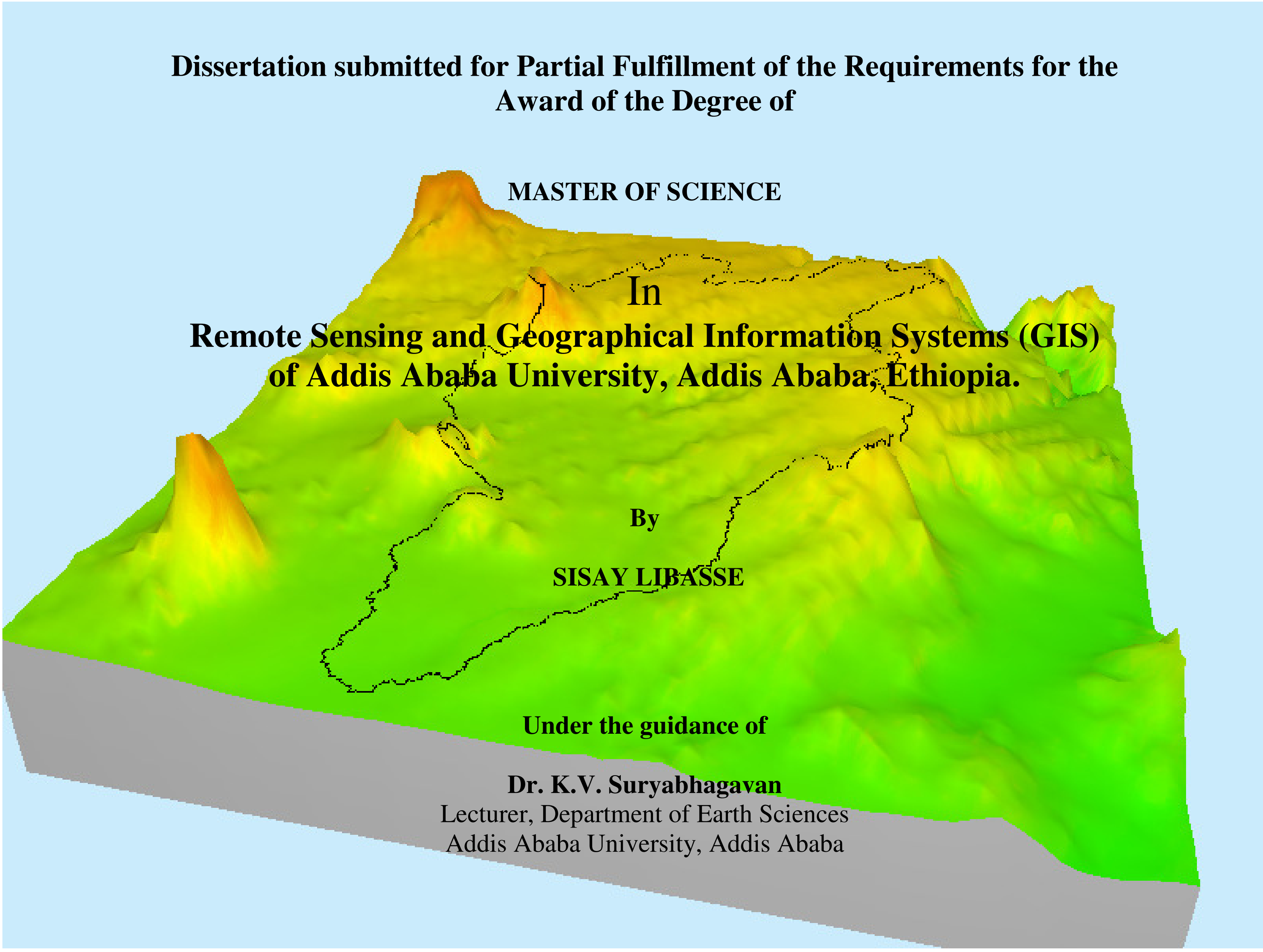
Application of Remote Sensing and GIS for Groundwater Potential Zone Mapping in Northern Ada'a Plain (Modjo Catchment)



Dissertation submitted for Partial Fulfillment of the Requirements for the Award of the Degree of

MASTER OF SCIENCE

In

Remote Sensing and Geographical Information Systems (GIS) of Addis Ababa University, Addis Ababa, Ethiopia.

By

SISAY LIBASSE

Under the guidance of

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MARCH 2007

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ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

Application of Remote Sensing and GIS for Groundwater Potential Zone Mapping in Northern Ada'a Plain (Modjo Catchment)

By

SISAY LIBASSE

Faculty of Natural Science

Department of Earth Sciences

Remote Sensing and GIS

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Examiner

D E C L A R A T I O N

I here by declare that the dissertation entitled "Application of Remote Sensing and GIS for Groundwater Potential Zones Mapping in Northern Ada'a Plain (Modjo Catchment)" has been carried out by me under the supervision of Dr. K. V. Suryabhagavan, Department of Earth Sciences, Addis Ababa University, Addis Ababa during the year 2006-2007 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.

Place: Addis Ababa
Date: March 3, 2007

(Sisay Libasse)

C E R T I F I C A T E

This is certified that the dissertation entitled "Application of Remote Sensing and GIS for Groundwater Potential Zones Mapping in Northern Ada'a Plain (Modjo Catchment)" is a bonafied work carried out by Sisay Libasse under my guidance and supervision. This is the actual work done by Sisay Libasse for the partial fulfillment of the award of the Degree of Master of Science in Remote Sensing and GIS from Addis Ababa University. Addis Ababa.

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Abstract

An integrated approach with remote sensing, Geographic Information Systems (GIS) and more traditional fieldwork techniques was adopted to map the groundwater potential sites in the central rift valley area of Northern Ada`a Plain (Modjo Catchment). Catchment delineation was done in ILWIS 3.3 DEMHYDROPROCESSING module. Digital image processing of enhanced color from Landsat ETM+ was interpreted to produce thematic maps such as lithology, lineaments, land use/cover and geomorphology. Contours and drainage lines were digitized for slope and drainage density mapping. GIS analysis of distance for lineaments, density for drainage, slope for elevation and reclassification were done for each factor maps. Selected springs and wells were visited to study their topographic and hydrogeological setting. Digital Elevation Models (DEM) derived from contours and acquired in the Shuttle Radar Topographic Mission (SRTM V-3) were compared in relation to drainage and lineaments extraction, landform mapping and catchments delineation. DEM derived from SRTM V-3 using DEMHYDROPROCESSING are better for catchments delineation and landform mapping than those derived from contours. A model that incorporates Weighted Linear Combination (WLC) was built using ARCGIS 9 model builder engine. The model was executed and groundwater potential map was generated. The spatial distributions of the various ground water potential zones obtained from the model generally show regional patterns of lithology, landform and lineaments. Spatially the very good and good categories are distributed along plain geomorphic units, near to lineaments, less dense drainage density and where the lithology is affected by secondary structure and having interconnected pore spaces. Groundwater potential zones demarcated through the model are in agreement with borehole data collected from the area. The validity of the model developed was tested against the borehole data, where out of 107 boreholes 50 are on very good and good zones, 37 on moderate zones, 14 on fair and 6 on poor zones. Moreover out of 52 bore holes with discharge rate from 24 l/s to 69 l/s are on the very good and good zones, which reflects the actual ground water potential. Although some wells exist in all ground water potential zones, the best yielding wells lie in the very good and good ground water prospect zone. The results demonstrate that the integration of remote sensing, GIS, traditional fieldwork, and geomorphology provide a powerful tool in the assessment and management of water resources and development of groundwater exploration plans.

1. INTRODUCTION

1.1 General

Water is one of the main resources that are important for sustainable development of a country. In order to make it sustainable proper investigation and utilization is vital. Recent studies indicate that groundwater is becoming the main source of water supply for many countries. Even though groundwater is a subsurface phenomenon Remote Sensing and GIS have opened new systematic and efficient exploration of groundwater, landform mapping, geological mapping, mineral exploration, geo-hazard studies and the like. The use of aerial photographs and satellite imagery is known for visualizing the landscape. The satellite imagery helps in understanding and correlating various landforms, which cannot readily be observed from the ground due to limited range of observation. The last decade has seen an increasing growth in the use of Remote Sensing and GIS technology in groundwater studies, as the groundwater has become the most important natural resource due to over increasing population of the world and industrial growth.

Lack of adequate water supplies that may serve for drinking and as well as for agricultural activities inhibits the progress of developing countries and has been the cause of considerable hardship to such countries. In order to alleviate the repeated occurrences of famine and lack of clean potable water, new scientific researches should be carried out. A thorough hydrogeologic understanding is also critical for cost-effective water resources development projects designed to alleviate these hardships. Establishing relationship between Remote Sensing data and hydrologic parameters can maximize the efficiency of water resources development projects.

