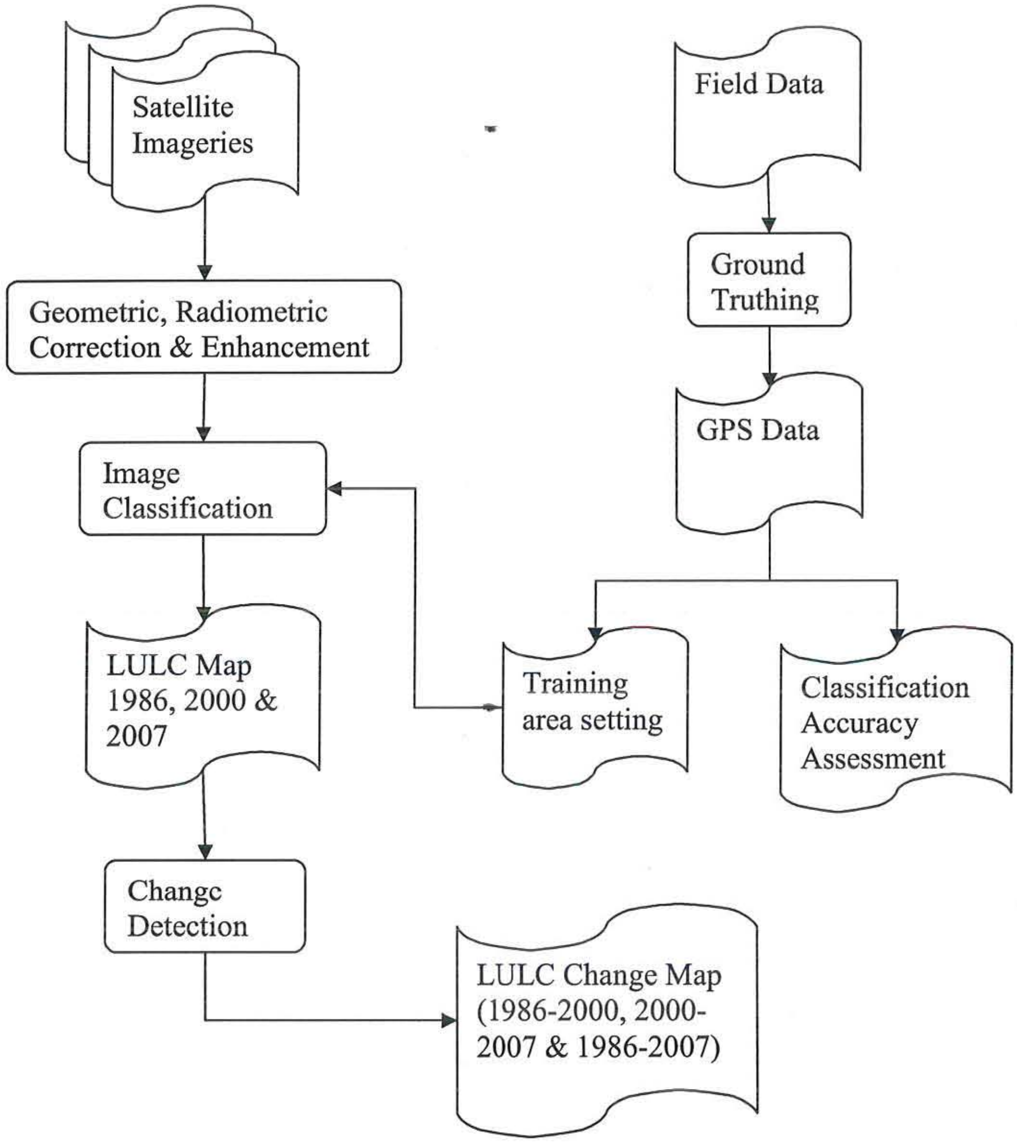

Figure 3-3 Flow Chart Used for Land Use/Cover Mapping

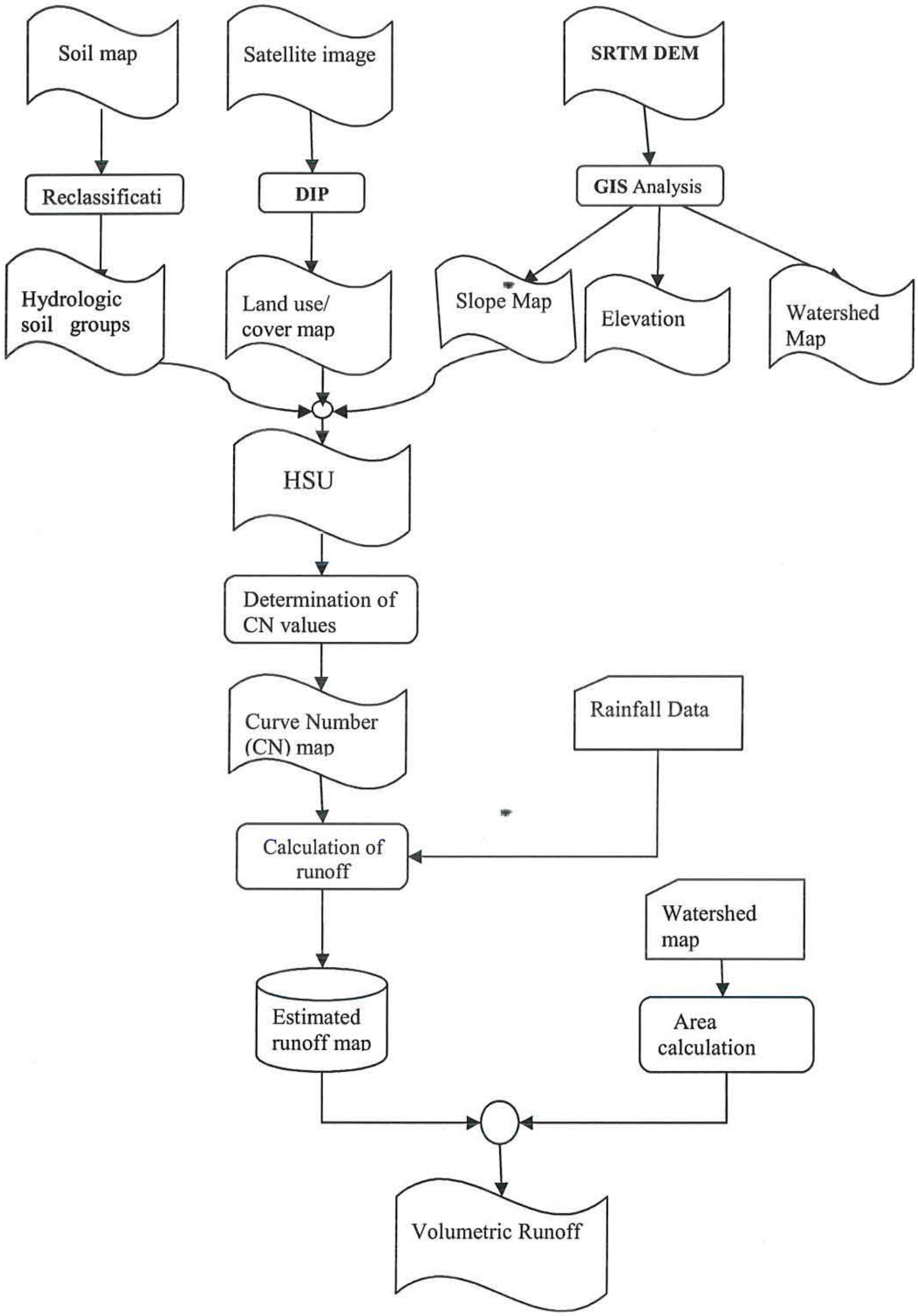

Figure 3-4 Flow Chart Showing the General Methodology

Chapter 4

Spatial Data Analysis

In this section the spatial analysis used which includes image processing and SCS-CN model will be discussed with the purpose of presenting important preliminary results and the model parameters.

4.1 Image Processing

4.1.1 Radiometric Correction

Figure 4-1 and Figure 4-4 show the variation after haze correction and topographic normalization which is caused by atmospheric scattering and sun illumination variation due to topographic variation or shadowing.

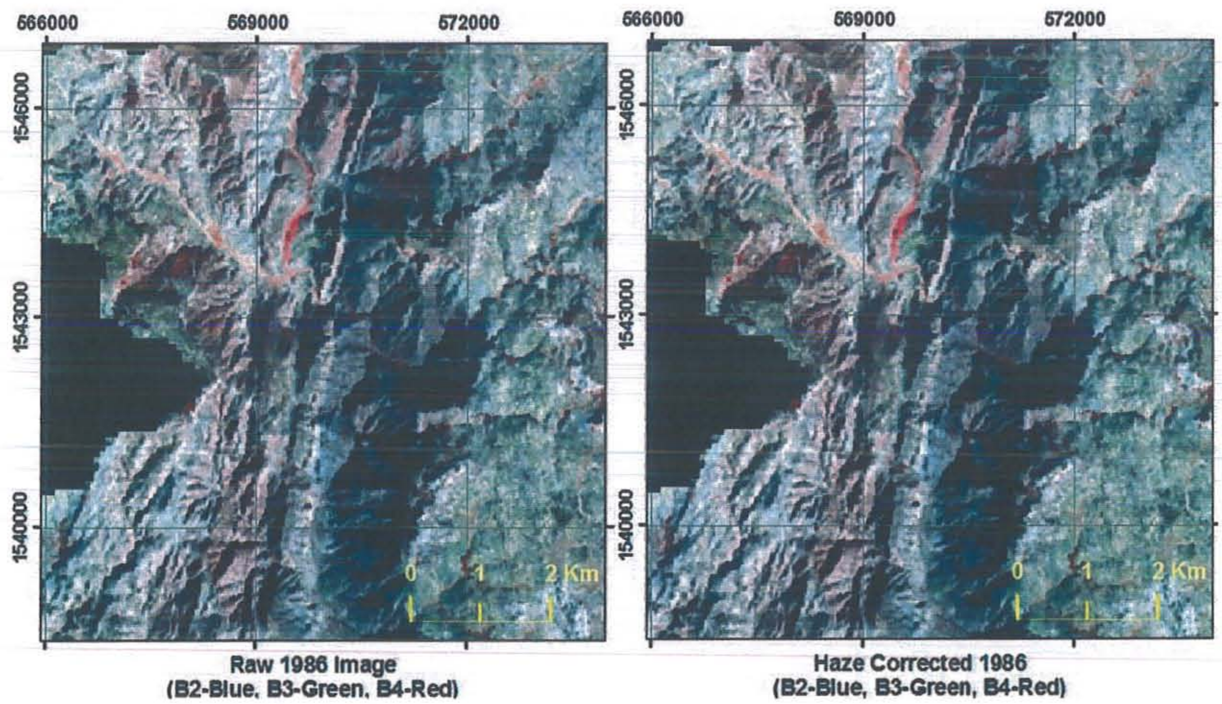

Figure 4-1 Before and After Haze Reduction (Zoomed 7x)

The histogram of the haze corrected image shows a shift towards the left when it is compared with the uncorrected image as shown in Figure 4-2 and Figure 4-3 below.

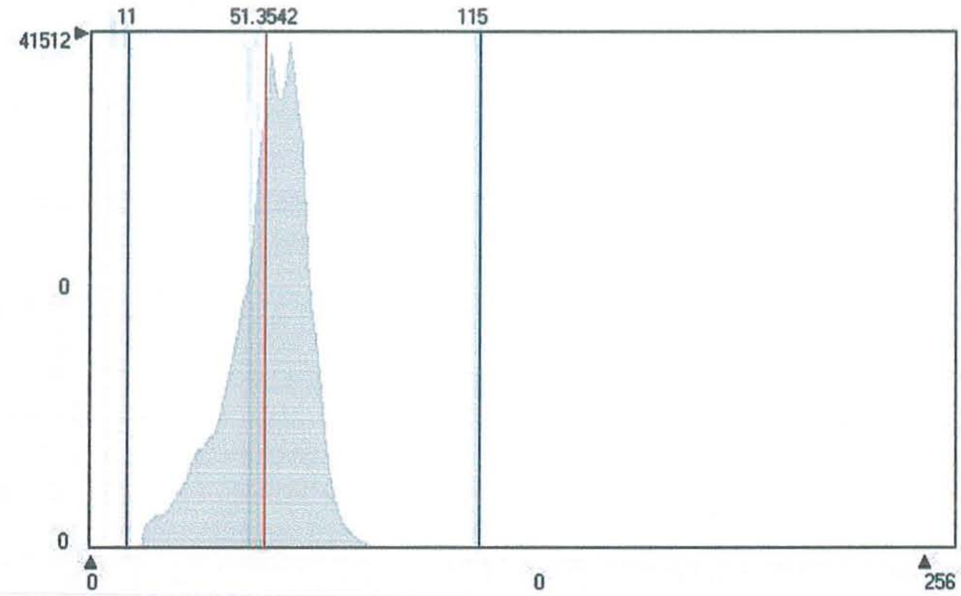

Figure 4-2 Histogram for Band 2 of 1986 Image before Haze Correction

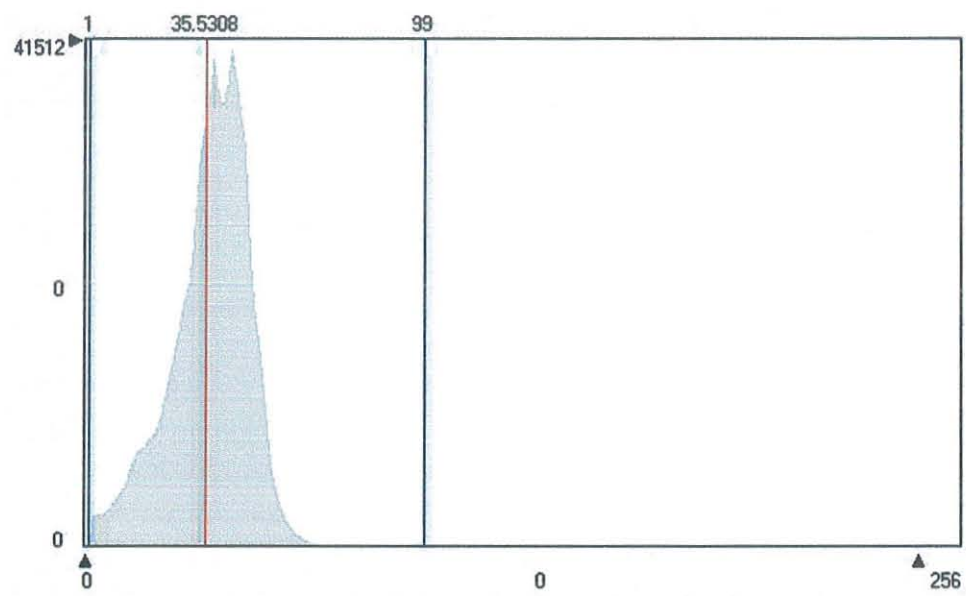

Figure 4-3 Histogram for Band 2 of 1986 Image after Haze Correction

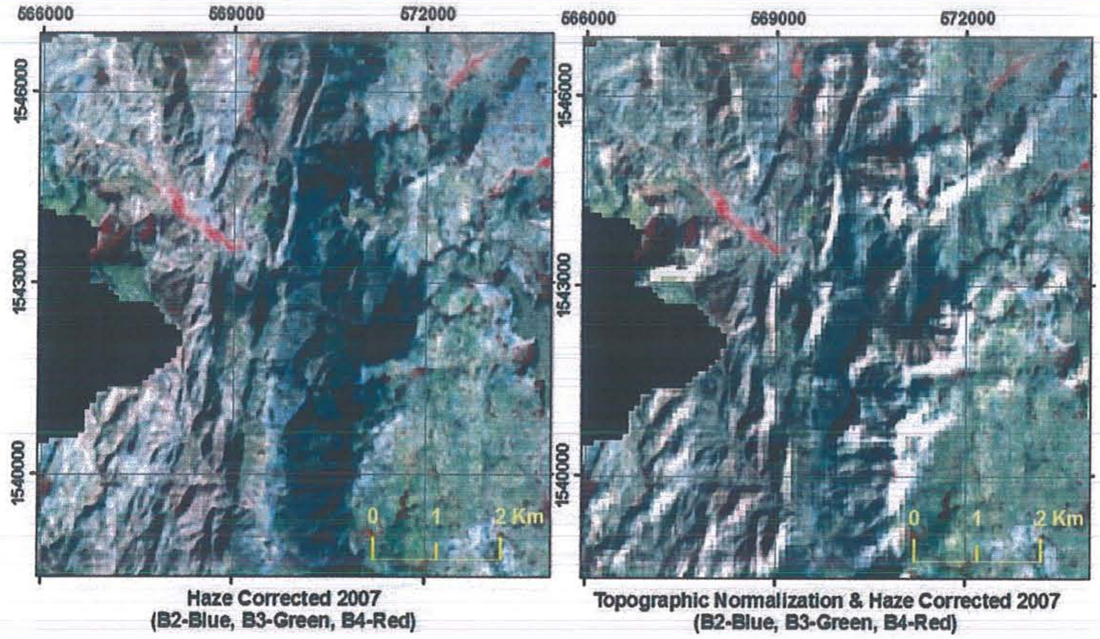

Figure 4-4 Before and After Topographic Normalization (Zoomed 7x)

4.1.2 Image Enhancement

The outputs of the various image enhancement techniques conducted before image classification are illustrated as follow.

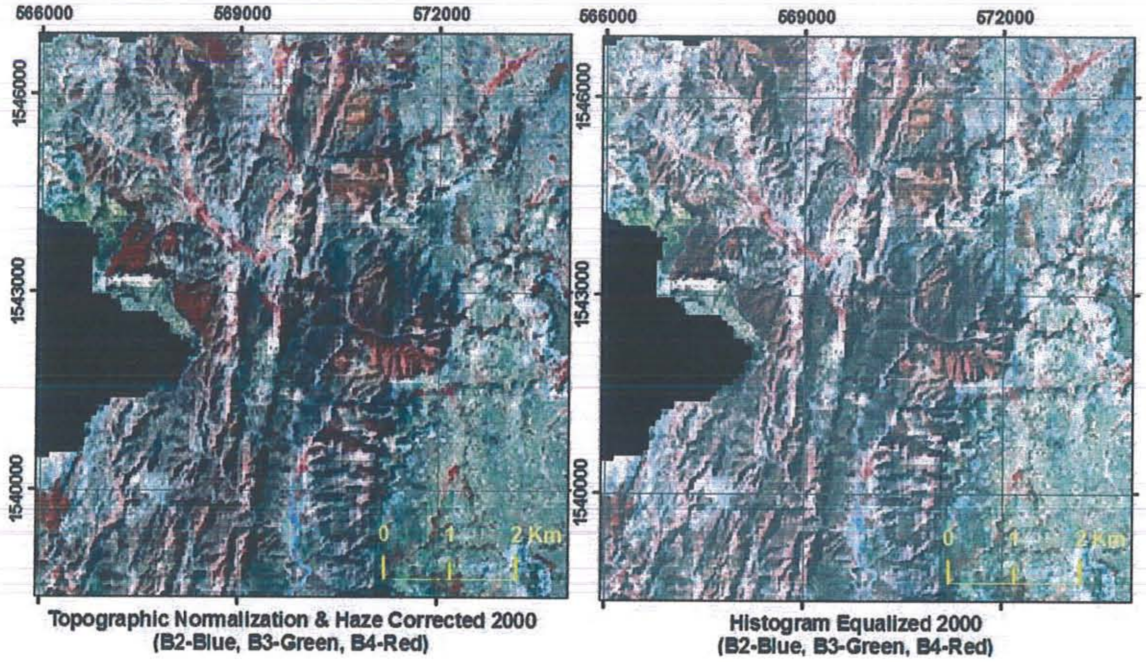

Figure 4-5 Before and After Histogram Equalization (Zoomed 7x)

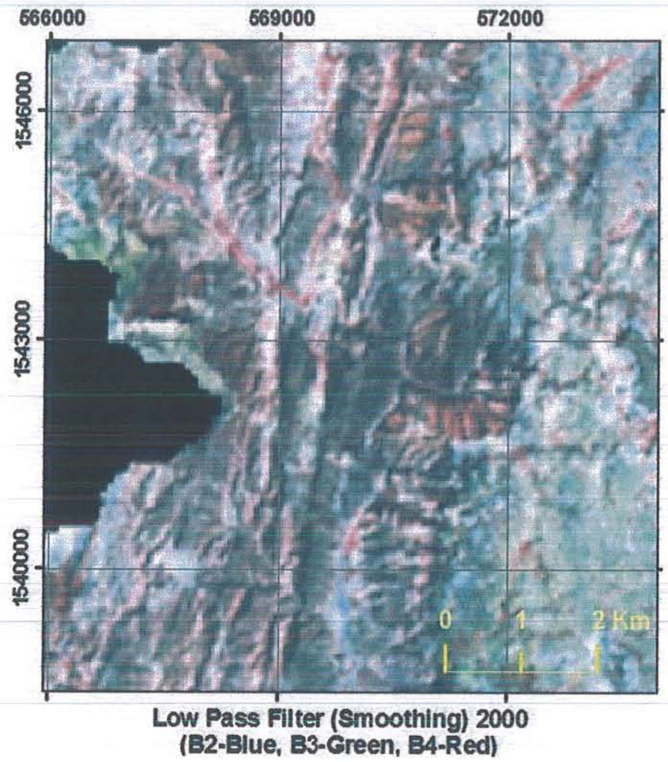

Figure 4-6 After Low Pass 3*3 Filter (Zoomed 7x)

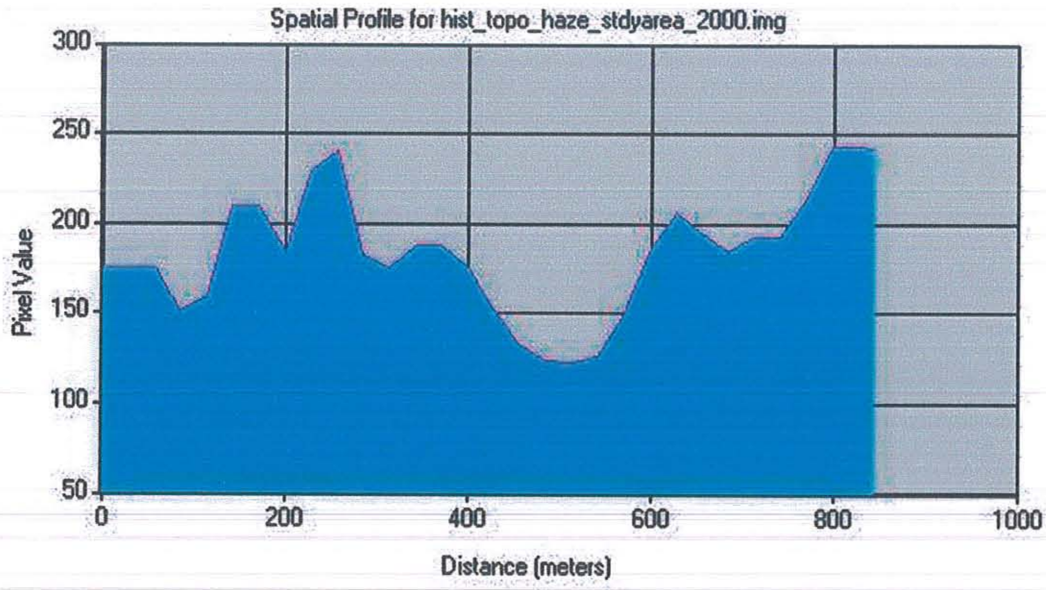

Figure 4-7 Spatial Profile before Low Pass Filtering

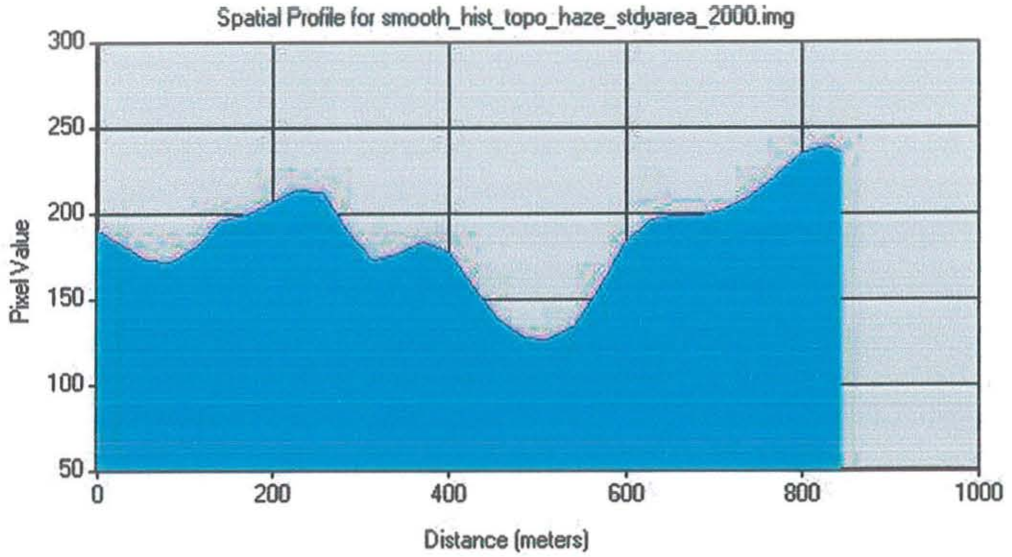

Figure 4-8 Spatial Profile after Low Pass Filtering

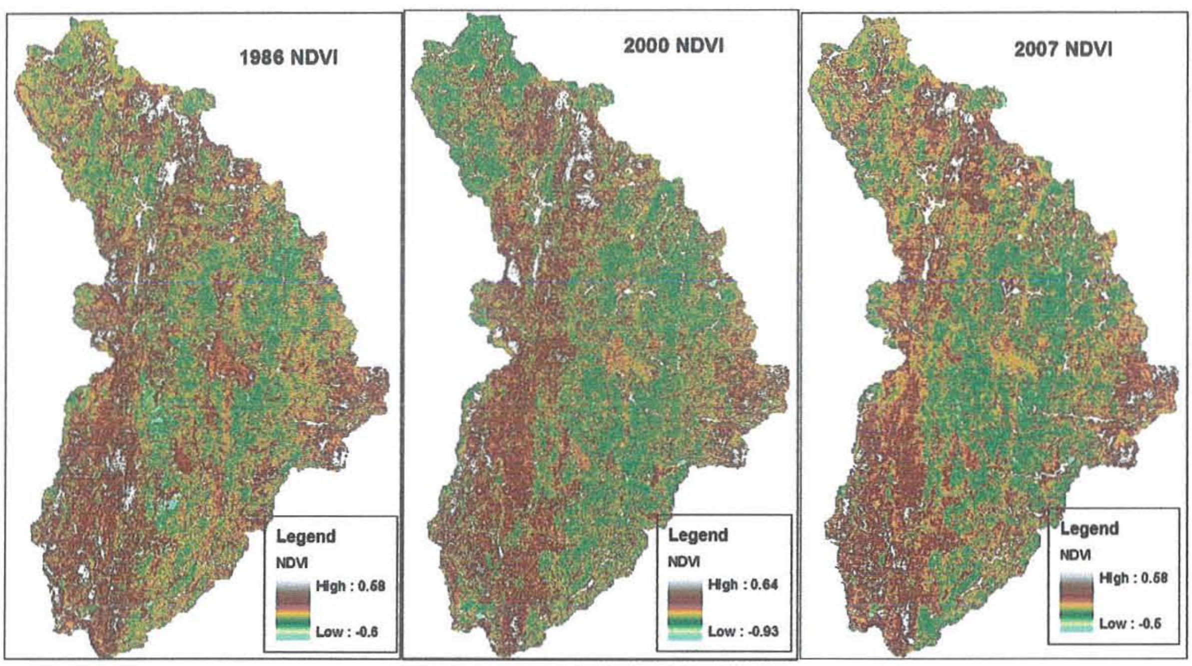

Figure 4-9 NDVI Map

4.1.3 Image Classification

Based on spectral characteristics, field observation, interviewing farmers in the area and classifying the satellite imageries seven (for 1986) and eight land use/cover classes (for 2000 and 2007) were discriminated. Because of micro-dam constructions after [illegible] was identified on 2000 and 2007. The result of image classification is presented as follow.

4.1.3.1 Land Use/Cover Classes for Year 1986

According to the result of image analysis for the year 1986, the leading land use/cover class in terms of area coverage was farmland. This class almost took half of the total area (43.2%) specially dominant in the eastern part starting from the fault escarpment to the east of Wukro town to the eastern boundary of the study area, which is close to Atsbi town and coves 21891 ha (Figure 4-10 and Figure 4-11). The second dominant class was scrubland covering 10668 ha (21.0%) and observed mainly along the central North-South trending fault escarpment. Then followed by shrubland with area coverage of 6476 ha (12.7%) and observed in the western part of the area which is characterized by rugged topography and in the east following the slope sides of Enticho Sandstone plateau. For the year 1986, there is no water body mapped and woodland was the least in area coverage when compared to other classes and accounts about 3.9% (1987 ha).