Currently groundwater is gaining more attention due to drought problem, rural water supply, irrigation project and low cost of development it requires.

Despite the extensive research and technological advancement, the study of groundwater has remained more risky, as there is no direct method to facilitate observation of water below the surface. Its presence or absence can only be inferred indirectly by studying the geological and surface parameters.

Some of the main factors that control groundwater occurrence in a given area are,

(i) Drainage Density
(ii) Slope Steepness
(iii) Land use/Land cover
(iv) Soil
(v) Rainfall
(vi) Geological Structures/Lineaments
(vii) Landforms/Geomorphology
(viii) Lithology/Geology

Remotely Sensed data by its wide area coverage and multispectral nature help in identification and mapping of most of the above factors with selective ground checks in a cost-effective manner. An integrated analysis of these factors together with the available well and ancillary data in the GIS environment helps in identifying the potential groundwater zones. This helps in narrowing down the target areas for conducting detailed hydrogeological and geophysical surveys on the ground, and ultimately to locate the site for drilling. Considering the importance of Remote Sensing and GIS techniques, the present study has been undertaken in northern part of Ada'a (Modjo Catchment) to map different landforms, understand geomorphic processes involved and delineate prospective groundwater zones.

1.2 Objectives

Even though Ethiopia has been claimed to be the "water tower of Africa" clean water is a scarce resource in the country. The majority of water used for domestic purposes comes from groundwater sources. In most villages in Ethiopia water supply comes mainly from dug-wells and to some extent from boreholes that are found along seasonal streams and valleys. Extensive studies of existing productive wells in relation to lithology and structures are absent. Most surveys for selection of well sites for groundwater supply mainly rely on traditional field studies using existing water point sites as well as ground information that is gathered as guidelines. In general a systematic approach to groundwater exploration is lacking.

The overall aim of this study is:

To contribute towards systematic groundwater studies utilizing Remote Sensing, field studies, Digital Elevation Models (DEM) from digitized contour of topographic map and Geographic Information Systems (GIS) in the delineation of groundwater potential areas, in ”Ada`a” plain (Modjo Catchments).

The specific objectives of the study are:

- To prepare thematic maps of the area such as lithology, lineaments, landforms and slopes from remotely sensed data and other data sources like DEM.
- To assess groundwater controlling features by combining remote sensing, field studies and DEM.
- To identify and delineate groundwater potential zones through integration of various thematic maps with GIS techniques.
- To compare previous works with the present study.
- To make recommendations for future work and provide guidelines for groundwater prospecting.

1.3 The study area

1.3.1 Location, Accessibility and Areal Extent

The project area, ”Adaa” (Modjo Catchments) is located 40k.m southeast of Addis Ababa in the central Main Ethiopian Rift, in Oromiya regional state (Fig.1.1). It is located in the Zone 37 UTM grids of 930000meter N to 1010000meter N and 480000meter E to 540000meter E .The area is bordered with Yerer mountain and water divide with Kesem river and mountain Zikuala in the south. Modjo river that flows from northeast to southwest is the main stream draining the area.

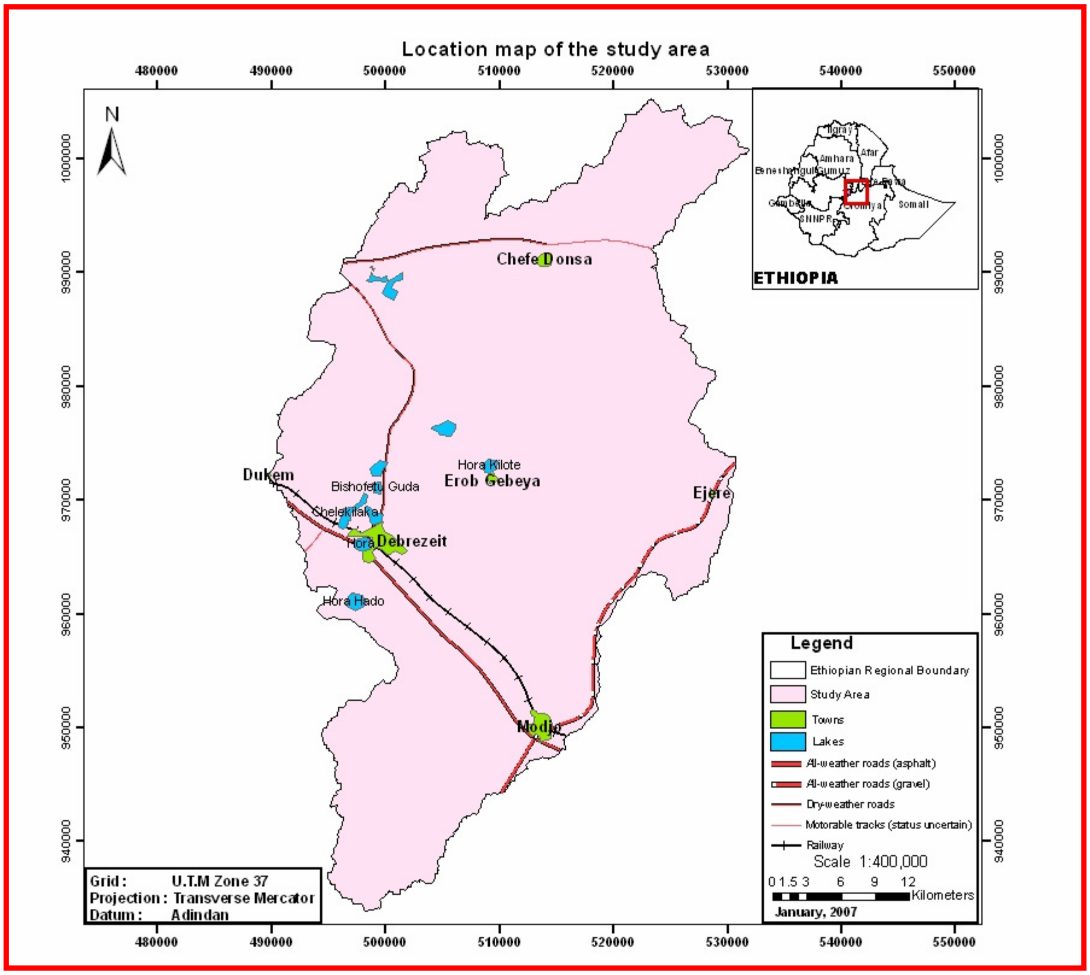

Figure 1.1 Location map of the study area

The area is traversed by the main high way from Addis Ababa to Djibuti. Most parts of the area are accessible from all directions by a number of all weathered roads, dry season roads and footpaths as well asphalt road. It covers an area of 1720 square kilometers.

The study area, which is characteristic for the Ethiopian rift, was selected based on the availability of hydrogeological data, accessibility for field investigations and its importance as an input for the project which is being conducted by Ethiopian Water Works Design and Supervision Enterprise.

1.3.2 Physiography and Climate

The project area is generally characterized by flat topography mostly underlain by diverse volcanic products of the Quaternary rift volcanics (Tamiru and Antonio, 1995), and sediments (Fig.1.2).

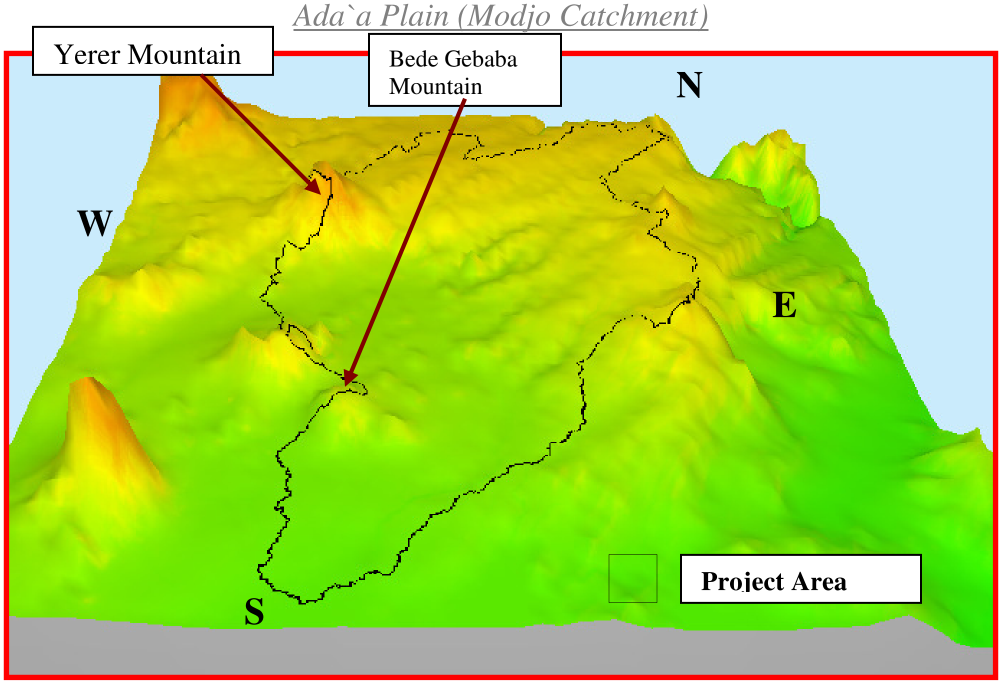

Figure 1.2. 3D view of the study area derived from SRTM V-3 data

The topographic elevation of the study area ranges from elevations 1600 to 2900 m.a.s.l. According to KOEPPEN classification the area belongs to tropical rainy climate and experiences heavy rainfall in June and July. Rainfall data from NMSA (National Meteorological Service Agency) has shown average annual precipitation of 1088mm.The mean annual temperature of the area is 22^0 C.