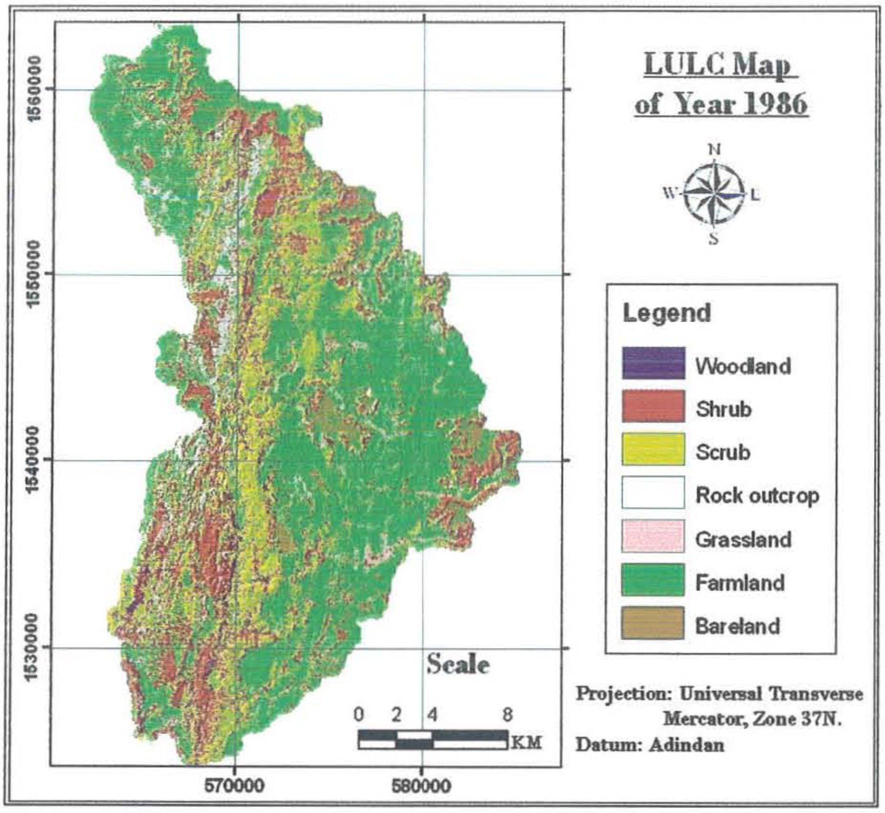

Figure 4-10 Land Use/Cover Map of Year 1986

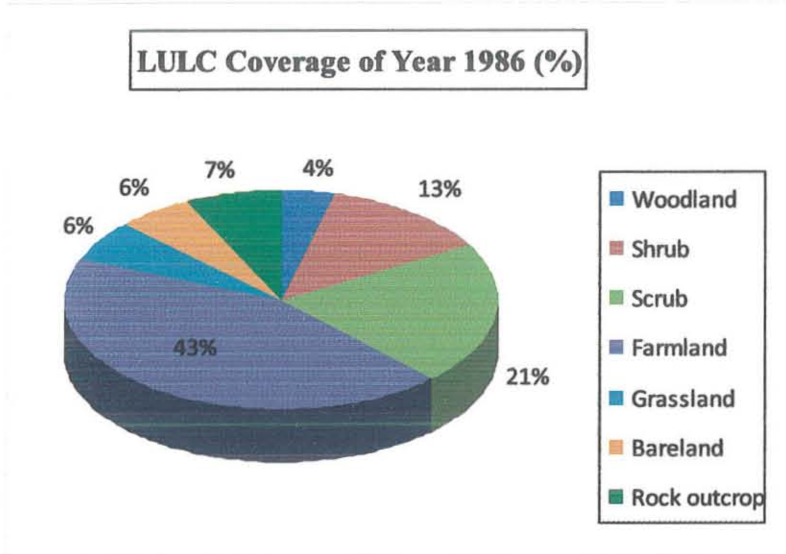

Figure 4-11 Pie Chart Showing Percentile of Each Land Use/Cover Class for Year 1986

4.1.3.2 Land Use/Cover Classes for Year 2000

For the year 2000, the dominant class was farmland as that of 1986 with increment in coverage (24950 ha) and accounts about 49.2% of the total area (Figure 4-12 and Figure 4-13). Scrubland was the second dominant class covering around 10589 ha of land, followed by shrubland with area coverage of 5580 ha and shows slight decrement when compared with the year 1986. Starting from 2000, micro water bodies were discriminated with a total of less than 0.1% (50 ha).

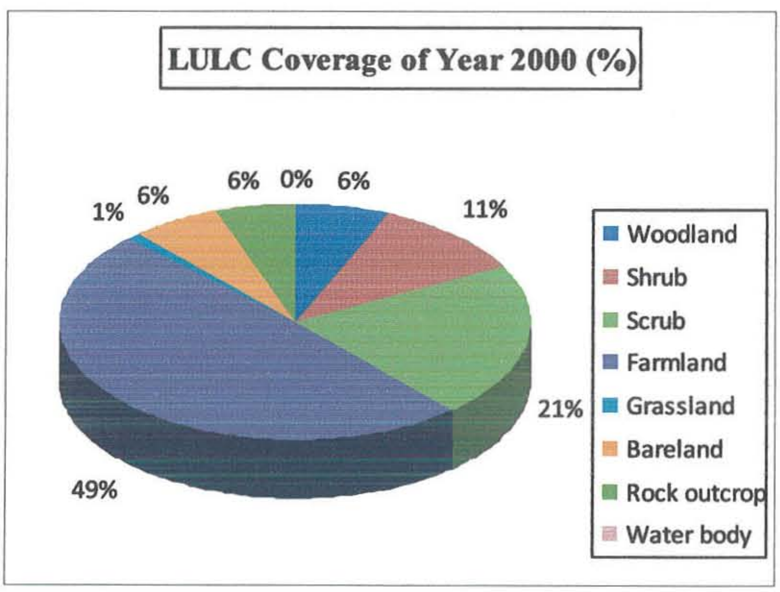

Figure 4-12 Pie Chart Showing Percentile of Each Land Use/Cover Class for Year 2000

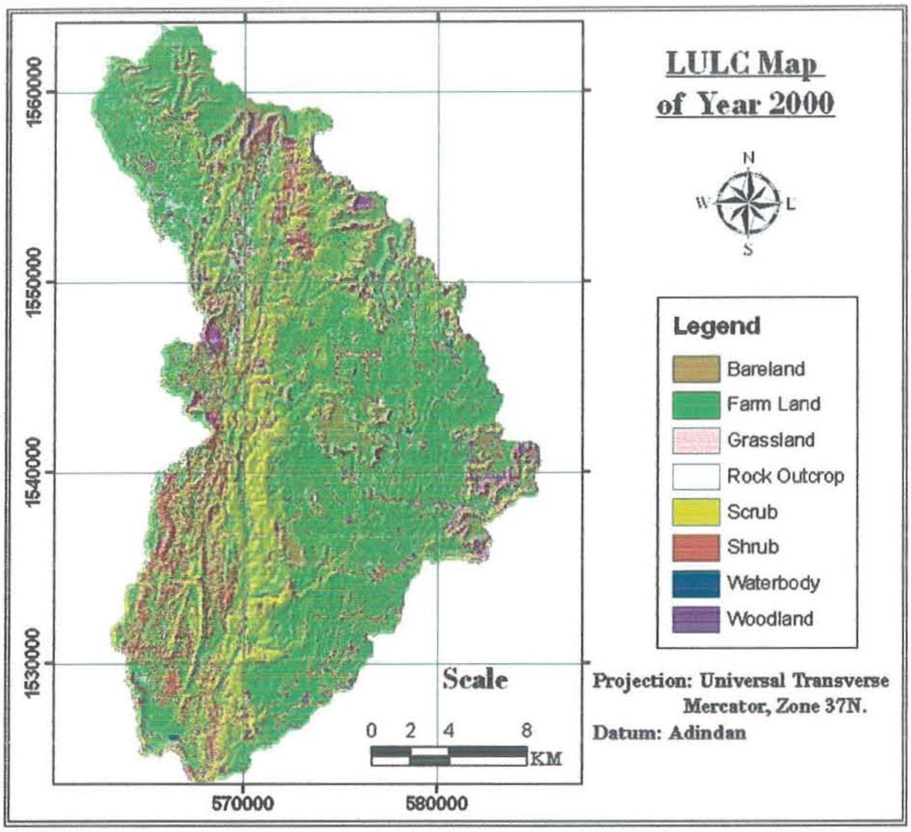

Figure 4-13 Land Use/Cover Map of Year 2000

4.1.3.3 Land Use/Cover Classes for Year 2007

Farmland was the first class in terms of area coverage for the year 2007, followed by scrub and shrub covering 26255 ha (51.8%), 9511 ha (18.7%) and 8046 ha (15.8%) respectively (Figure 4-14 and Figure 4-15). Still water body class was mapped and the least in terms of area coverage. Woodland observes a significant decrease than ever when compared with the past years.

Generally, Farmland was dominant in 1986, 2000 and 2007 having an area of 21891 ha (43.2%), 24,950 ha (49.2%) and 26,255 ha (51.8%) respectively. The second dominant land use/cover class identified for all the years was scrubland with 10668 ha (21.0%), 10589 ha (20.9%) and 9512 ha (18.7%) respectively. The third dominant class for 1986, 2000 and 2007 were shrubland covering 6476 ha (12.7%), 5580 ha (11.0%) and 8046 ha (15.8%) respectively. The next class was rock outcrop for the year 1986 covering 3595 ha (7.1%), Woodland for the year 2000 covering 3185 ha (6.2%) and bareland for the year 2007 covering

4064 ha (8.0%) respectively. Grassland was 3126 ha (6.1%) in 1986, bareland which cover 3014 ha (5.9%) for 2000 and rocky outcrop 1518 ha (3%) for 2007 took the fifth place in terms of dominancy.

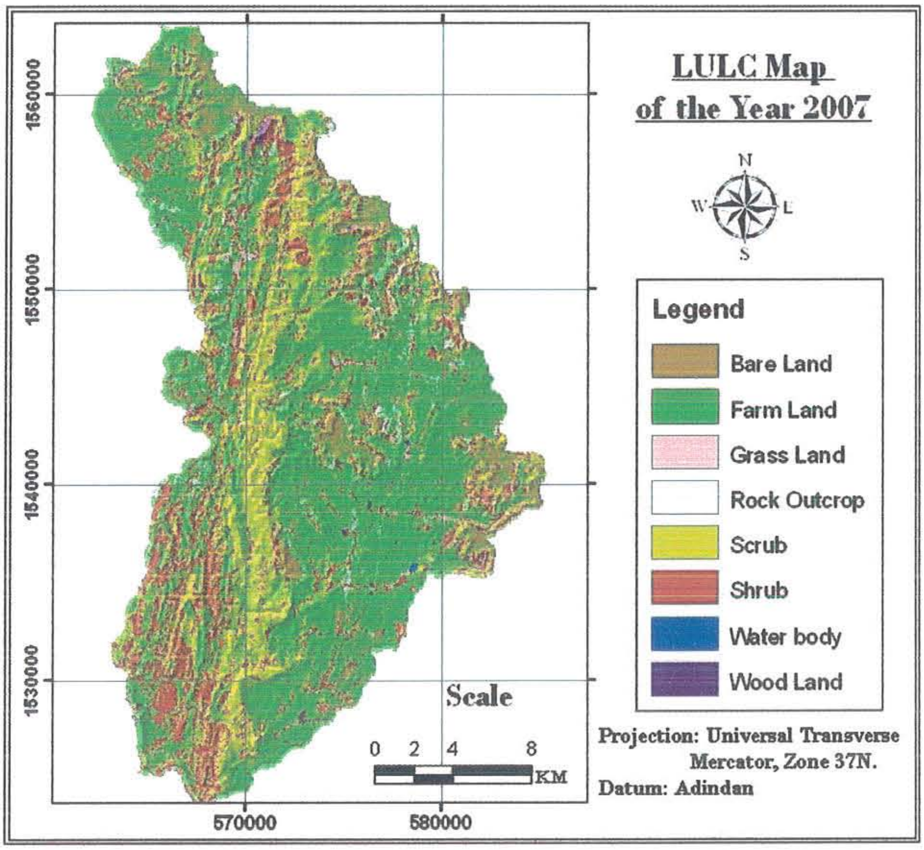

Figure 4-14 Land Use/Cover Map of the Year 2007

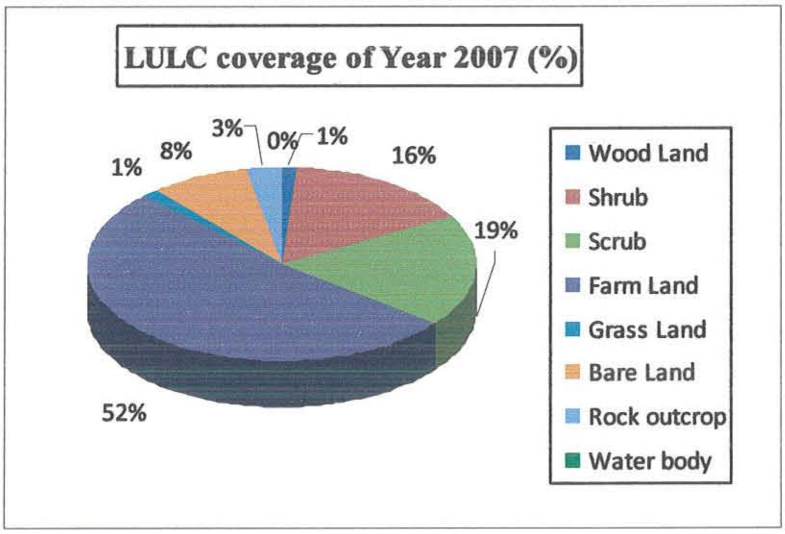

Figure 4-15 Pie Chart Showing Percentile of Each Land Use/Cover Class for Year 2007

4.1.4 Accuracy Assessment

Overall accuracy, producer's accuracy, user's accuracy and Kappa coefficient were calculated for the classifications and the overall accuracy and overall Kappa statistic for the year 1986 image were 87.5% and 0.85 respectively. For the 2000 image, overall accuracy and Kappa statistic were 88.4% and 0.87 respectively and were 87.3% and 0.86 for the 2007. In 1986 image classification, the producer's and user's accuracy were greater than 75% for the majority of land use/cover classes. In the 2000 image classification, shrub was the poorest (77.7%) in producer's accuracy, and grassland and woodland showed low user's accuracy (75%) whereas the majority of the land use/cover classes had greater than 75% producer's and user's accuracy (Appendix A). For the 2007 classification, no producers accuracy less than 77.7% and users accuracy less than 75% were observed (Table 4-1).

Table 4-1 Confusion Matrix for 2007 Image Classification

Classi. Data	Unclas	Wtr bdy	Gr	Wd	Frm	Bar	Rck	Sh	Sc	Row Total	Produc Accurc	Users Accurc
Unclas	8	0	0	0	0	0	0	0	0	8	------	-----
Wtr bdy	0	6	0	0	0	0	0	0	1	7	85.7%	85.7%
Gr	0	0	7	1	0	0	0	0	0	8	77.7%	87.5%
Wd	0	0	0	7	0	0	0	1	0	8	87.5%	87.5%
Frm	0	0	1	0	6	0	0	0	1	8	100.0%	75.0%
Bar	0	0	0	0	0	7	1	0	0	8	87.5%	87.5%
Rck	0	0	1	0	0	0	7	0	0	8	87.5%	87.5%
Shr	0	1	0	0	0	0	0	7	0	8	87.5%	87.5%
Sc	0	0	0	0	0	1	0	0	7	8	77.7%	87.5%
Colmn Total	8	7	9	8	6	8	8	8	9	71		

Overall Classification Accuracy = 87.3%

Overall Kappa Statistics = 0.8574

Producer's accuracy = Number correct/ Reference total * 100

User's accuracy = Number correct/ Classified total * 100

4.2 Hydrological Analysis and Model Parameters

4.2.1 Rainfall Data

Because significant portion of the annual rainfall occurs and contributed by the rain that precipitate on August, the average daily aerial depth of rainfall of August for the past eight years (2001-2008) were calculated and used for assessing the effect of land use/cover change on direct and total volumetric runoff. The average of the maximum daily aerial depth of precipitation (2001-2008) was also another rainfall event used to represent storm rainfall. Because the two rainfall events have about 19mm gap, to minimize this variation hypothetical rainfall event were taken by averaging the two rainfall events. Because poor results are often obtained for small events and the CN model does not work well for small events (Hawkins, 1975), the average daily aerial depth of rainfall was rejected. Thus, 20mm and 36mm rainfall events were the two rainfall events used in the assessment (Table 4-2 and Table 4-3).

Table 4-2 Average Daily Rainfall in August

	2001	2002	2003	2004	2005	2006	2007	2008	Sum	Average
Aver. Aug	8.52	7.47	5.48	6.13	5.75	9.22	5.62	3.63	51.82	7.00

Table 4-3 Average Maximum Rainfall in August

	3/08/01	7/08/02	7/08/03	8/08/04	26/08/05	26/08/06	1/08/07	6/08/08	Sum	Aveg.
Max Aug	49.61	30.37	26.67	44.05	34.90	41.17	27.05	34.96	288.7	36.1

4.2.2 Hydrologic Soil Group (HSG)

HSG map of the area generated after reclassifying the soil map based on the soil texture and infiltration rate is presented in Figure 4-16 below. The eastern half of the area is mainly characterized by HSG B and HSG A is the second in terms of area coverage. The sloppy valleys close to the rivers are characterized by the low infiltration soil type (HSG C). HSG B covers about 53% of the total area, followed by HSG A which covers around 41% and HSG C only covers 6% of the total area.

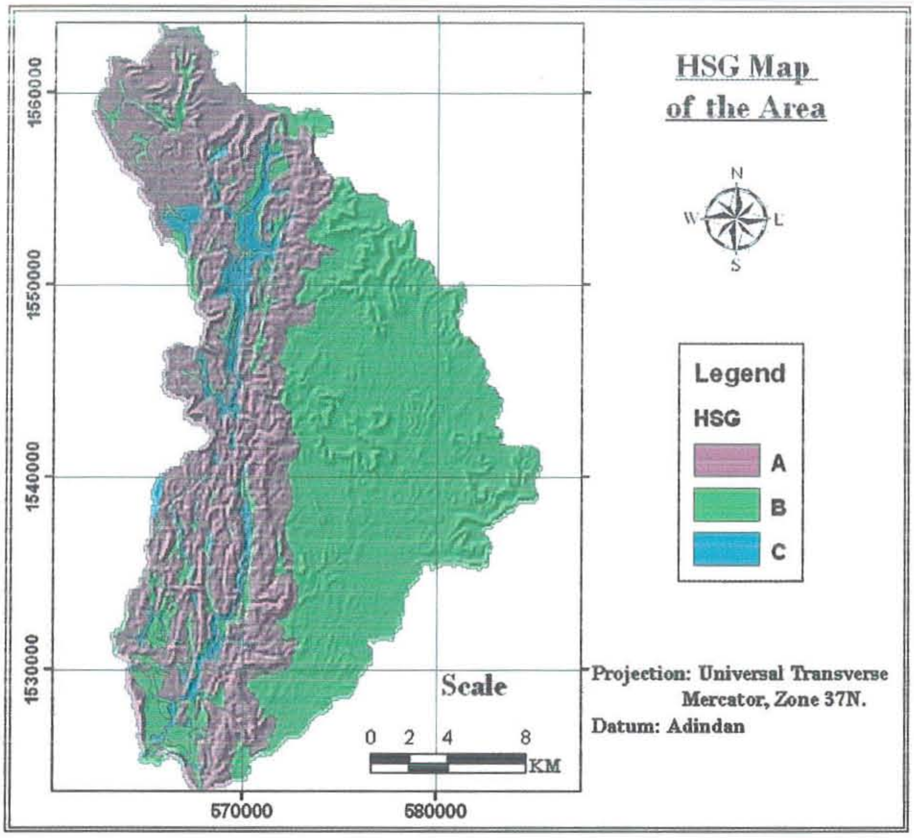

Figure 4-16 HSG Map of the Area

4.2.3 Slope

As Figure 4-17 shows majority of the study area is characterized by slope gradient ranging from 0-8°. Especially the central eastern and south eastern portion of the area is dominated by flat to gentle slope. The next slope category ranges from 8-18° that mainly covers the central west and northern part of the area. The rugged topography along the west and east bank of the main Genfel river is dominated by the 8-18° and 18-47° of slope category. The 18-47° category mainly characterizes the eastern bank of the main river starting from south to the central part.

4.2.4 Land Use/Cover

The results obtained from the image classification were used for the determination of direct runoff and total volumetric runoff from a given rainfall per day. The land use/cover classes are illustrated in section 4.1.3.

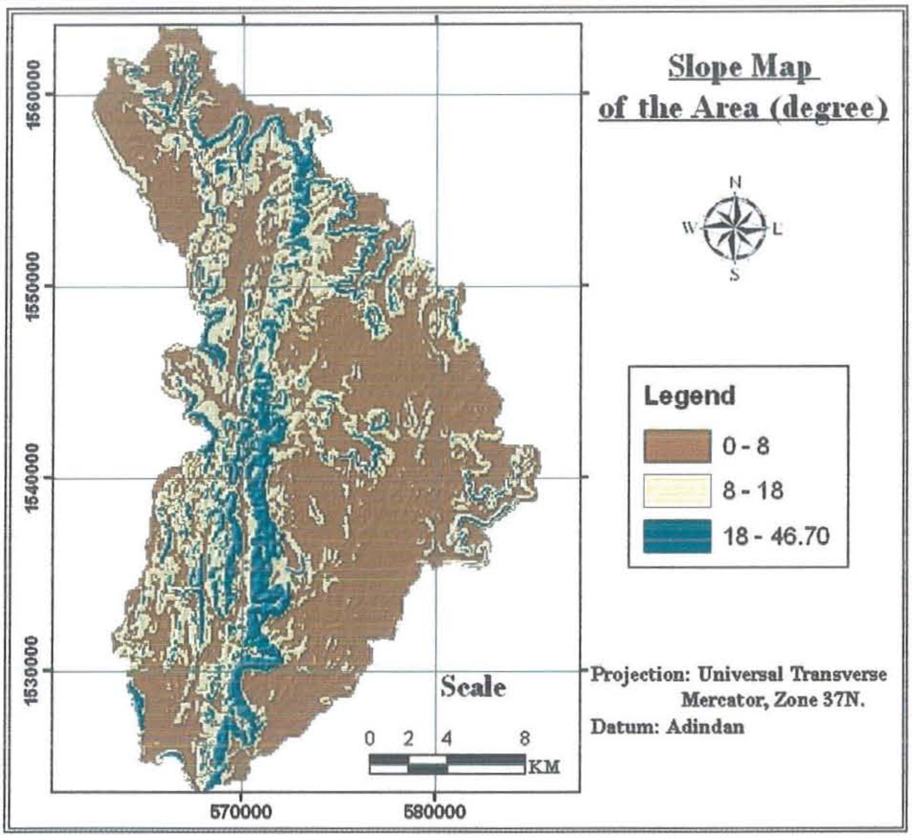

Figure 4-17 Slope Map of the Area

4.2.5 Hydrological Similar Units (HSUs)

Hydrological Similar Units (HSUs) are areas or polygons which represent the same land use/cover class and Hydrologic Soil Group (HSG) derived from overlying of land use/cover layer with HSG layer. Total number of HSUs derived for the year 1986, 2000 and 2007 are 1104, 1120 and 1118 respectively.

4.2.6 Model Output

The runoff generated from the catchment assuming AMC II and land use/cover condition for the three years taking rainfall events of 20 mm and 36 mm is presented in Figure 4-18 and Appendix D.

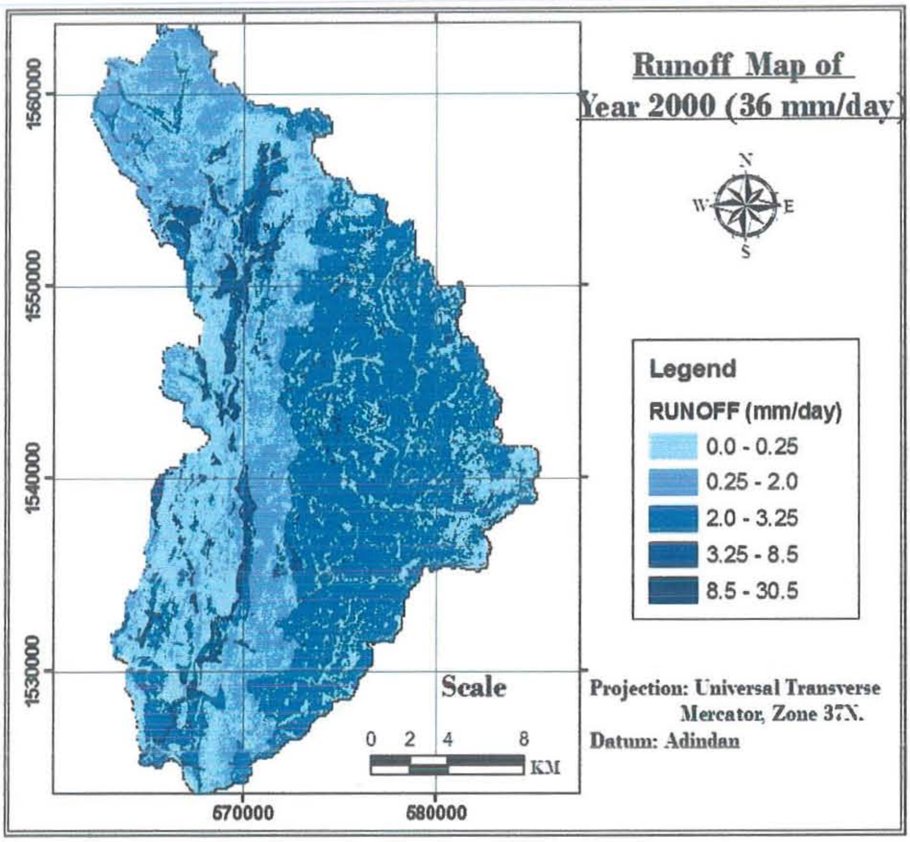

Figure 4-18 Runoff Map

Chapter 5

Results and Discussion

5.1 Change Detection by Post Classification

Post classification change analysis for the periods (1986-2000 and 2000-2007) revealed that some important land cover changes were occurred. The land use/cover change occurred is presented in the Table 5-1 and Table 5-2.

During the period 1986-2000, significant decrement was occurred on grassland followed by shrub with 2656 ha and 895 ha respectively (Table 5-1 and Figure 5-1). There was also an increment on farmland and woodland by 3060 ha and 1198 ha respectively. Due to construction of micro dams in the area after 1986, an increment of water body was observed by 47 ha.

Table 5-1 Land Use/Cover Area Change Occurred in Hectares during 1986-2007

Land use/cover Class	Land use/cover Area (ha)			Land use/cover Area change between 1986 and 2007		
	1986	2000	2007	1986-2000	2000-2007	1986-2007
Woodland	1987.4	3185.2	497.0	1197.8	-2688.1	-1490.3
Shrubland	6475.5	5580.1	8046.4	-895.4	2466.2	1570.8
Scrubland	10667.5	10589.9	9511.9	-77.5	-1078.0	-1155.6
Farmland	21890.7	24950.3	26255.2	3059.5	1304.8	4364.4
Grassland	3125.8	470.1	705.4	-2655.7	235.2	-2420.4
Bareland	2877.6	3013.6	4064.8	135.9	1051.2	1187.2
Rocky Outcrop	3595.4	2784.1	1517.6	-811.2	-1266.4	-2077.7
Water Body	0.00	46.62	27.5	46.6	-19.0	27.5

In the period 2000-2007, significant decrement of woodland and scrub were occurred by 2688 ha and 1078 ha. On the other hand, shrubland followed by farmland and bareland were increased by 2466 ha, 1305 ha and 1051 ha respectively. Figure 5-2 shows the change occurred in this period.

Table 5-2 Land Use/Cover Percentile Change Occurred During 1986-2007

Land use/cover Class	Land use/cover area coverage in (%)			Land use/cover area coverage change between 1986 and 2007 (%)		
	1986	2000	2007	1986-2000	2000-2007	1986-2007
Woodland	3.9	6.2	0.9	2.3	-5.3	-2.9
Shrubland	12.7	11.0	15.8	-1.7	4.8	3.1
Scrubland	21.0	20.9	18.7	-0.1	-2.1	-2.2
Farmland	43.2	49.2	51.8	6.0	2.5	8.6
Grassland	6.1	0.9	1.3	-5.2	0.4	-4.7
Bareland	5.6	5.9	8.0	0.2	2.0	2.3
Rocky Outcrop	7.1	5.5	3.0	-1.6	-2.5	-4.1
Water Body	0.00	0.09	0.05	0.09	-0.04	0.05

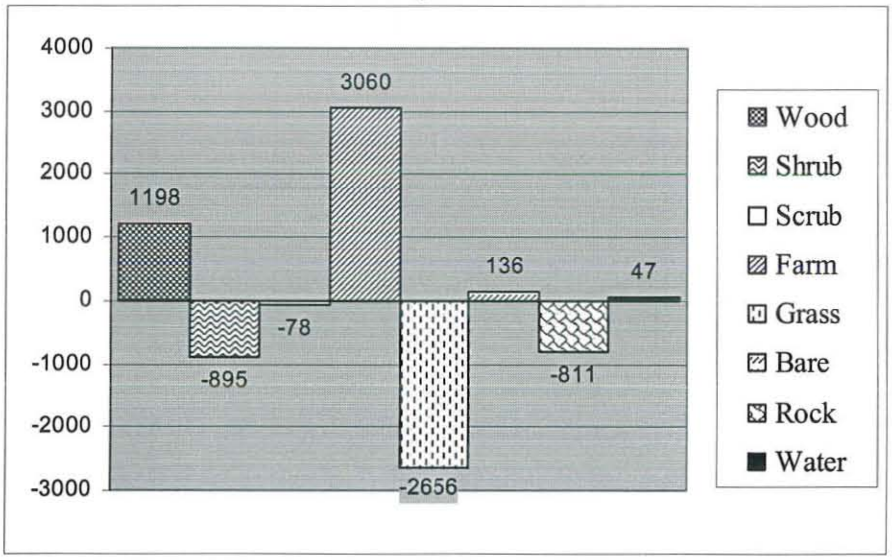

Figure 5-1 Graph Showing the Land Use/Cover Area Change in Hectares b/n 1986-2000

The analysis also indicated an overall decrement of woodland, grassland and rock outcrop by 1490 ha, 2420 ha and 2078 ha respectively and increment of farmland, shrub and bareland by 4364 ha, 1571 ha and 1187 ha respectively over the past twenty one years (1986-2007). Comparing the general trend of land use/cover change occurred during the periods, there was a continuous increment of farmland by about 8% for the entire period (1986-2007). Even though the percentile changes differ, the change trend is equivalent to that of Kiros Meles (2008) result. The change trend observed by shrubland is also supported by the result of Kiros Meles (2008). Relatively inconsistence trend of change is shown on woodland and scrub (Figure 5-3).