1.3.3 Geological setting

Ethiopian volcanic province is broadly classified in to Trap and Aden series (Mohr, 1963) based on the eruption that took place prior to or after East Africa rift formation, which is supposed to have commenced at about 15Ma. In Modjo river basin, Central Ethiopia, both series are exposed. Pre-rift volcanic sequences occur on the plateau while Aden series occur on the escarpment and on the rift floor. Since only the latter is extensively exposed in the study area, this regional overview of the volcanic rocks entirely deals with the Aden series.

The Modjo river drainage basin is underlain by a variety of volcanic rocks that depict a geologic history from Miocene to recent. They comprises of Nazreth series/Nazreth group basalt, Chilalo formation, Mursi & Bofa basalt, Bishoftu formation, Dino formation/Wonji Group, Ryolite volcanic complex and Alkaline basalt (Kazmine et al., 1980, 1979, Zanettin& Justin-Visentin 1974, Mayer et al., 1975 Mengesh et al., 1996, Cherent et al., 1999).

Nazreth Series rocks which consist welded ignimbrite, pumice, ash and rhyolite flow and dome with rare interaction of basaltic flows occur in Main Ethiopian Rift (MER) and rift margin especially, north and east of Modjo town (Kazmin and Berhe, 1978). On the plateau margins, their thickness varies from 1 to 30 meters where as with in the rift group attains a maximum thickness of up to 250 m. Ignimbrites of the Nazret series are of the fall type and are considered to be products of explosive eruptions, mainly on marginal faults of the Rift (Morbideilli et al., 1973). Many widely distributed rhyolitic domes have been observed indicating that central type explosive eruptions played a significant role in the formation of the Nazret volcanics. According to Kazmin and Berhe (1978), K-Ar age determinartion of Nazret series rocks yielded between 9.5 and 3Ma.

Chilalo formation is found along the margin of the MER and is constituted of strongly porphritic dark trachyte with sanedene phenocryst, trachy basalt and ignimbrite as subordinate. This formation exhibits ages ranging from 8 to 4Ma (Kazmin et al., 1980b; Cherent et al., 1999).

Bofa basalt is represented by flood basalt volcanism comprising aphyric locally vesicular basalt with predominantly transitional to alkaline nature. These basaltic units form a wage between Nazert series and Dino formation. Existing ages on samples collected from the study area range between 4 and 1.6Ma(Kazmin et al., 1980b).

Basalt flow with well preserved scoria cones with affinity to alkaline form Bishoftu formation. The volcano is placed on tectonic lines transversal to the axial and shows ages ranging from 2 to 2.8 Ma (Zanettin&Justin-Visentin., 1974; Kazmin et al., 1980).

Dino formation/Wonji series constitute the latest constitute volcanism that is after the last major episode of rifting and is also related to its axial extension zone which is known as the Wonji fault belt. It comprises green & grey fiamme ignimbrites associated with unwelded pyroclastics with intercalated lacustrin beds aphyric basalt. Dino ignimbrite is the oldest of the group followed by pantelleritic volcanic centers, and finally by recent fissural basalts. The oldest unit of the group is dated to be 1.5Ma. The majority of pantelleritic volcanic centers exhibit alignment along segments of Wonji Fault Belt. The main components of these centers are rhyolites, trachytes, obsidian, and recent fissural basalts (Kazmin et al., 1979).

The age of the lacustrine rift sediments is contemporaneous with the Wonji volcanics. They are mainly of volcanoclastic sediments and tuffs with silts, clays and diatomites; silts and clays are the dominant ones. Alluvial deposits are also common in the rift, associated with flood plains and at some places mixed with volcano clastic sediments.

Detailed geological mapping in Debrezite area has classified the underlain volcanic rocks into three non-formal litho-stratigraphic complexes; viz, Western rift margin complex consisting of Addis Ababa basalt unit, central volcano unit and Akaki units; intra rift complex comprising nazret unit, Tulu rie basalt unit and Chefe donsa unit, and rift axis complex that comprises Zikwala Volcano unit, Bede Gebabe volcano unit, Bishoftu volcanic unit and lacustrine deposit (F.Mazzarini et al., 1999).

1.3.4 Regional structures

The Main Ethiopian Rift is a structural depression characterized by several step faults. The relief between the Ethiopian plateau escarpment and the central part of the rift reaches about 1000m. Accordingly, the escarpment of the rift consists of a number of step faults with down through side that may reach 300m for a single step fault. According to several authors for example, Kazmin et al.,1979; Zanettin, 1992, the geological history of the Rift is linked with the regional up-lifting occurred in the Eocene, as a part of Afro-Arabian up doming, which later gave rise to large scale faulting with clear western and eastern fault margin escarpments of MER, showing morphological differences between the eastern and western escarps. The eastern margin is characterized by well-defined lineaments throughout its length, while the western margin progressively dies-out toward the southwest.

1.3.5 Tectonic and Structures of The Study Area

Modjo river catchement area was subjected to extensional tectonic activities and intense volcanism. The Wonji fault belts are the prominent (Main Ethiopian Rift) MER structures that represent a NNE-SSW trending fault system forming minor graben and horst structures such as Modjo graben and Delocha horest to the west and east of the Modjo town.

Some faults have been observed in Modjo area (eastern, southern, southwestern parts) forming minor fault escarpments. The river channels, large gullies seem to outline and follow the concealed faults line. In the (Main Ethiopian Rift) MER, faults, joints, fractures, volcanic flows and layering and flow folding, which are associated with silicic lava flows, are main geologic structures. The presence of thick fluvo-lacustrine deposits and active erosional or denudational processes in the (Main Ethiopian Rift) MER during the Quaternary period obscure some of the rift fault/lineaments.

Brittle deformation consisting of fractures, joints and faults are dominant in the area. Structures are extensional and affect chiefly the rocks of the Intra Rift Complex and partially those of the Western Rift Margin Complex. These structures are grouped into four main fracture systems consisting mainly of joint sets and some faults (Abebe et al., 1999). These are:

1. The N-S/NNE-SSW fracture system which is analogous to Wonji Fault Belt, constitutes normal faults with steeply dipping joints with dip amount of >85o.

2. The NE-SW fracture system that parallels the regional trend of the MER, and has normal fault of about 1m thrown and dip amount >85o. It is widespread especially in the Nazret unit where the most important physiographic features are NE trending ridges and escarpments.

3. The E-W fracture system mainly concentrated in zones close to the Yerer Volcano to the east of Addis Ababa. It parallels the trend of the Yerer-Tullu Wellel Volcanic Lineament (YTVL) structure. It consists of sub vertical to vertical joints with an estimated dip amount >850

4. The NW-SE fracture system. Few high angle normal faults have been documented with high morphologic evidence (escarpments). This system affects mainly the oldest units of western Rift margin.

The structural geometry of the area is controlled by the left-lateral oblique rifting of the MER (Boccalitti et al., 1999) and right lateral transtensional Yerer-Tullu Wellel Volcanic Lineament structure (Abebe et al., 1998). Thus, the interference between the MER and YTVL structures would be the first order cause of features like gradual transition between the rift floor and the West Rift shoulder.

1.3.6 Literature review

Groundwater is essentially a subsurface phenomenon; Remote Sensing from aircrafts or satellite has become an increasingly valuable tool for understanding subsurface water condition (David Todd, 1980). The common current remote sensing platforms record features on the surface. Most of the information for groundwater, as yet, has to be obtained by qualitative reasoning and semi-quantitative approaches. The remotely sensed information is often of surrogate nature and has to be merged with geohydrologic data to become meaningful. The general method for assessing regional groundwater resources, which starts with conceptualization of the hydrogeology consists building-up of the three dimensional hydrogeological setting based on surface and subsurface geology followed by estimation of the regional groundwater surface (G.A.Schultz, 2000, E.T.Engman, 2000). Availability in any terrain is largely controlled by the prevalence and orientation of primary and secondary porosity (Semere, 2003)

In Debre Zeit the majority of water used for domestic purposes comes from groundwater sources. Several groundwater related studies have been conducted in Debre Zeit which includes the whole Ada`a plain. Tamiru and Antonio (1995) have used all possible geological and hydrogeological methods for evaluation of groundwater potentiality together with chemical characteristics and their interactions with the country rocks. They have also explained that the area is part of the Ethiopian rift System that is characterized by a Plio-Quaternary volcanism which gave rise to trachitic domes, rhyolitic lava flows and rhyolitic ignimbrites in the upper part of the area and successive olivine basaltic lava flows, surge deposits and alluvial deposits. In their result of investigation the basaltic lava flows, occurring as alternative layers of amygdaloidal, fractured, vesicular and scoraceous basalts are found to be the best and the most productive aquifers in the area. In addition, they pointed out that groundwater occurs within the basaltic layers under unconfined, semi confined or confined conditions, where the thick clayey and pyroclastic layers play an important role of aquitards. In their analysis of lake level fluctuation, they have shown that there is a good hydraulic connection between the explosion crater lakes and the groundwater circulation. Tibebe (2006) carried out Integrated Geophysical Investigation For The Evaluation of Groundwater Resources At Ada`a Plain Near Debre Zeit, in his MSc thesis. According to the author, the research was conducted to verify the inferred groundwater barrier and its possible connection to the linear structures. In his geophysical interpretation results, the magnetic survey was found to be useful in lithological mapping and identifying linear geologic features. On the magnetic map, NW-SE trending anomalies are in conformity with the anticipated groundwater barrier and the inferred groundwater barrier was not detected and mapped by resistivity method.

Alem (2006) carried out Hydrogeology of Modjo River, in his Msc thesis. In his research he has carried out conventional hydrogeological investigation in order to define the basic hydrogeological factors controlling the occurrence, movement and storage of groundwater in the Modjo river basin. In his research result he pointed that alluvial deposits, basaltic flows and domes are important permeable units, while fractured ignimbrite and rhyolitic ignimbrite are considered as medium permeability group and are also good water bearing units. The rest of geological units such as massive ignimbrites and lacustrine deposits are considered to be low permeable units.

Studies about Surface Water and Groundwater Pollution Problems in The Upper Awash River Basin, Ethiopia carried out by Adane (1999) show that the scoracious and vesicular basalts that out crop in the vicinity of Debre Zeit and Akaki are highly permeable due to interconnection of pore space and high fracture system.

Generally most of previous works conducted in the study area did not apply the full capability of integrated remote sensing and GIS for groundwater mapping of the Ada'a plain (Modjo Catchment).

1.4 Methodology, Data, Materials and Software used

1.4.1 Methodology

The methodology employed is summarized in the flow chart in (Fig 1.3). It involves catchment extraction using ILWIS DEMHYDROPROCESSING module, digital image processing for the extraction of geomorphology, lithological, linear features, land use/cover etc... The field studies are comprised of hydrogeological, structural and geomorphological investigations. DEM, which is produced from digitized contours and from SRTM, was used to extract lineaments and for landform mapping. All data were integrated in a Geographic Information System (GIS) and analyzed to assess the groundwater controlling features. Finally groundwater potential map was prepared based on GIS analysis.

1.4.2 Data and Material Used

The remote sensing data used for the study are Landsat Thematic Mapper (ETM+) (28.5 m. resolution) path/row (168/054), Year 2000 with 7 bands and orthorectified. The Lansat ETM+ has different spectral and spatial resolution. The spectral bands ranges from the panchromatic data having 15m resolution, six band in the visible, near-IR and mid-IR at a resolution of 30m and one thermal band at 60m. resolution. Mosaic of six topographic map having a scale of 1: 50,000 (Fig 1.4) were used during field survey, digitization of contours, drainage, towns and places.

Primary data derived were land cover/use, geomorphology, drainage density, lineaments and slope. Secondary data, which were modified and used, were lithology, rainfall, and soil map of the area. GPS for point and rout data collection, compass for direction, digital camera for taking pictures and magnifying glass for magnifying contours during digitization.

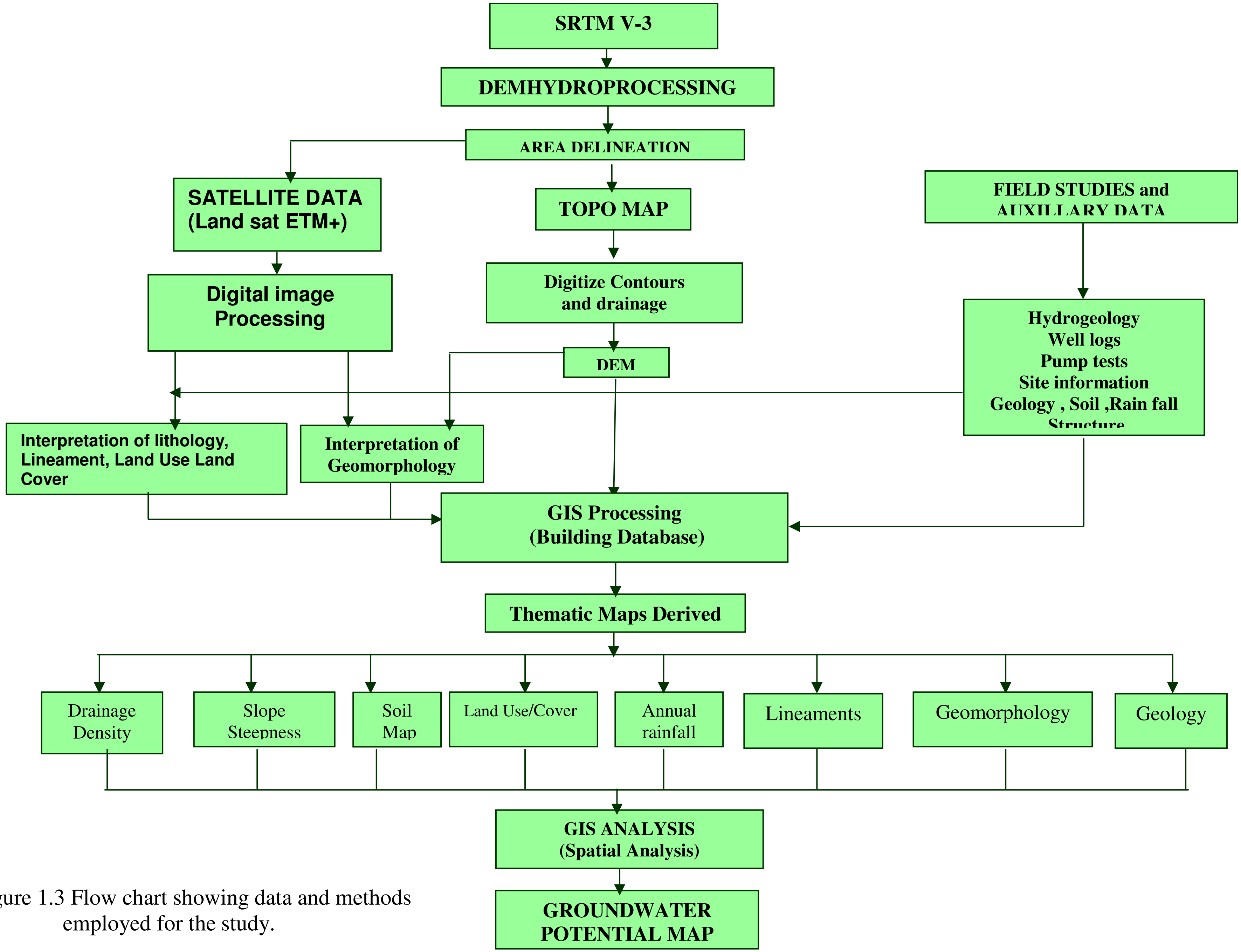

Figure 1.3 Flow chart showing data and methods employed for the study.

0938 D4 ADDIS ABABA NE	0938 C3 SENDAFA
0838 B2 ADDIS ABABA SE	0839 A1 CHEFE DONSA
0838 B4 ZIKWALA	0839 A3 MODJO

Figure 1.4 Index of topographic sheets used for the study

1.4.3 Software used

ILWIS 3.3 DEMHYDROPROCESSIN module was used for catchments delineation

Arcview 3.2a, Mapinfo 7 and ArcGis9 were used for GIS analysis.

ERDAS Imagine 8.6 and ENVI 4.2 were used for georeferencing, image analysis and coordinate transformation of all the data used in to UTM 37 Zone, Adindan Datum.