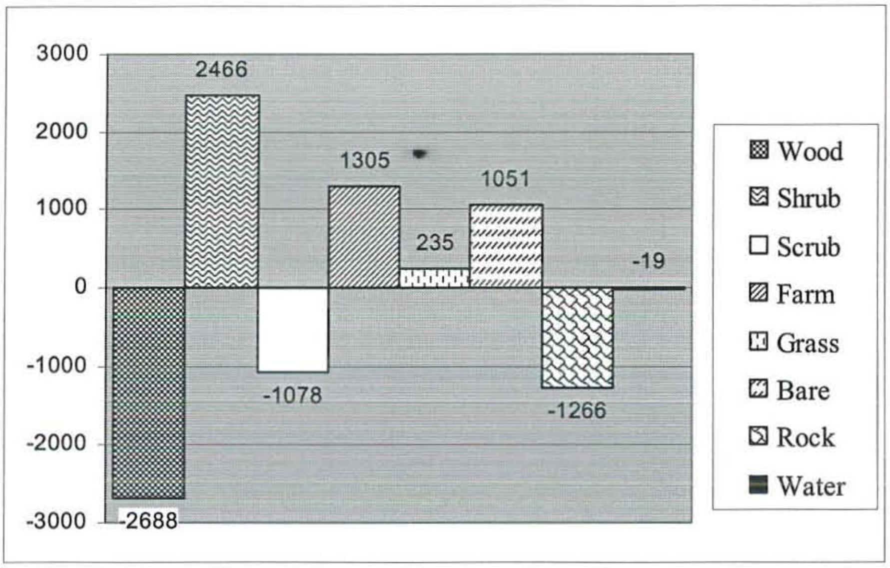

Figure 5-2 Graph Showing the Land Use/Cover Area Change in Hectares b/n 2000-2007

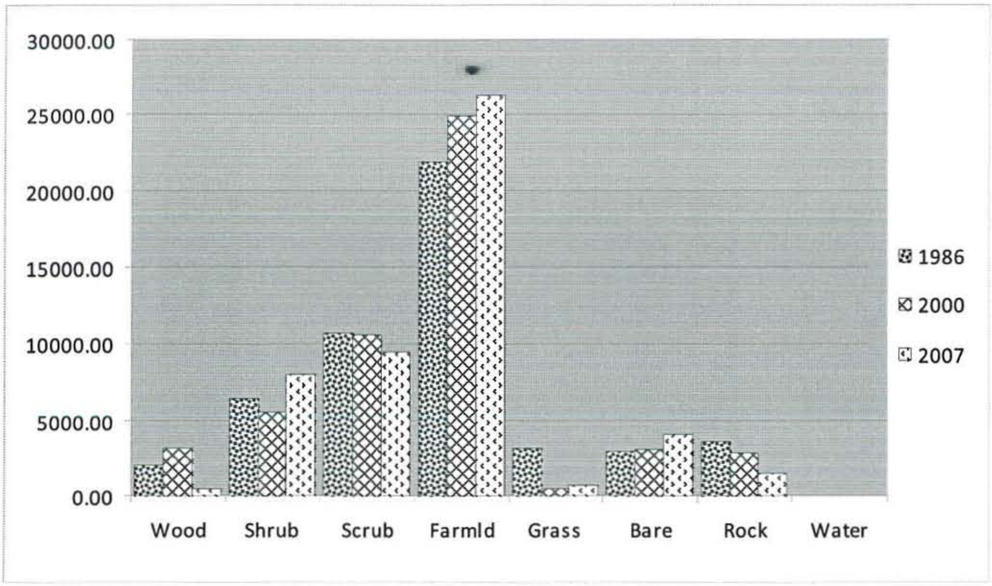

Figure 5-3 Graph Showing Area Coverage of Each Land Use/Cover Class for Year 1986, 2000 and 2007

5.2 Land Cover Change Matrix

Changes detected using conversion matrix differs significantly from a simple differencing of two imageries or change detection using post classification. The conversion matrix indicates the change for each initial state classes into which those pixels changed in the final state image or in other word it answers the question what is changed into what. The conversion matrix was analyzed for the periods (1986-2000 and 2000-2007) and presented in Table 5-3 and Table 5-4. The row of the tables represents the initial stage (1986 or 2000) and the column of the table represents the final stages (2000 or 2007).

The conversion matrix for the period 1986-2000 revealed that shrubland in the initial stage was changed by 74.8% into land use/cover classes different from shrub in the final stage. Out of the initial shrubland 29.6% was changed into scrub, followed by woodland (24.4%) and farmland (15.9%). About 25.1% of scrub in the initial stage (1986) was converted to farmland. Grassland was transferred to farmland and shrub by 39.9% and 28.6% respectively.

Table 5-3 Conversion Matrix for the Period b/n 1986-2000 (%)

		1986						
		Shrub	Farmland	Scrub	Woodland	Grassland	Row Total	Class Total
	Water body	0.06	0.08	0.01	0.03	0.61	89.3	100.0
	Woodland	24.4	2.9	3.2	6.5	7.6	92.6	100.0
	Grassland	1.2	0.2	0.08	0.49	9.3	92.3	100.0
	Shrub	25.1	5.6	5.3	13.9	28.6	82.4	100.0
2000	Farmland	15.9	75.8	25.1	32.5	39.9	88.9	100.0
	Rock Outcrop	0.19	4.4	1.6	0.80	9.3	53.0	100.0
	Bareland	3.3	7.2	0.45	0.60	3.3	65.0	100.0
	Scrub	29.6	3.5	64.1	45.0	1.2	98.9	100.0
	Class Total	100.0	100.0	100.0	100.0	100.0	0.00	0.00
	Class Changes	74.8	24.1	35.8	93.4	90.6	0.00	0.00

The highest change was detected on woodland by about 93.4% and the change to scrub accounts around 45.0%. On the other hand, the least conversion was seen on farmland and about 75.8% of the initial stage remained the same in the final stage (2000).

During the period 2000-2007, 44.0% of the initial grassland was converted to farmland and about 22.2% to shrub. In the same way, 41.4% of shrub was changed to farmland followed by scrub taking about 21.0% of the initial shrubland. Other significant conversion to farmland was observed by scrub and around 35.1% of the initial scrub was changed to farmland. The highest conversion was occurred on woodland with 97.8% of the initial stage (2000) was converted to classes other than woodland. The least conversion was identified on farmland resulting about 62.3% of the class in the initial stage remained unchanged (Table 5-4).

Table 5-4 Conversion Matrix for the Period b/n 2000-2007 (%)

		2000						
2007		Wood land	Grass land	Farm land	Scrub	Shrub	Row Total	Class Total
	Water body	0.05	0.09	0.06	0.01	0.03	72.8	100.0
	Grassland	1.5	8.7	1.4	0.6	1.5	84.3	100.0
	Woodland	2.1	1.7	0.95	0.35	1.3	86.4	100.0
	Farmland	39.7	44.0	62.3	35.1	41.4	87.9	100.0
	Bareland	12.5	4.8	7.9	4.7	4.6	77.7	100.0
	Rock Outcrop	2.6	3.3	2.9	2.1	2.8	81.4	100.0
	Shrub	20.0	22.2	12.3	18.2	26.9	90.3	100.0
	Scrub	21.1	14.8	11.7	38.6	21.0	94.0	100.0
	Class Total	100.0	100.0	100.0	100.0	100.0	0.00	0.00
	Class Changes	97.8	91.2	37.6	61.3	73.0	0.00	0.00

5.3 Land Use/Cover, HSG and Runoff Distribution in the Area

When the spatial distribution of runoff generated in the catchment is assessed, there is a significant relation with topographic gradient and land use/cover type. But in some cases, local influence of HSG was observed especially in areas where HSG A is dominant. This is also stated by Descheemaeker et al. (2008). Land use type was an important explanatory factor for the variation in Curve Number in the area, whereas HSG was not (Descheemaeker et al., 2008). For instance, the Eastern part of the study area is dominantly characterized by moderate infiltration rate (HSG B) and covered by farmland, observed with high runoff potential. However, there are patches of woodland and shrub on the sides of sloppy hills and around river banks in this part of the study area, observed with low runoff potential despite the soil type (Figure 4-18). Therefore, the spatial distribution of runoff is more controlled by topographic gradient and land use type than the HSG. The Runoff map for year 1986, 2000 and 2007 are included in Appendix D.

5.4 Effect of Land Use/Cover Change on Total Volumetric Runoff

For each rainfall event, runoff generated from the study area was calculated for the land use/cover situation during 1986, 2000 and 2007. Then the change on the runoff was analyzed considering the whole cumulative land use/cover change occurred during the periods 1986-2000 and 2000-2007. For separate land use/cover class change considering the HSG, the 2007 land use/cover condition was selected for scenario analysis taking significant change identified using the post classification change detection. All the assessments were done taking the Antecedent Moisture Condition II (AMC II) which is moderated condition.

After estimating the runoff generated from 20mm and 36mm rainfall events using ArcCN Runoff tool and examining the results, the analyses revealed a decrement on the total volumetric runoff by 15.3% and 19.9% for 20mm and 36mm of rainfall events respectively taking the period 1986-2000. The decrement was mainly due to the increment of woodland by 2.3% of the total study area and farmland by 6.0% of the total study area at the expense of other land use/cover classes during the period 1986-2000 (Figure 5-4).

Even though, the change on mean runoff depth generated for the entire catchment isn't the best parameter to determine the effect of land use/cover change on runoff, a decrement by 0.3mm (11.1% of the 1986) and 1.0mm (15.4% of the 1986) were observed for 20mm and 36mm of rainfall event respectively during the 1986-2000 period. This change was due to the cumulative effect of the change occurred on the whole land use/cover class during the period.

On the other hand, an increment on the total volumetric runoff by 3.8% of the 2000 and 23.3% of the 2000 were observed for 20mm and 36mm of rainfall events respectively, during the period 2000-2007. This is explained by the significant decrement of woodland by 5.3% of the total study area mainly to farmland and increment of bareland (uncultivated land) by 2.0% of the total study area during the period. When we see the change on the mean runoff depth over the entire area, decrement by 0.3mm (12.5% of the 2000) and 0.3mm (4.5% of the 2000) occurred for 20mm and 36mm of rainfall events respectively.

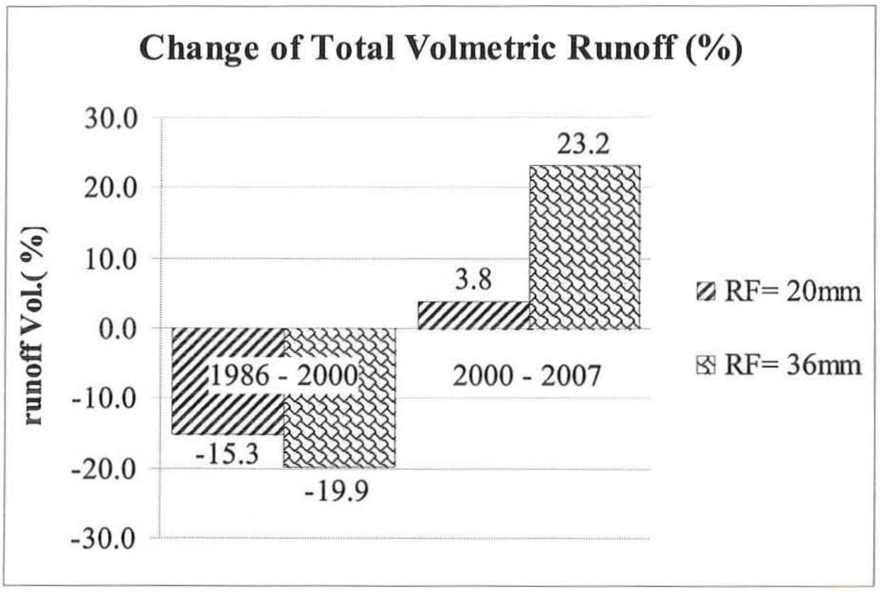

Figure 5-44 Cumulative Effect of Land Use/Cover Change on Total Vol. Runoff (%)

5.5 Effect of Land Use/Cover Change on Runoff Depth

Different historical and hypothetical land use changes were analyzed to understand its impact on the direct runoff generated in the catchment considering AMC II, variation in HSG and rainfall (20mm and 36mm). Mainly the influences of land use/cover change were assessed on the direct runoff depth (mm) and the result of the analysis for land use/cover change is presented in Table 5-5. To keep the homogeneity of the HSUs in terms of spatial variation and insitu condition, the change scenarios were performed on selected suitable areas specially to include a variety of soil type.

Based on the result of the land use/cover scenario analysis, land use change from shrub to woodland with HSG A, scrub to shrub with HSG A and scrub to farmland with HSG B resulted a decrease in runoff depth by 55.1%, 10.2% and 3.8% taking 20mm of rainfall. On the other hand, from woodland to farmland with HSG B, farmland to bareland with HSG C and farmland to scrub with HSG A resulted an increment in runoff depth by 57.2%, 6.7% and 1.2% respectively when 20mm rainfall was taken (Table 5-5). These results are somewhat exaggerated when compared to the 36mm rainfall event for the reason that poor results are often obtained for most small events (Van Mullem et al.,1990). Thus, the results obtained from high events are more reasonable and acceptable when compared with the result from small event.

Considering 36mm of rainfall, there was a decrement of runoff depth by 37.6% for shrub to woodland conversion, 6.1% for scrub to shrub change and 2.1% for scrub to farmland change with HSG A, A and B respectively. And on the other extreme, there was an increment of runoff depth by 30.4% for woodland to farmland, by 3.7% for farmland to bareland and by 0.72% for farmland to scrub with HSG B, C and A respectively. One of the reason why conversion of forest to short crop causes in increment in runoff usually in drier climates is because of the root systems of forests are generally much deeper than those of short vegetation or agricultural crops, forests can reach more soil water to maintain transpiration during dry periods and this lead to higher evaporation overall. Conversion of forest to short crops is therefore expected to result in increased runoff (Dagnachew et al., 2003). And the other reason is that woodland usually has high interception capacity than farmland or shrubland.

Table 5-5 Shows the Result and Land Use/Cover Change Considered in the Analysis

RF (mm)	HSG	Land Use/Cover Change		Runoff Depth Difference (%)
		From	To	
20	B	Scrub	Farmland	-3.8
	B	Woodland	Farmland	57.6
	A	Farmland	Scrub	1.2
	A	Scrub	Shrub	-10.2
	A	Shrub	Woodland	-55.1
	C	Farmland	Bareland	6.7
	C	Farmland	Shrub	0.93
36	B	Scrub	Farmland	-2.1
	B	Woodland	Farmland	30.4
	A	Farmland	Scrub	0.72
	A	Scrub	Shrub	-6.1
	A	Shrub	Woodland	-37.6
	C	Farmland	Bareland	3.7
	C	Farmland	Shrub	0.51

5.6 Comparison of the Research Output with Other Researches

The variation in methodology, the difference in assumption, variation in the scale of studies and the difference in the environment setting had resulted in a range of variations on the final output. When we compare the output of this research with other research outputs taking the above mentioned facts and other, the results of this research shows reasonable matching in terms of the land use/cover effect towards runoff generation as shown in Table 5-6.

Table 5-6 Comparison of the Current Research Output with Other Researches

Scale	Site	AMC	Av. % Change of Total Vol. Runoff	Source
Small	Nepal	I-III	2.2-12.2	Shrestha, 2003
Small	Czech Republic	II III	~9.9 ~4.8	Jenicek, 2007
Medium	Current study	II	3.3-11.5	Current study

The average total volumetric runoff changes (%) obtained by this study ranges from 3.3% to 11.5% which is within the range of Shrestha (2003) output. But the actual amount varies because it is dependent on the vegetation type, precipitation amount and the above mentioned factors. When the total volumetric runoff calculated by the model is compared with some equivalent historical events in the area, especially for 20mm event selected in this study and the 2000 land use/cover condition, it shows slight over estimation which ranges from 11% to 25% and under estimation by about 2% as shown in figure below.