DNRGARMIN, which is extension of arcview 3.2a, was used for transferring GPS data in to computer.

Globalmapper 6 was used for analysis of landforms/Geomorphology,

IDRISI 32 for calculation of weight.

2. REMOTE SENSING AND GIS ANALYSIS

2.1 Introduction

Satellite images data facilitate the preparation of lithological, structural, and geomorphological maps, especially at a regional and small scale according to the resolution of the images. These data show major rock groups, structural features, such as folds, faults, lineaments and fractures, and different landforms, due to their synoptic coverage and multispectral capability (Siegal and Gillespie, 1980, Drury, 1987).

Visual interpretation of remote sensing images is achieved in an efficient and effective way using basic interpretation keys or elements (Sabins, 1987). An interpretation key comprises combinations of characteristic features to identify objects in an image. Typical key features are size, shape, tone, texture, pattern and color. Similarly many procedures are available for image data manipulation (Lillesand and Kiefer, 1994).

The extensive ground coverage and high resolution of satellite images enables regional and local information extraction for analysis.

The routine procedure for extraction of information from digital remote sensing data usually involves initial digital image enhancement followed by manual interpretation and classification into various categories after conducting ground conformation.

Final step in producing out put from remotely sensed data involves interactive digitization of classified categories, which enables capturing of information in database with different formats. The final out put can be analysed according to desired interest separately or with other data in GIS.

2.2 Remote Sensing Analysis

2.2.1 Study Area Delineation

The study area was delineated using ILWIS 3.3 DEMHYDROPROSESSING module after eight consecutive processes (Fig 2.1) on 4 SRTM data, which are described below:

1. IMPORTING of 4 SRTM: 1 by 1 degree tiles in ILWIS (N8E038, N8E039, N9E038, N9E039) and they were mosaic.

2. INTEPOLATION of the raster map in kriging methods to fill sinks (areas with no data) for the undefined values, which are weighted average values, similar to a moving average operation.

3. FLOW DIRECTION determination to determine into which neighboring pixel any water in a central pixel will flow naturally.

4. FLOW ACCUMULATION that performs a cumulative count of the number of pixels that naturally drains into outlets. The operation can be used to find the drainage pattern of a terrain.

5. DRAINAGE NETWORK EXTRACTION of drainage based on user defined drainage length.

6. DRAINAGE ORDERING for assigning drainage order for each drainage line.

7. CATCHMENT MERGING for the extraction of catchments based on user-defined out late point (UTM, 498176E, 934014N), which was taken from topographic map.

For delineation of the study area six topographic maps of scale 1:50,000, which are scanned by A0 size scanner were imported to ERDAS IMAGINE 8.6 software and they were georeferenced based on the topographic map projection: UTM zone 37, spheroid Clark 1880 (modified) in

Adindan datum and they were mosaic in to one raster map and the study area was delineated after overlain of the extracted catchments (Fig. 2.2) on the rater map.

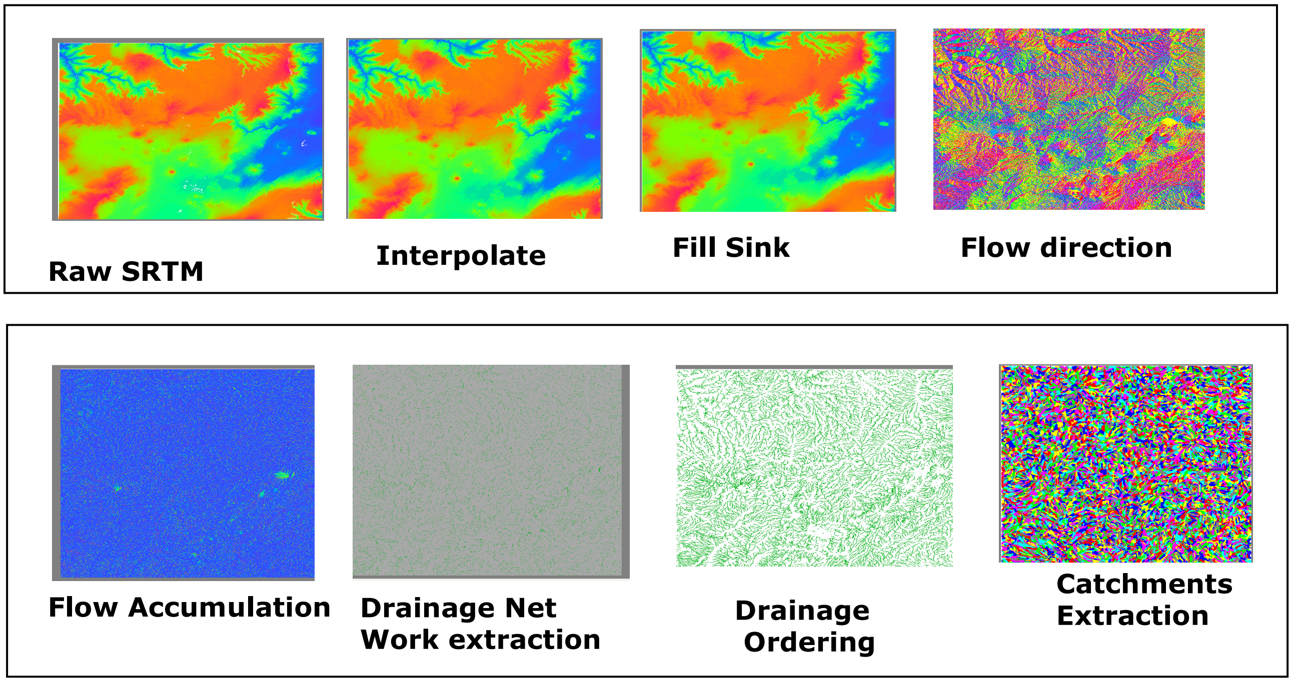

Figure 2.1 ILWIS 3.3 DEMHYDROPROSESSING processes for delineating the study area.

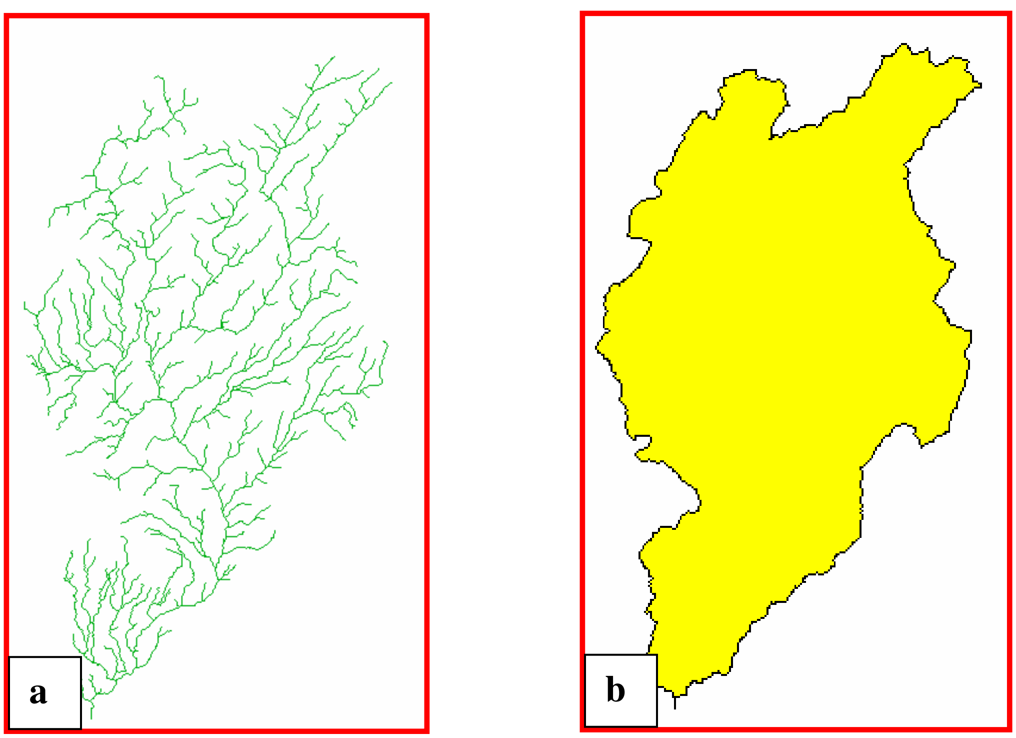

Figure 2.2 Drainage (a) and delineated study area boundary (b) extracted from SRTM.

2.2.2 Image processing and Interpretation

Satellite image of Landsat 7 sensor ETM+, path 168 and row 54, which was acquired on January 27, 2000 and processed Sep 09, 2001 (with a map projection of UTM zone 37, spheroid and datum WGS 84) has been used for most of the processing and mapping activities after re-projection into Adindan datum. From this image, 7 bands were used. Bands 1, 2, 3, 4, 5,7 and 8 in visible, near infrared and far infrared electromagnetic spectrum having spatial resolution of 25 meters and band 8 is panchromatic having 12.5 meter spatial resolution.