Table 5-7 Comparison of the Model Output with Actual Historical Events

Date ppt	Amnt (mm)	AMC	Date runoff	Runoff (m^3/sec)	Total Vol. Runoff(m^3)	Calculated (m^3)	Diff. (m^3)	Diff. (%)
8/21/2000	23	25	8/24/2000	65	5584	6997	1413	25
8/6/1996	20	63	8/7/1996	82	7112	6997	-115	-2
7/13/1996	14	35	7/15/1996	73	6324	6997	673	11

Chapter 6

Conclusions and Recommendations

6.1 Conclusions

The current study involves multi-temporal classification of Landsat TM and ETM+ imageries to detect and map the land use/cover change between the year 1986 and 2007. The time period was selected mainly based on the availability of satellite imageries. Since the area is known for scarcity of hydro-meteorological records, SCS-CN method was chosen despite its limitation for assessing the effects of land use/cover change on direct runoff and total volumetric runoff generated from the area. ArcCN Runoff Tool was a main tool in estimating the direct runoff depth by integrating Remote Sensing and GIS techniques.

Based on the output of image classification, seven (for 1986) and eight (for 2000 and 2007) land use/cover classes were discriminated. Namely: - woodland, shrub, scrub, farmland, grassland, rock outcrop, bareland (fallow) and water body. Land cover post classification change analysis for the periods (1986-2000 and 2000-2007) revealed some significant land cover changes. Taking the period 1986-2000, farmland and woodland were increased by about 3060 ha (6.0% of the total study area) and by 1998 ha (2.3% of the total study area) respectively. On the other hand, a decrement by 895 ha (1.7%) for shrubland and by 1.6% for rocky out crops were occurred. During the period 2000-2007, significant decrement of woodland by 5.3% and scrubland by 2.1% were identified. Simultaneously, shrubland and farmland were increased by 4.8% and 2.5% respectively.

The conversion analysis indicated a relative increment of farmland at the expense of woodland, shrub and scrub. Generally, an overall increment of farmland and shrub and decrement of woodland were observed for the past 21 years (1986-2007).

Regarding the impact of land use/cover change on direct runoff, two rainfall events (20mm and 36mm) were selected which are hypothetical rainfall and average August maximum rainfall for the years 2001-2008 respectively. The analysis was conducted assuming the AMC II which is a moderate condition and based on the result, a decrement on the total volumetric runoff by 15.3% and 19.9% for 20mm and 36mm of rainfall events respectively taking the cumulative land use/cover change occurred for in period the 1986-2000. These were happened mainly because of the increment in woodland and farmland at the expense of shrub and scrub. On the other side, an increment of the total volumetric runoff by 3.8% and 23.2% were observed for 20mm and 36mm of rainfall due to the cumulative effect of land use/cover change occurred in the period 2000-2007. These can be mainly due to the decrement of woodland by 5.3% of change on woodland that was occurred during the period.

For land use/cover change from shrub to woodland with HSG A result a decrement on runoff depth by 55.1% and 37.6% for 20mm and 36mm of rainfall respectively. For land use/cover change from scrub to farmland with HSG B, there was a decrease on the runoff depth by 3.8% and 2.1% for 20mm and 36mm respectively. Because usually poor results are obtained for small events, the results from 20mm and 36mm rainfall are quit reasonable.

6.2 Recommendations

- Special attention should be given on conservation and protection of land use/cover classes that shows inconsistent dynamics in the area. Mainly, woodland and shrub which relatively contributes a large portion in reducing the direct runoff generated from a given rainfall events.
- An intensive work need to be done on the sloppy hills in the area to reduce the potential of generating high runoff and to rehabilitate the degraded environment by implementing conservation activities like Plantation, Terracing etc.
- Creating awareness among the society concerning optimum use of natural resources, conservation systems and their benefits by policy makers and NGOs could play important role in rehabilitation of the environment which return a positive impact on the hydrology of the area by improving the portion of rainfall that infiltrates to the soil.
- Further study on determination of CN for those land use/cover classes which were not considered by Descheemaeker et al. (2008) and for those with high standard error will improve the reliability of the SCS-CN method in semi-arid environments of Ethiopian highlands.

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Appendix

Appendix-A Confusion Matrix

Confusion Matrix of 1986 image classification

	Reference Data										
Classif. Data	Unclass	Shrub	Grass	Bare	Scrub	Rock out	Wood	Farm Ld	Row Total	Producers Accuracy	Users Accuracy
Unclass	17	0	0	0	0	0	0	0	17	---	---
Shrub	1	7	0	0	1	0	0	0	9	77.78%	77.78%
Grass	0	0	4	0	0	0	0	0	4	80.00%	100.00%
Bare	0	0	0	5	0	0	1	0	6	100.00%	83.33%
Scrub	0	0	1	0	6	0	0	1	8	75.00%	75.00%
Rockout	0	0	0	0	0	4	0	0	4	80.00%	100.00%
Wood	0	1	0	0	0	0	3	0	4	75.00%	75.00%
Farm Ld	0	1	0	0	1	1	0	17	20	94.44%	85.00%
Column Total	18	9	5	5	8	5	4	18	72		

Overall Classification Accuracy = 87.50% and Overall Kappa Statistics = 0.8488

Confusion Matrix for 2000 image classification

	Reference Data											
Classif Data	Unclas	Wtr bdy	Wd	Gr	Sh	Frm	Rck	Bar	Sc	Row Total	Produc. Accurcy	Users Accurcy
Unclas	8	0	0	0	0	0	0	0	0	8	---	---
Wtrbdy	0	5	0	0	0	0	0	0	0	5	100.00%	100.00%
Wd	0	0	6	0	1	0	1	0	0	8	85.71%	75.00%
Gra	0	0	1	6	1	0	0	0	0	8	85.71%	75.00%
Sh	0	0	0	1	7	0	0	0	0	8	77.78%	87.50%
Frm	0	0	0	0	0	7	0	1	0	8	87.50%	87.50%
Rck	0	0	0	0	0	0	8	0	0	8	88.89%	100.00%
Bar	0	0	0	0	0	1	0	7	0	8	87.50%	87.50%
Sc	1	0	0	0	0	0	0	0	7	8	100.00%	87.50%
Colmn Total	9	5	7	7	9	8	9	8	7	69		

Overall Classification Accuracy = 88.41% and Overall Kappa Statistics = 0.8693

Appendix-B OIF for 1986, 2000 and 2007 Imageries

$$OIF = \frac{\sum_{i=1}^{3} SDi}{\sum_{j=1}^{3} ABS(CCj)}$$

SDi is the standard deviation of band i and ABS(CCj) is the absolute value of the correlation coefficient between any two of the possible three pairs.

Serial	Band Comb	€∂i	€|CCj|	OIF
1.00	3,5,7	102.81	2.97	34.60
2.00	2,3,4	91.09	2.96	30.78
3.00	2,3,5	89.21	2.97	30.08
4.00	4,5,7	87.44	2.95	29.69
5.00	1,5,7	84.92	2.92	29.04
6.00	3,4,5	85.56	2.95	29.01
7.00	1,3,5	83.04	2.93	28.31
8.00	2,3,7	82.73	2.96	27.91
9.00	3,4,7	79.09	2.94	26.91
10.00	1,3,7	76.56	2.93	26.14
11.00	2,4,5	73.84	2.95	25.02
12.00	1,2,5	71.31	2.94	24.23
13.00	1,4,5	67.66	2.93	23.09
14.00	2,4,7	67.36	2.94	22.92
15.00	2,5,7	65.48	2.96	22.10
16.00	1,2,7	64.84	2.94	22.08
17.00	1,2,3	62.96	2.97	21.23
18.00	1,4,7	61.19	2.91	20.99
19.00	1,3,4	59.31	2.94	20.16
20.00	1,2,4	47.59	2.96	16.06

OIF for 1986 Image

Serial	Band Comb.	€∂i	€|CCj|	OIF
1.00	3,5,7	85.25	2.97	28.71
2.00	4,5,7	83.04	2.96	28.06
3.00	3,4,5	80.00	2.96	27.00
4.00	2,3,4	78.36	2.91	26.93
5.00	1,3,5	75.32	2.92	25.77
6.00	2,5,7	76.17	2.96	25.76
7.00	1,4,5	73.11	2.92	25.02
8.00	2,3,5	73.13	2.96	24.67
9.00	2,4,5	70.92	2.96	23.99
10.00	1,2,5	66.24	2.93	22.60
11.00	3,4,7	63.32	2.96	21.43
12.00	1,3,7	58.64	2.92	20.10
13.00	1,4,7	56.43	2.91	19.40
14.00	2,3,7	56.46	2.96	19.06
15.00	2,4,7	54.25	2.95	18.41
16.00	1,3,4	53.39	2.94	18.15
17.00	1,5,7	51.21	2.98	17.21
18.00	1,2,7	49.57	2.92	16.95
19.00	1,2,3	46.53	2.96	15.71
20.00	1,2,4	44.32	2.96	14.99

OIF for 2000 Image

Serial	Band Comb.	€∂i	€ | CCj |	OIF
1.00	3,5,7	134.57	2.97	45.28
2.00	4,5,7	131.26	2.96	44.42
3.00	2,3,4	129.33	2.95	43.80
4.00	2,5,7	125.01	2.96	42.24
5.00	1,5,7	123.45	2.92	42.21
6.00	2,3,5	123.08	2.96	41.52
7.00	1,3,5	121.53	2.93	41.44
8.00	3,4,7	120.66	2.95	40.94
9.00	2,4,5	119.78	2.95	40.54
10.00	1,4,5	118.22	2.93	40.30
11.00	2,3,7	114.41	2.96	38.59
12.00	1,3,7	112.85	2.93	38.53
13.00	1,2,5	111.97	2.94	38.06
14.00	2,4,7	111.10	2.94	37.73
15.00	1,4,7	109.55	2.92	37.50
16.00	3,4,5	109.18	2.97	36.80
17.00	1,3,4	107.62	2.95	36.53
18.00	1,2,7	103.30	2.94	35.19
19.00	1,2,3	101.37	2.97	34.16
20.00	1,2,4	98.06	2.97	33.07

OIF for 2007 Image

Appendix-C Local CN Determined by K. Descheemaeker et al. (2008)

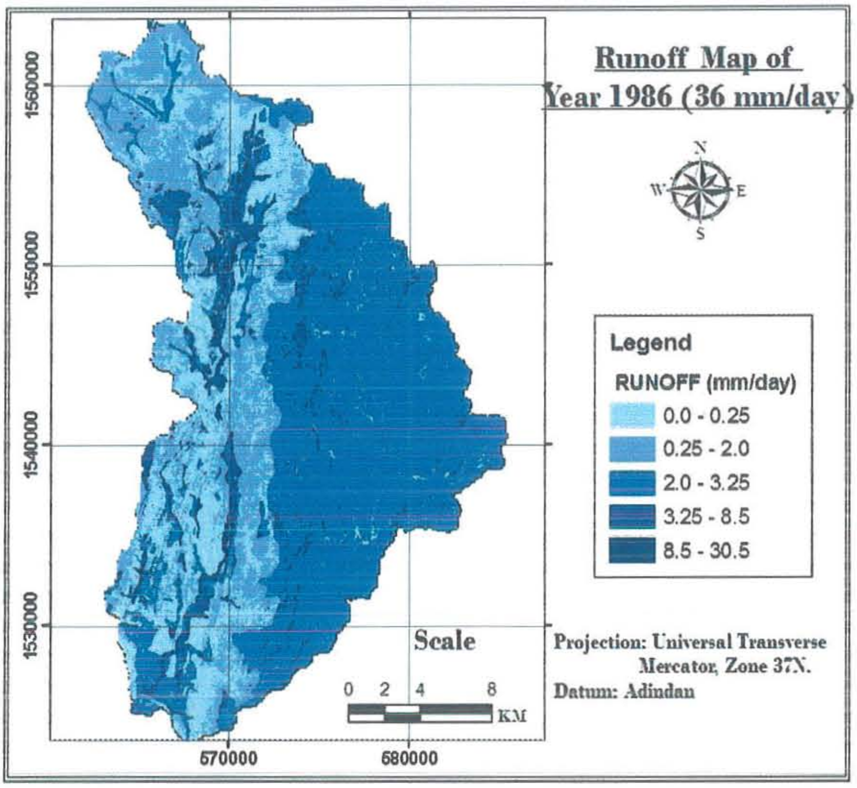
Land use Type1	Plot Code	AMC I n	AMC I SI	AMC I CNI	AMC I R2	AMC I st err	AMC II n	AMC II SII	AMC II CN II	AMC II R2	AMC II st err	AMC III n	AMC III SIII	AMC III CN III	AMC III R2	AMC III st err
Grazing Land	MRA1	90	6.4	98	0.96	0.5	46	6.5	98	0.93	0.6	46	9.9	96	0.87	1.39
	MRA2	90	12.9	95	0.89	1.1	46	11.8	96	0.85	1.3	46	12.4	95	0.92	1.24
	KRA	95	81.1	76	0.47	5.4	47	28.5	90	0.37	4.9	33	41.5	86	0.64	4.93
	ARA	75	108.7	70	0.18	15.5	40	11.5	96	0.87	1.5	48	23.8	91	0.76	2.78
	Average CN(stdev)			84.8 (13.8)					95.0(3.5)					92.0(4.5)		
young exclosure	MXYI	90	51.4	83	0.87	2.3	46	46.5	85	0.7	3.7	46	38.6	87	0.69	4.89
	MXY2	90	31.9	89	0.8	2.4	46	31.5	89	0.79	2.6	46	26.6	91	0.9	2.19
	MXY3	90	35.3	88	0.84	2.1	46	38.3	87	0.64	3.7	46	33.3	88	0.91	2.12
	KXY1	95	214.8	54	0.12	9.7	47	132.9	66	0.25	8.9	33	87	74	0.51	11.21
	KXY2	86	73.6	78	0.64	4.7	38	70.7	78	0.29	10	22	62	80	0.8	6.01
	KXY3	95	116.8	69	0.37	7.3	47	28	90	0.29	6.3	33	28.6	90	0.59	5.35
	AXY1	75	363.6	41	0.19	27.6	40	140.1	64	0.28	12.2	47	232.9	52	0.06	16.82
	AXY2	75	274	48	0.18	28.6	40	53.7	83	0.33	10.4	47	107.3	70	0.56	8.72
	Average CN(stdev)			68.8(18.9)					80.3(10.2)					79.0(13.3)		
Mid+old 1 exclosure	MXO1	90	132.8	66	0.46	8.4	46	87.8	74	0.81	3.5	46	192.2	58	0.64	10.7
	MX02	90	167.3	60	0.52	7.9	46	100.6	71	0.82	3.8	46	146.5	63	0.74	8.41
	MXO4	90	186.1	58	0.54	8.2	46	144	64	0.29	10.4	46	218.6	47	0.32	21.2
	MXO8	90	189.7	57	0.59	7.6	46	122.6	67	0.16	26	46	188.9	57	0.76	8.57
	KXM1	95	318.2	44	0	25.3	47	176.2	59	0.16	12	33	183.5	58	0.67	9.33
	KXM2	95	261.9	49	0.12	12.2	47	173.5	59	0.49	5.9	33	231.4	52	0.85	5.43
	Average CN(stdev)			55.7(7.9)					65.7(6.2)					55.8(5.6)		
Old 2 exclosure	MXO3	90	286	47	0.03	30.3	46	$5.4*10^9$	$5*10^{-6}$	0	$5.2*10^5$	46	336.9	43	0.74	11.04
	MXO5	90	386.9	40	0.01	20.2	46	$5.4*10^9$	$5*10^{-6}$	0	$2.4*10^5$	46	436.4	37	0.18	23.04
	MXO6	90	396.6	39	0.06	17.7	46	$5.4*10^9$	$5*10^{-6}$	0	$1.6*10^5$	46	485.9	34	0.06	27.35