These images were imported to ERDAS IMAGINE 8.6 software and the study area was subset from the full scene of path 168 and row 54. On the subset image of band 8, directional filter was done in order to digitize the existing geological structures and the result was compared with the previous structural map of the area. Printouts of different band combinations were used to identify features during field survey.

Digital elevation model (DEM) was derived from digitization of contours from 1:50000 topographic maps where slope data layer were produced (Fig.2.3). Moreover comparisons DEM derived from digitized contours from topographic map of the area and from the Shuttle Radar Topographic Mission (SRTM V-3) was made in relation extraction of drainage networks, linear features, catchments delineation and landform mapping. The result has shown that due to their continuous data coverage and recent update, SRTM are better in catchments delineation and landform mapping.

2.2.2.1 Pre-processing

This operation is done to correct distorted or degraded image data to create a more faithful representation of the original scene. It involves initial processing of the image data to correct for geometric distortion, to calibrate the data radiometrically and to eliminate noise present in the data (Lillesand, 2000).

Remote sensing imageries are inherently subjected to geometric distortions. These distortions may be due to the perspective of the sensor optics, the motion of the scanning system, the motion of the platform (the platform altitude, attitude and velocity), the terrain relief, or the curvature and rotation of the earth (Lillesand, 2000). Geometric corrections are done in order to compensate for these distortions so that the geometric representation of the imagery will be as close as possible to the real world. The Landsat satellite data, used in this study, were all orthorectified by Global Land Cover System (GLSF).

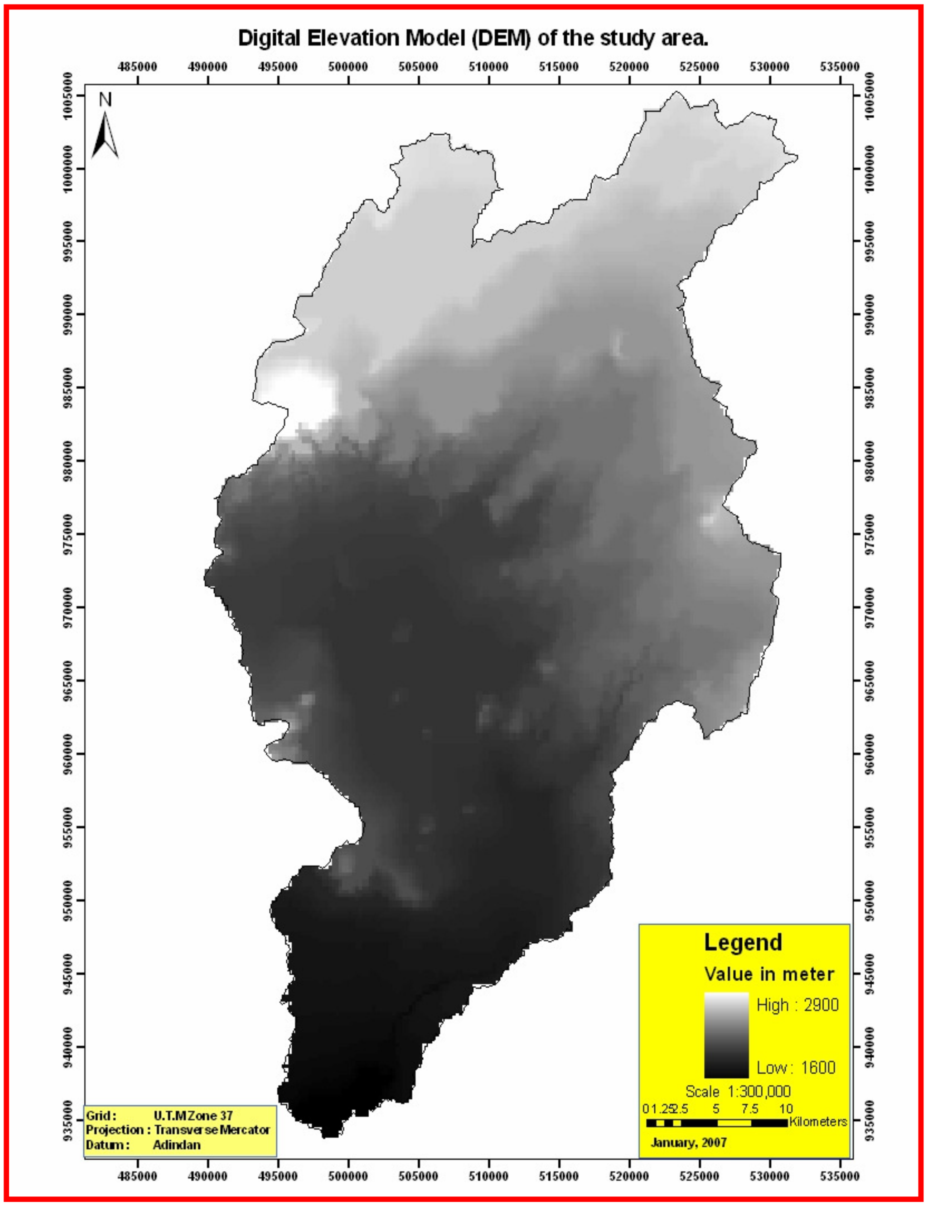

Figure 2.3 DEM derived from digitized contours and spot heights

2.2.2.2 Processing

Image Enhancement

Image enhancement is applied to image data in order to more effectively display or record the data for subsequent visual interpretation. These techniques are most useful because many satellite images, when examined on a color display give inadequate information for image interpretation. Contrast stretching, density slicing, edge enhancement, and spatial filtering are the more commonly used techniques.

Directional filtering is done on the panchromatic image of the year 2000 G. C. that has 12.5m spatial resolutions in order to enhance linear features and subdue other features. This was used to perform mapping of geological structures (faults and lineaments) of the area. .

Image Transformation

Image transformation is done in order to differentiate between the various brightness values, which are obtained from identical surfaces due to topographic slope and aspect, shadows, or seasonal changes in sunlight illumination angle, and intensity. This condition may hamper the ability of an interpreter to identify correctly surface materials or land use in remotely sensed image. Ratio transformation of the image can reduce the effect of such environmental conditions and may also additionally provide unique information not available in any single band that is useful for discriminating between soils and vegetation.

For vegetation discrimination in land use/cover mapping band ratio of 4 to 3 band and false color combinations in RGB order of bands 432 for Landsat 7 of ETM+ image was done. In the ration image vegetation cover has shown light color where as in false color composite open forest has brown to red color (Fig. 2.4).