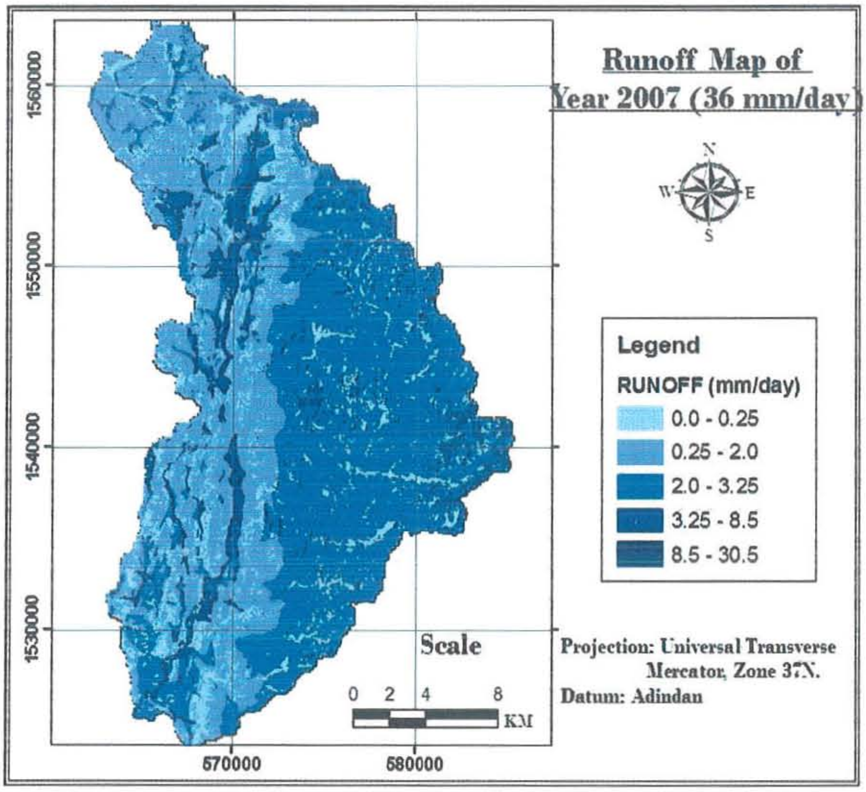
Land use Type1	Plot Code	AMC I n	AMC I SI	AMC I CNI	AMC I R2	AMC I st err	AMC II n	AMC II SII	AMC II CN II	AMC II R2	AMC II st err	AMC III n	AMC III SIII	AMC III CN III	AMC III R2	AMC III st err
	MXO7	90	316.1	45	0.64	7.1	46	260.2	49	0.44	6.7	46	563.2	31	0	108.2
	MXO9	90	319.4	44	0.51	9.5	46	$5.4*10^9$	$5*10^{-6}$	0	$1.3*10^5$	46	573	31	0	85.29
	KXO2	95	290.8	47	0.34	7.1	47	$2.7*10^9$	$5*10^{-6}$	0	$2.2*10^5$	33	181	58	0.45	14.7
	Average CN(stdev)			43.7 (3.4)					8.20 (20.0)					39.0 (10.3)		
	AEU1	87	69.5	79	0.74	4.5	43	78.6	76	0.39	9.6	51	112.8	69	0.25	13.76
Eucaly. Plantatio	AEU2	87	244.3	51	0.2	19.7	43	128.6	66	0.47	10	51	182.4	58	0.43	11.47
	Average CN(stdev)			65.0 (19.8)					71.0 (7.1)					390. (10.3)		
Church forest	MFO	90	449.8	36	0.24	8.2	46	$5.4*10^9$	$5*10^{-6}$	0	$5.9*10^5$	46	632.6	29	0	30.54

Number of observations (n), storage parameter (s), corresponding curve number (CN), R2 of the rainfall runoff model using the CN, standard error of the S estimate (st err) for each antecedent moisture condition (AMC) and average curve number for each land use type with standard deviation in parentheses.

(Source: Descheemaeker et al., 2008)

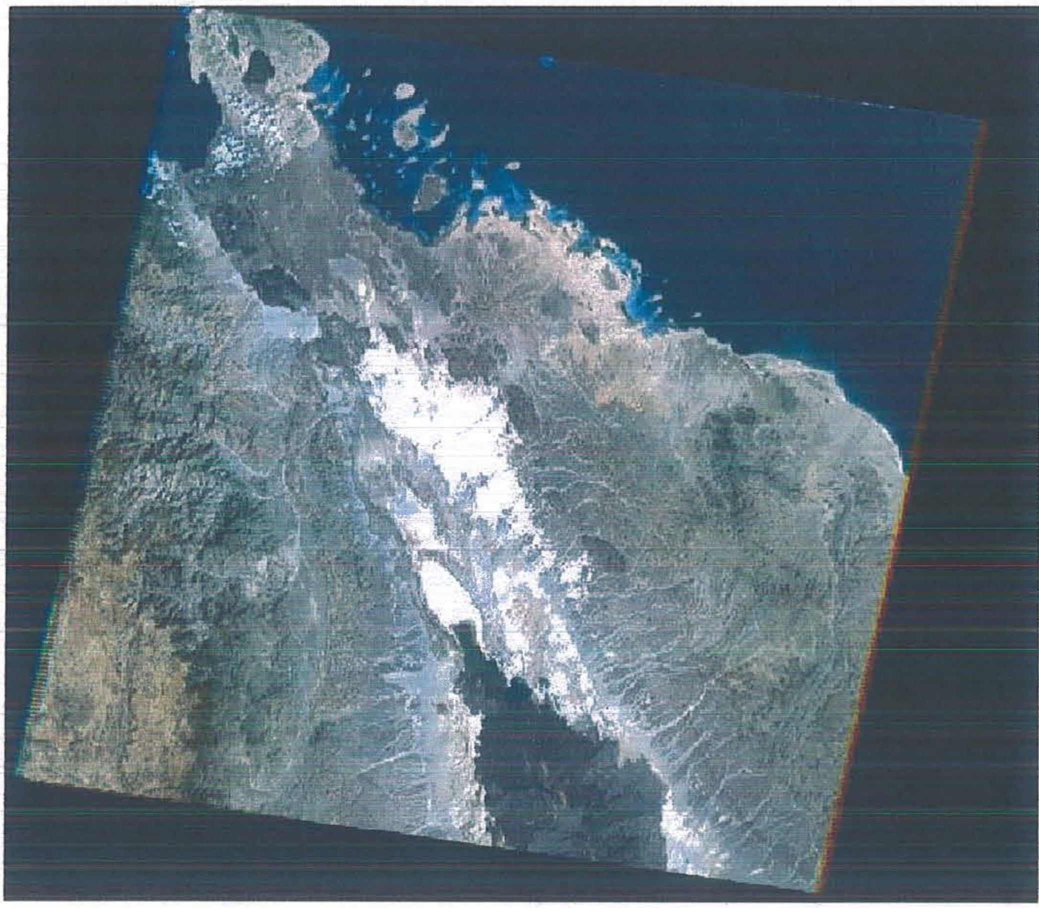
Appendix-D Runoff Map for the Year 1986 and 2007



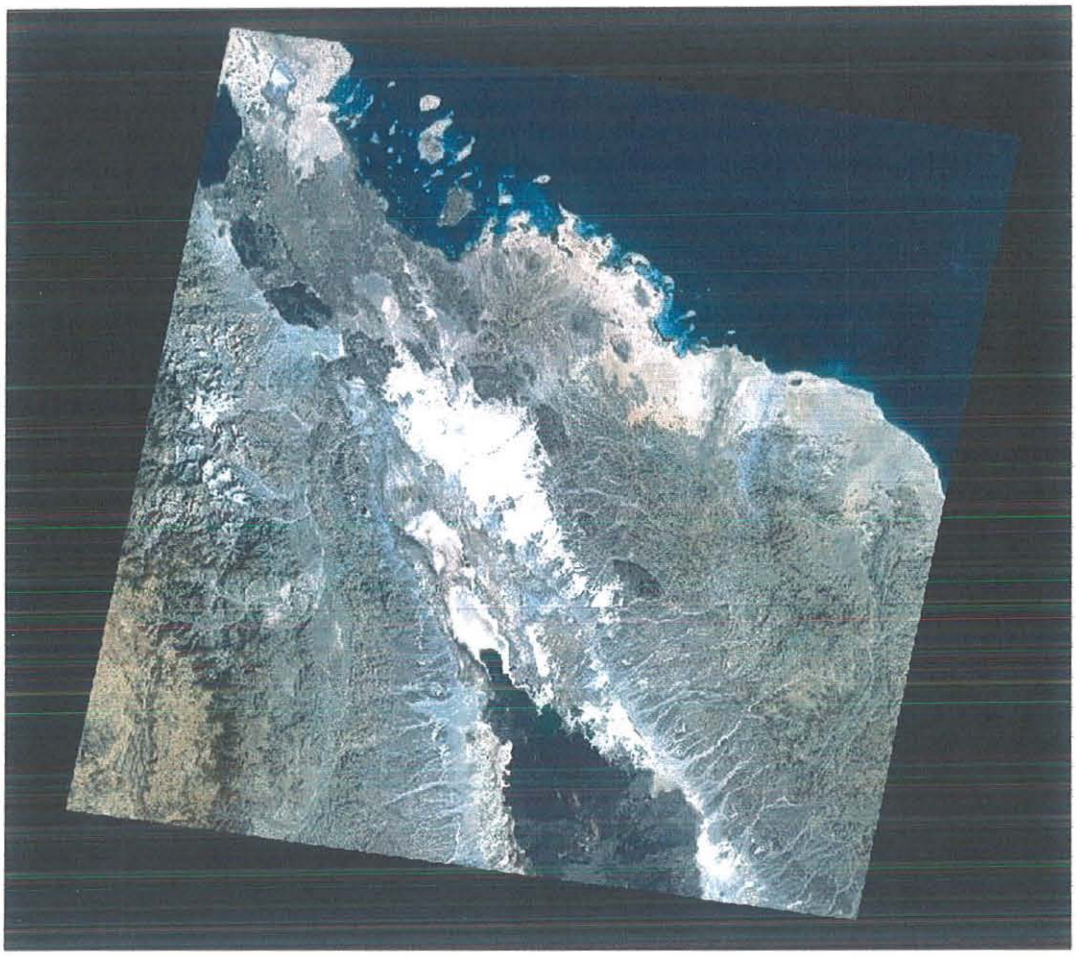


Appendix-E Raw Images

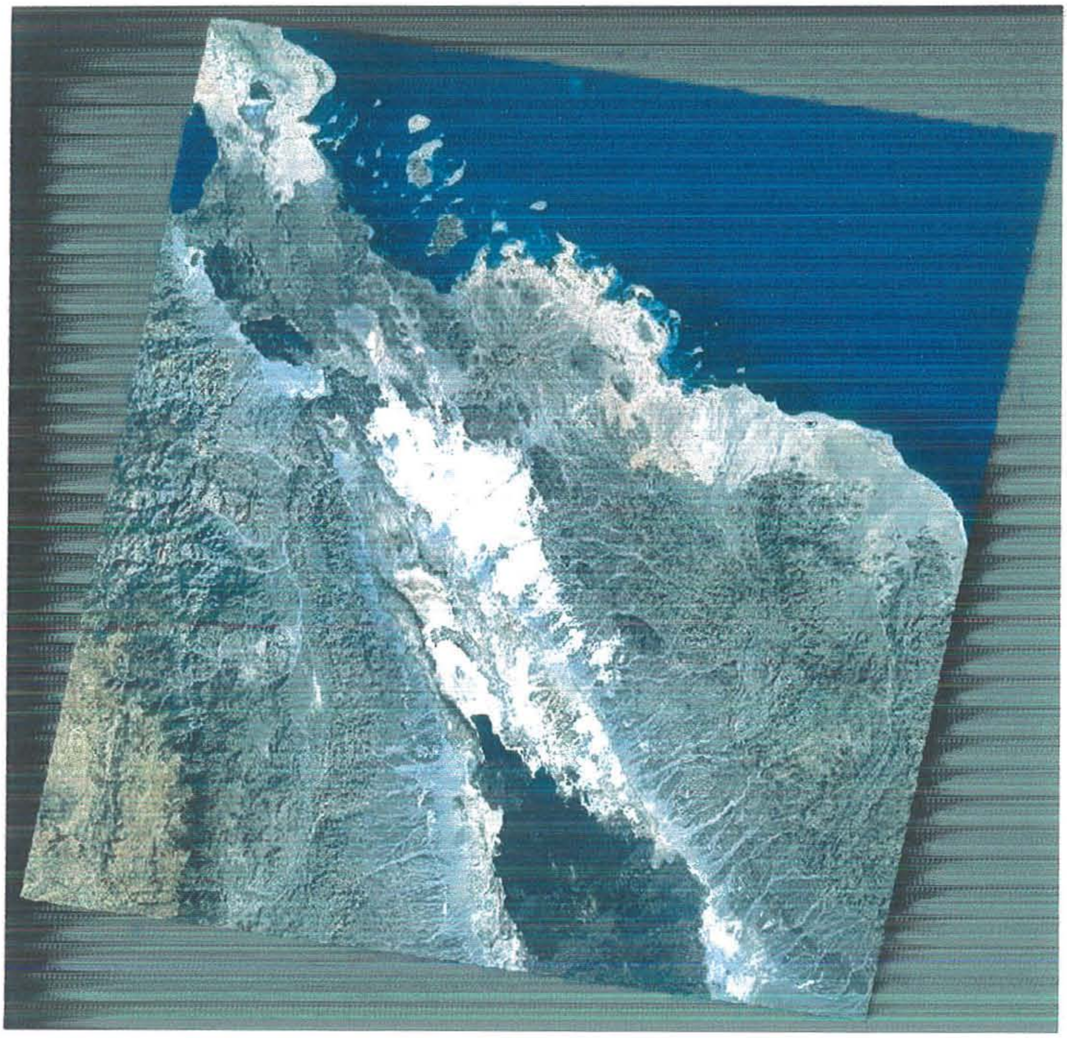
Landsat ETM+ 2007 Path 168 Row 050 (True Color Composite)



Landsat TM 2000 Path 168 Row 050 (True Color Composite)



Landsat TM 1986 Path 168 Row 050 (True Color Composite)