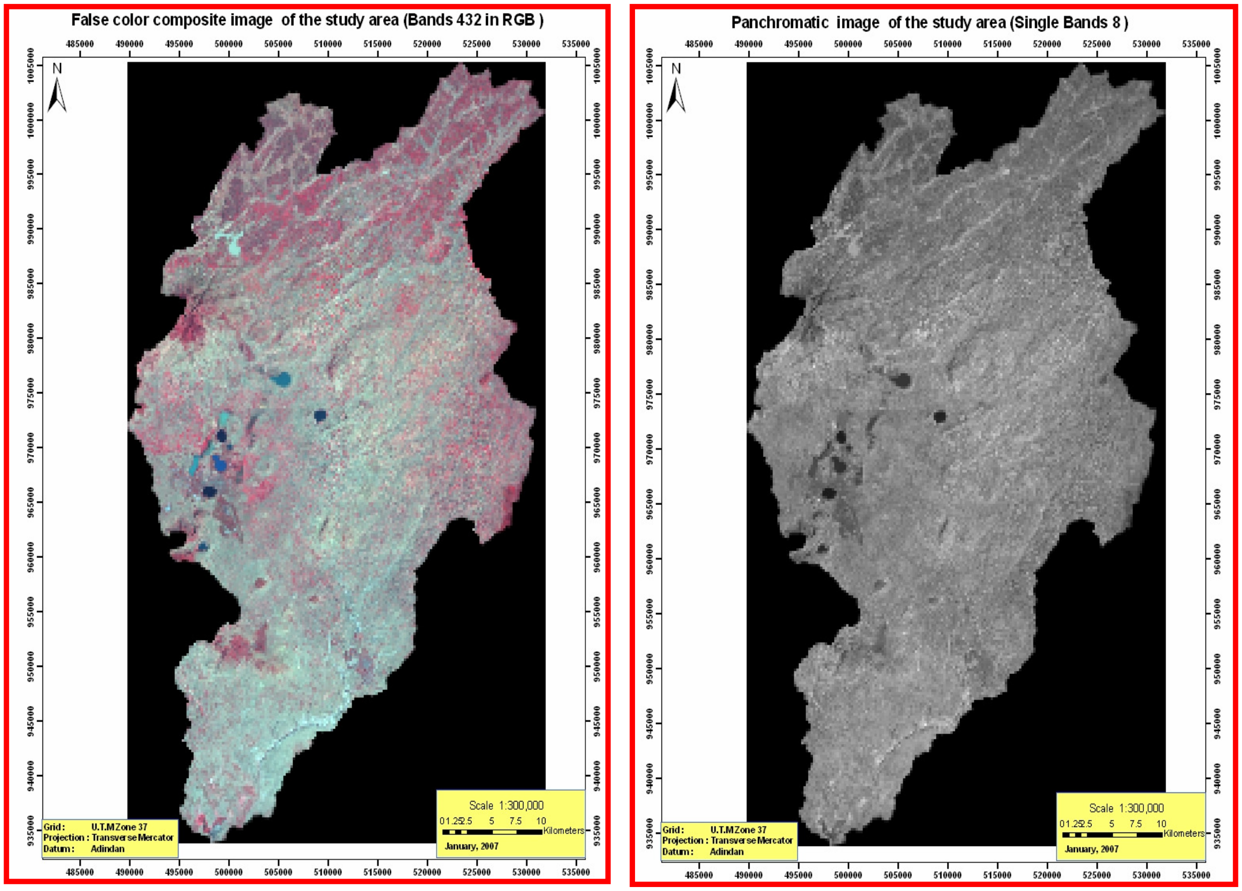

Figure 2.4 Study area images of year 2000 G. C., false color composite of bands 432 in RGB (left) and panchromatic band 8 (right).

Image Classification

Image classification involves the analysis of multispectral image data and the application of statistically based decision rules for determining the land cover identification of each pixel in an image. Decision based on spectral radiance classification process is *spectral* pattern recognition where as decision based on geometric shapes, size, and patterns the procedure falls into spatial pattern recognition (Lillesand, 2000).

Image classification depends on the brightness value of each pixel and it categorizes pixels of nearly the same values. Unsupervised classification was performed in order to have a general idea of the area. Supervised classification was performed for final land use/cover mapping.

2.3 GIS Analysis

The Geographic Information System offers spatial data management and analysis tools that can assist users in organizing, storing, editing, analyzing, and displaying positional and attribute information about geographical data (Burrough, 1986).

The different inputs taken for GIS analysis were from topographic maps, different available maps, Landsat satellite images and SRTM data. GIS analyses such as distance from geologic structures, density of drainage, interpolation of rainfall point data, derivation of slope from digitized contours and overlay analysis for producing the groundwater potential area were done, moreover weights and multi-criteria evaluation were done for analysis of the different parameters that control groundwater occurrences.

All data layers derived were converted to raster data sets having the same pixel size. Each data sets in a single map were given weight by pair-wise comparison in addition the factor maps were compared each other in pair-wise comparison. Reclassification of each map was done based on the weights produced. To produce groundwater potential zone map multi-criteria evaluation was used.

3. INTEGRATED APPLICATION OF REMOTE SENSING AND GIS FOR GROUNDWATER POTENTIAL ZONE IDENTIFICATION

3.1. Introduction

Remote Sensing and GIS are playing a rapidly increasing role in the field of hydrogeology for water resource developments by providing multi-spectral, multi-temporal and multi-sensor data of the earth's surface. One of the greatest advantages of using remote sensing data for hydrogeological investigation and monitoring is its ability to generate information in spatial and temporal domain, which is crucial for successful analysis, prediction and validation (Saraf, 1999).

The present study has attempted to apply integrated remote sensing and GIS for generating new thematic data layers as well existing data for delineating potential groundwater zone in Northern Adaa plain (Modjo Catchment). The eight thematic layers taken for the determination of potential groundwater were drainage density, slope steepness, land cover/use, soil, rainfall, distance from lineaments, geomorphology and lithology.

Prior to integration of the data sets, individual class weights and map scores were assessed based on Satty's Analytic Hierarchy Process (AHP) (Table .1); in this method the relative importance of each individual class with in the same map were compared by each other by pair-wise and eight importance matrices were prepared for assigning weight to each class.

Table 1. The Continuous Rating Scale developed by Saaty (1977).

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	**Very strongly**	**Strongly**	**Moderately**	**Equally**	**Moderately**	**Strongly**	**Very strongly**	**Extremely**

Less Important **More Important**

3.2 Factors Controlling Groundwater Occurrence in The Study Area

Factors that have significant influence in groundwater distribution and occurrence that are used for integration to demarcate potential groundwater zones are disused below:

3.2.1 Drainage density

The drainage system of any area always plays an important role in various ways. They reflect the lithology and structure of a given area.

The drainage network of the study area was digitized on screen using 1:50000 topographic maps (Fig.3.1). During digitization magnifying glass was used for magnification of blued and closely spaced contours. For each drainage line order was assigned in the attribute table. The major rivers present in the study area are Wedecha, Tiliku Modjo and Modjo river (Plate1). Both Wedecha and Tiliku Modjo are tributaries for Modjo river. Modjo River is considered to be the principal drainage system of the study area.

Plate 1. Modjo river the principal drainage system, southern part.

All the small river and large rivers, which are found in the study area drain from north to south following the topographic drops.

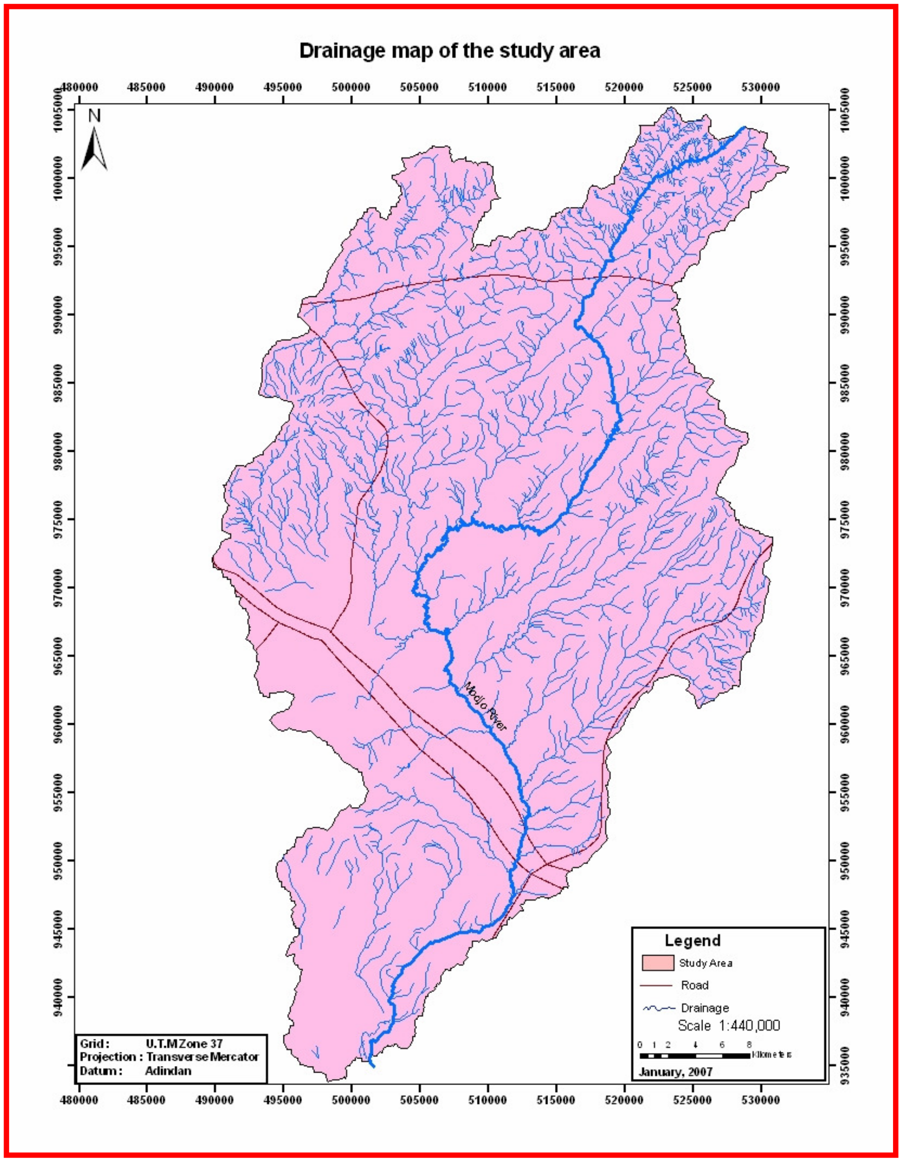

Figure 3.1 Drainage map digitized from topographic sheets.