Appendix-F August Daily Rainfall Data for Year 2001 to 2008

Date	Senkata	Edaga Hamus	Wukro	Hawzen	Thiessen Polygon
1-Aug-2001	5.8	9.25	10	12.7	7.45
2-Aug-2001	1.3	1.65	1.5	2	1.40
3-Aug-2001	19.6	10.65	128	1.7	49.61
4-Aug-2001	14.2	9.45	9.5	4.7	12.23
5-Aug-2001	0	0	0	0	0.00
6-Aug-2001	0.9	0.45	24.5	0	7.63
7-Aug-2001	12.8	32.25	26.4	51.7	19.22
8-Aug-2001	3.7	18.85	0	34	4.59
9-Aug-2001	1.8	1.4	0	1	1.23
10-Aug-2001	0	25.5	6.4	51	5.14
11-Aug-2001	77.1	48.55	0	20	51.24
12-Aug-2001	0	0	0	0	0.00
13-Aug-2001	14.3	17.15	0	20	10.56
14-Aug-2001	0	5.25	26.4	10.5	8.27
15-Aug-2001	1.2	13.1	40	25	13.89
16-Aug-2001	7.7	3.85	0	0	4.99
17-Aug-2001	0	0	0	0	0.00
18-Aug-2001	0	0.85	4.6	1.7	1.43
19-Aug-2001	8.6	7.8	0	7	6.02
20-Aug-2001	0	0	0	0	0.00
21-Aug-2001	0	0	0	0	0.00
22-Aug-2001	0.8	0.4	0	0	0.52
23-Aug-2001	2.4	6.55	6.4	10.7	4.09
24-Aug-2001	2.8	1.4	27.8	0	9.81
25-Aug-2001	0	0.85	27.8	1.7	8.10
26-Aug-2001	0	0	66	0	18.97
27-Aug-2001	6	3	0	0	3.89
28-Aug-2001	0	2.85	0	5.7	0.37
29-Aug-2001	0.9	5.55	0	10.2	1.24
30-Aug-2001	9.6	27.95	0	46.3	9.21
31-Aug-2001	2.4	11.55	0	20.7	2.89
1-Aug-2002	0.3	1.05	0	1.8	0.31
2-Aug-2002	0	9.5	2.3	19	1.89
3-Aug-2002	17.3	15.75	6.6	14.2	14.02
4-Aug-2002	8.4	6.55	60.4	4.7	23.11
5-Aug-2002	8.3	4.15	60.2	0	22.68
6-Aug-2002	14.4	25.7	5.5	37	13.30

Date	Senkata	Edaga Hamus	Wukro	Hawzen	Thiessen Polygon
7-Aug-2002	7.2	10.1	86.5	13	30.37
8-Aug-2002	6	11.5	40.2	17	16.54
9-Aug-2002	10.4	7.75	40.3	5.1	18.65
10-Aug-2002	0	0	0	0	0.00
11-Aug-2002	7.3	3.65	6.7	0	6.66
12-Aug-2002	0	0	8.4	0	2.41
13-Aug-2002	7.4	6.3	0	5.2	5.13
14-Aug-2002	20	10	0	0	12.96
15-Aug-2002	6.6	3.3	2.3	0	4.94
16-Aug-2002	20	31	20	42	21.42
17-Aug-2002	11.7	8.35	38.4	5	18.94
18-Aug-2002	22.2	14.75	6.6	7.3	16.75
19-Aug-2002	0	6.35	0	12.7	0.82
20-Aug-2002	0	0	0	0	0.00
21-Aug-2002	0	3	0	6	0.39
22-Aug-2002	0	0	0	0	0.00
23-Aug-2002	0	0	0	0	0.00
24-Aug-2002	0	0	0	0	0.00
25-Aug-2002	0	0	0	0	0.00
26-Aug-2002	0	0	0	0	0.00
27-Aug-2002	0	0	0	0	0.00
28-Aug-2002	0	0	0	0	0.00
29-Aug-2002	0	0	0	0	0.00
30-Aug-2002	0	1.7	0	3.4	0.22
31-Aug-2002	0	0.5	0	1	0.06
1-Aug-2003	2.8	1.4	16.6	0	6.59
2-Aug-2003	0	0	0.9	0	0.26
3-Aug-2003	0	0	0.1	0	0.03
4-Aug-2003	0	1.35	0.3	2.7	0.26
5-Aug-2003	13.6	6.8	35.4	0	18.99
6-Aug-2003	8.4	5.35	25	2.3	12.78
7-Aug-2003	40.8	21.8	0.2	2.8	26.67
8-Aug-2003	3.7	7.1	4.5	10.5	4.37
9-Aug-2003	0	2.35	2.1	4.7	0.91
10-Aug-2003	4.2	5.85	50	7.5	17.58
11-Aug-2003	0	5.05	5	10.1	2.09
12-Aug-2003	0	0	0	0	0.00
13-Aug-2003	19.4	15	15	10.6	17.57
14-Aug-2003	24.3	12.15	0.3	0	15.83

Date	Senkata	Edaga Hamus	Wukro	Hawzen	Thiessen Polygon
15-Aug-2003	0	0	0	0	0.00
16-Aug-2003	2.5	12	37	21.5	13.65
17-Aug-2003	0	0	0	0	0.00
18-Aug-2003	0	0	0.9	0	0.26
19-Aug-2003	0	3.65	11.5	7.3	3.78
20-Aug-2003	10.2	5.1	3.2	0	7.53
21-Aug-2003	0	2.85	0	5.7	0.37
22-Aug-2003	4.2	2.1	2.3	0	3.38
23-Aug-2003	0	0.75	2.6	1.5	0.84
24-Aug-2003	0	0	10.9	0	3.13
25-Aug-2003	0	0	5.6	0	1.61
26-Aug-2003	0	2	10.8	4	3.36
27-Aug-2003	0	0.85	5.7	1.7	1.75
28-Aug-2003	0	0.25	0	0.5	0.03
29-Aug-2003	0	0	0.6	0	0.17
30-Aug-2003	0	0.6	20.6	1.2	6.00
31-Aug-2003	0	0	0	0	0.00
1-Aug-2004	29.3	18.9	6.7	8.5	21.46
2-Aug-2004	13.5	14.25	39	15	20.93
3-Aug-2004	34.5	26.9	16	19.3	28.20
4-Aug-2004	0	2.05	0	4.1	0.26
5-Aug-2004	0	11.4	0	22.8	1.47
6-Aug-2004	12.8	11.5	7.5	10.2	11.11
7-Aug-2004	1.4	0.7	17.4	0	5.91
8-Aug-2004	64.4	50.2	0	36	44.05
9-Aug-2004	0	0	16.4	0	4.71
10-Aug-2004	2.2	2.5	6.3	2.8	3.42
11-Aug-2004	0	0	0	0	0.00
12-Aug-2004	0	0	0	0	0.00
13-Aug-2004	11.6	5.8	16	0	12.12
14-Aug-2004	1.2	1.6	4.2	2	2.11
15-Aug-2004	29	19	15.7	9	23.88
16-Aug-2004	0	2.4	0	4.8	0.31
17-Aug-2004	0	0	0	0	0.00
18-Aug-2004	0	0	0	0	0.00
19-Aug-2004	0	0	0	0	0.00
20-Aug-2004	0	0.5	10.7	1	3.14
21-Aug-2004	0	5.5	0.8	11	0.94
22-Aug-2004	0	0	1.4	0	0.40

Date	Senkata	Edaga Hamus	Wukro	Hawzen	Thiessen Polygon
23-Aug-2004	0	0	0	0	0.00
24-Aug-2004	0	0	0	0	0.00
25-Aug-2004	0	5.7	1.1	11.4	1.05
26-Aug-2004	0	0	0	0	0.00
27-Aug-2004	0	0	0	0	0.00
28-Aug-2004	1.3	0.65	0	0	0.84
29-Aug-2004	0	0	0	0	0.00
30-Aug-2004	0	1.65	0	3.3	0.21
31-Aug-2004	0	0	12.3	0	3.54
1-Aug-2005	0	0	0	0	0.00
2-Aug-2005	1.7	4	6.3	6.3	3.32
3-Aug-2005	0	1.15	1	2.3	0.44
4-Aug-2005	0	5.9	0	11.8	0.76
5-Aug-2005	0	0.25	0	0.5	0.03
6-Aug-2005	0	0	0	0	0.00
7-Aug-2005	0	0	0	0	0.00
8-Aug-2005	4.7	4	4.5	3.3	4.55
9-Aug-2005	3.5	2.2	2.3	0.9	2.99
10-Aug-2005	32.6	35.2	23.3	37.8	30.26
11-Aug-2005	16.5	8.25	0	0	10.69
12-Aug-2005	0	2.5	0	5	0.32
13-Aug-2005	0	0	0	0	0.00
14-Aug-2005	36.7	18.35	0	0	23.78
15-Aug-2005	1.4	3.7	0	6	1.29
16-Aug-2005	0	8.15	4.7	16.3	2.40
17-Aug-2005	0	0	1.9	0	0.55
18-Aug-2005	0	0	0	0	0.00
19-Aug-2005	2.6	12.3	17.8	22	8.22
20-Aug-2005	12.7	12	30.2	11.3	17.64
21-Aug-2005	0	0.4	0	0.8	0.05
22-Aug-2005	9.2	7.6	40	6	17.85
23-Aug-2005	0	3.15	20.8	6.3	6.39
24-Aug-2005	0	4	10.1	8	3.42
25-Aug-2005	0	5	0	10	0.65
26-Aug-2005	36.2	33.7	32.8	31.2	34.90
27-Aug-2005	0	0	0	0	0.00
28-Aug-2005	0	0	5.7	0	1.64
29-Aug-2005	0	0	0	0	0.00
30-Aug-2005	0	0	0	0	0.00

Date	Senkata	Edaga Hamus	Wukro	Hawzen	Thiessen Polygon
31-Aug-2005	7	4	4.9	1	6.01
1-Aug-2006	14.8	8.7	0	2.6	9.76
2-Aug-2006	12.5	12.15	15.3	11.8	13.26
3-Aug-2006	23.5	11.75	2.4	0	15.92
4-Aug-2006	0	0	2.6	0	0.75
5-Aug-2006	28.2	15.5	1.5	2.8	18.88
6-Aug-2006	1.2	5.9	0	10.6	1.46
7-Aug-2006	0	1.7	5.4	3.4	1.77
8-Aug-2006	37.5	38.5	61.3	39.5	44.47
9-Aug-2006	2.6	2.4	1.8	2.2	2.34
10-Aug-2006	0	0	6.9	0	1.98
11-Aug-2006	20.4	10.7	0	1	13.28
12-Aug-2006	0	2.6	1	5.2	0.62
13-Aug-2006	11.4	6.75	21	2.1	13.56
14-Aug-2006	43.5	22.75	42	2	40.39
15-Aug-2006	3.2	22.1	1.5	41	5.15
16-Aug-2006	20.4	15.7	20	11	19.68
17-Aug-2006	2.1	1.45	1.8	0.8	1.93
18-Aug-2006	0	1.6	0	3.2	0.21
19-Aug-2006	0	3.25	0	6.5	0.42
20-Aug-2006	0	0	0	0	0.00
21-Aug-2006	1.2	7.75	9.8	14.3	4.52
22-Aug-2006	6.4	7.2	0	8	4.66
23-Aug-2006	0	2.15	3.3	4.3	1.23
24-Aug-2006	0	0	0	0	0.00
25-Aug-2006	0	1.75	10.3	3.5	3.19
26-Aug-2006	35.7	20.85	61.4	6	41.17
27-Aug-2006	3.2	7.8	0	12.4	2.87
28-Aug-2006	0	0	0	0	0.00
29-Aug-2006	0	3	0	6	0.39
30-Aug-2006	1.6	8.9	10	16.2	4.96
31-Aug-2006	14.4	22.2	20.3	30	17.10
1-Aug-2007	33.5	24.75	15	16	27.05
2-Aug-2007	21.4	13.1	27	4.8	21.94
3-Aug-2007	5.3	3.25	10.7	1.2	6.59
4-Aug-2007	2	8.5	0	15	2.27
5-Aug-2007	12.5	15.9	9.5	19.3	12.08
6-Aug-2007	27.2	18.25	5.5	9.3	19.80
7-Aug-2007	0	2.75	5.3	5.5	1.88

Date	Senkata	Edaga Hamus	Wukro	Hawzen	Thiessen Polygon
8-Aug-2007	0	0.15	0	0.3	0.02
9-Aug-2007	4.4	5.55	12	6.7	6.73
10-Aug-2007	0	5.1	3	10.2	1.52
11-Aug-2007	3.7	1.95	0	0.2	2.41
12-Aug-2007	0	0.6	15.4	1.2	4.50
13-Aug-2007	2.8	5.15	40.4	7.5	13.91
14-Aug-2007	0	0	0	0	0.00
15-Aug-2007	5.5	6.9	24.2	8.3	11.06
16-Aug-2007	1.7	0.85	0	0	1.10
17-Aug-2007	0	0	0	0	0.00
18-Aug-2007	0	0	0	0	0.00
19-Aug-2007	2.2	6.9	38.6	11.6	13.27
20-Aug-2007	9.3	13.75	22.2	18.2	13.58
21-Aug-2007	1.4	3.3	10.6	5.2	4.29
22-Aug-2007	0	0.25	0	0.5	0.03
23-Aug-2007	0	0.6	0	1.2	0.08
24-Aug-2007	0	0.1	0	0.2	0.01
25-Aug-2007	0	0	0	0	0.00
26-Aug-2007	0	0	0	0	0.00
27-Aug-2007	2.2	2.7	1.3	3.2	2.01
28-Aug-2007	0	0	0	0	0.00
29-Aug-2007	0	0	0	0	0.00
30-Aug-2007	0	1.5	0	3	0.19
31-Aug-2007	0	0.2	27.2	0.4	7.85
1-Aug-2008	0	2.35	8.2	4.7	2.66
2-Aug-2008	0	0	4.5	0	1.29
3-Aug-2008	3.5	2.7	1	1.9	2.68
4-Aug-2008	0	1.2	0	2.4	0.16
5-Aug-2008	1.5	6.45	10	11.4	4.58
6-Aug-2008	36.1	21.95	38.5	7.8	34.96
7-Aug-2008	5.4	13	9	20.6	7.42
8-Aug-2008	0	2.25	10	4.5	3.17
9-Aug-2008	6.8	4.55	31.5	2.3	13.61
10-Aug-2008	8.7	4.85	0	1	5.70
11-Aug-2008	0	0	2.8	0	0.80
12-Aug-2008	0	1.35	0	2.7	0.17
13-Aug-2008	4.4	4.8	13.7	5.2	7.13
14-Aug-2008	3.4	6.25	11.6	9.1	6.13
15-Aug-2008	7.2	15.45	0	23.7	6.20

Date	Senkata	Edaga Hamus	Wukro	Hawzen	Thiessen Polygon
16-Aug-2008	2.5	1.25	0	0	1.62
17-Aug-2008	0	1.4	5.3	2.8	1.70
18-Aug-2008	7.9	6.6	8.9	5.3	8.02
19-Aug-2008	0	0	0	0	0.00
20-Aug-2008	0	0	0	0	0.00
21-Aug-2008	0	0	0	0	0.00
22-Aug-2008	0	0.5	5.9	1	1.76
23-Aug-2008	0	0	0	0	0.00
24-Aug-2008	0	0	0	0	0.00
25-Aug-2008	0	0	0	0	0.00
26-Aug-2008	0	0	0	0	0.00
27-Aug-2008	0	0	0	0	0.00
28-Aug-2008	0	0.15	0	0.3	0.02
29-Aug-2008	2.4	1.2	2.1	0	2.16
30-Aug-2008	0	0	0	0	0.00
31-Aug-2008	0.9	1.05	0	1.2	0.66

(Source: National Metrological Agency, Ethiopia)

DECLARATION

I here by declare that the dissertation entitled 'The Effect of Land Use Land Cover Change On the Hydrologic Response of Wukro-Genfel Catchment, Tekeze Basin, Ethiopia' has been carried out by me under the supervision of Dr. Dagnachew Legesse, Department of Earth Sciences, Addis Ababa University, Addis Ababa during the year 2009-2010 as a part of Master of Science programme in Remote Sensing and GIS. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

Fitsum Melaku
Jan., 2010
Addis Ababa