Comparison of the drainage system of the area and structure has shown that the drainage system of the area is structurally controlled following lineaments directions (Fig.3.2). In the study area dendritic and parallel drainage pattern are recognized, which are indicative of the presence of structures that act as conduits or storage for sub-surface water. Structurally controlled drainage patterns are observed in NE part of the study area.

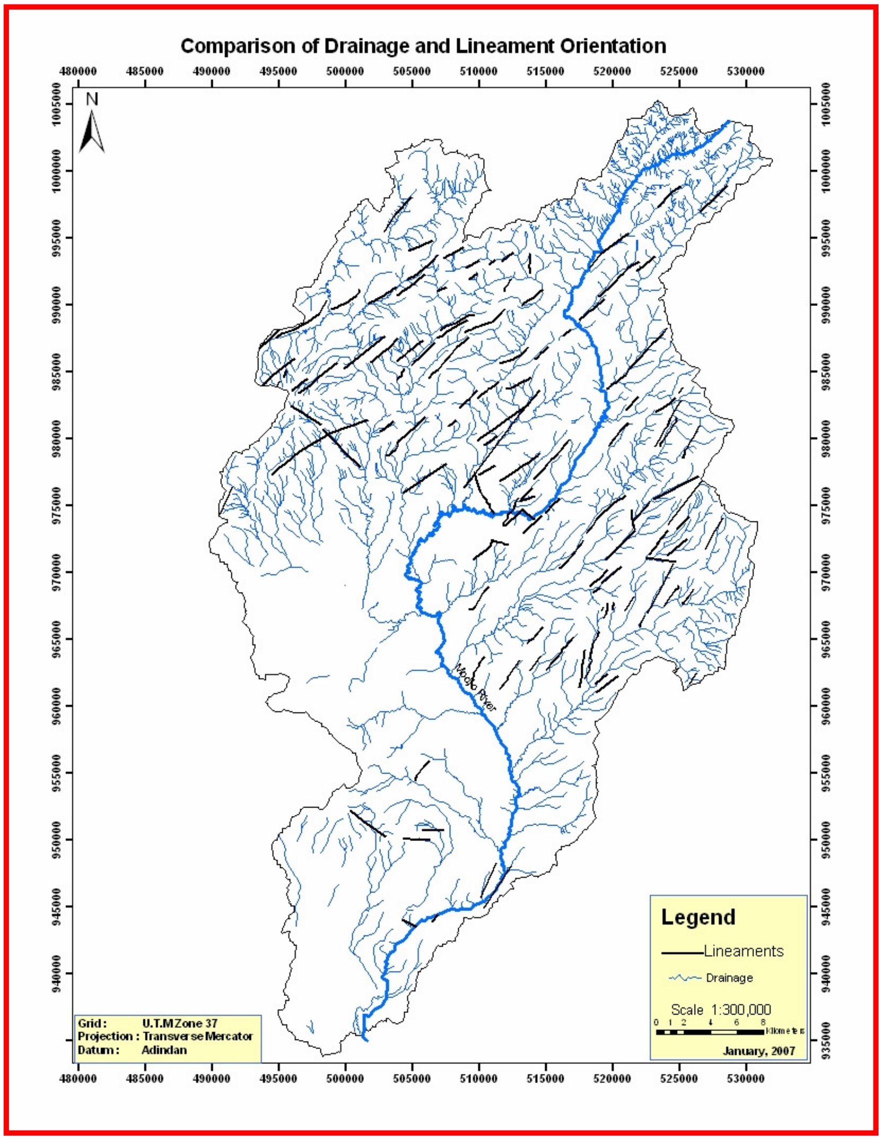

Figure 3.2 Comparison of drainage and lineament orientation

The drainage density was calculated directly in Arcmap using spatial analyst extension. In the study area, mainly 4 drainage density categories have been identified and mapped as shown in (Fig.3.3). Very high drainage density is found in the northern part of the study area whereas high drainage density is found in eastern, western and central parts. Moderate and low drainage density concentrate in the southern and central part of the study area. Structurally controlled drainage is normally seen in northern part of the study area. Drainage texture and patterns are controlled by different litho-units, structure and morphology. In the northern part of the area drainage pattern is sub-dendritic to sub-parallel.

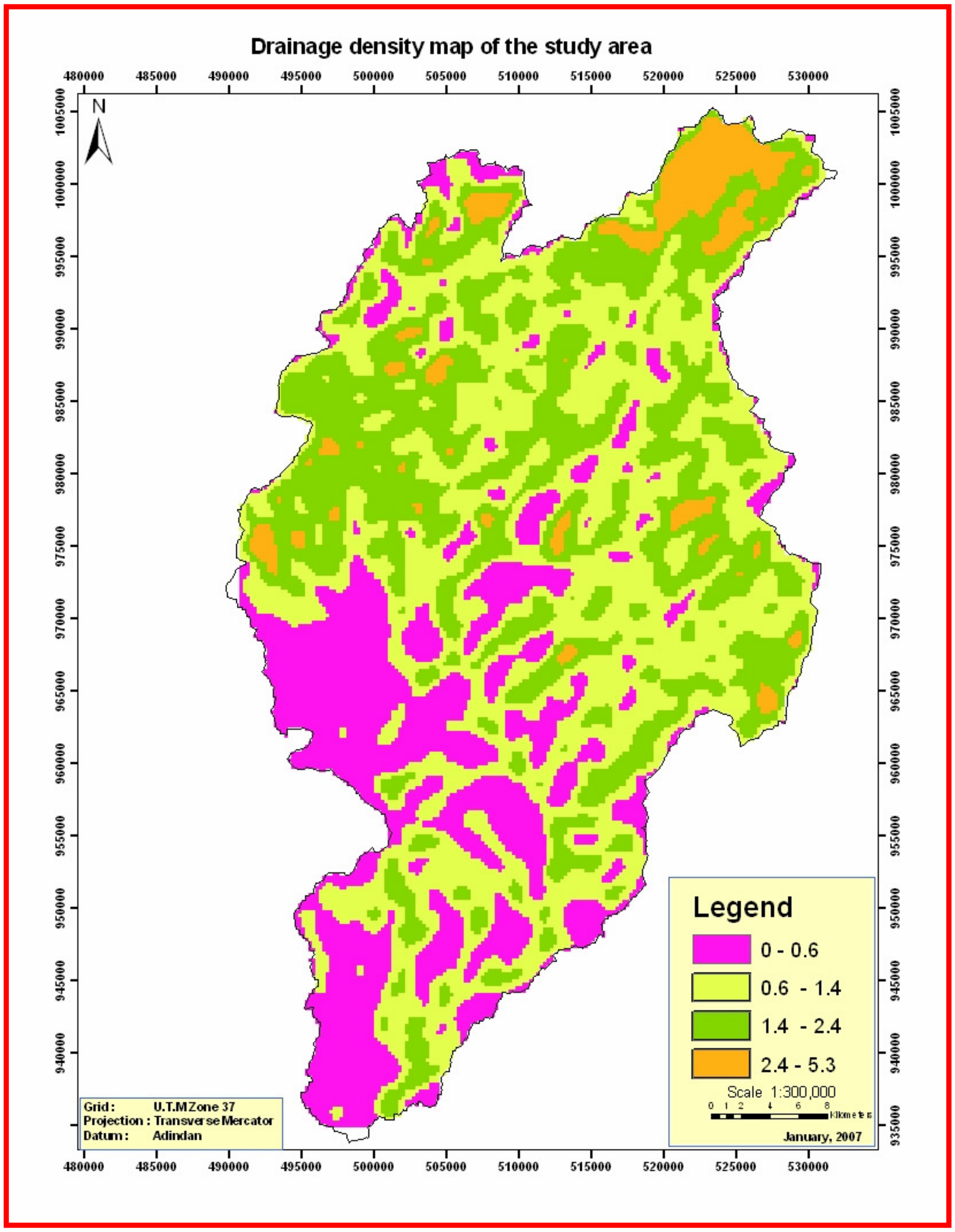

Figure 3.3 Drainage density map of the study area.

With respect to groundwater occurrences the higher drainage density is related to less infiltration of water to the ground, which in turn leads to higher run off and vice versa. The pair-wise comparison done based on this fact has shown that for areas with low drainage density higher weight was calculated (Table 2) and vice versa and the reclassified map of drainage density (Fig.3.4) was produced based on these weight.

Table 2. Weight for drainage density map of the study area

(Km/Km^2)	Very High	High	Moderate	Low	Weight	Weight * 100
Low	1				0.5232	52
Moderate	1/3	1			0.2976	30
High	1/7	1/3	1		0.1222	12
Very High	1/9	1/7	1/3	1	0.0570	6

Consistency ratio = 0.03

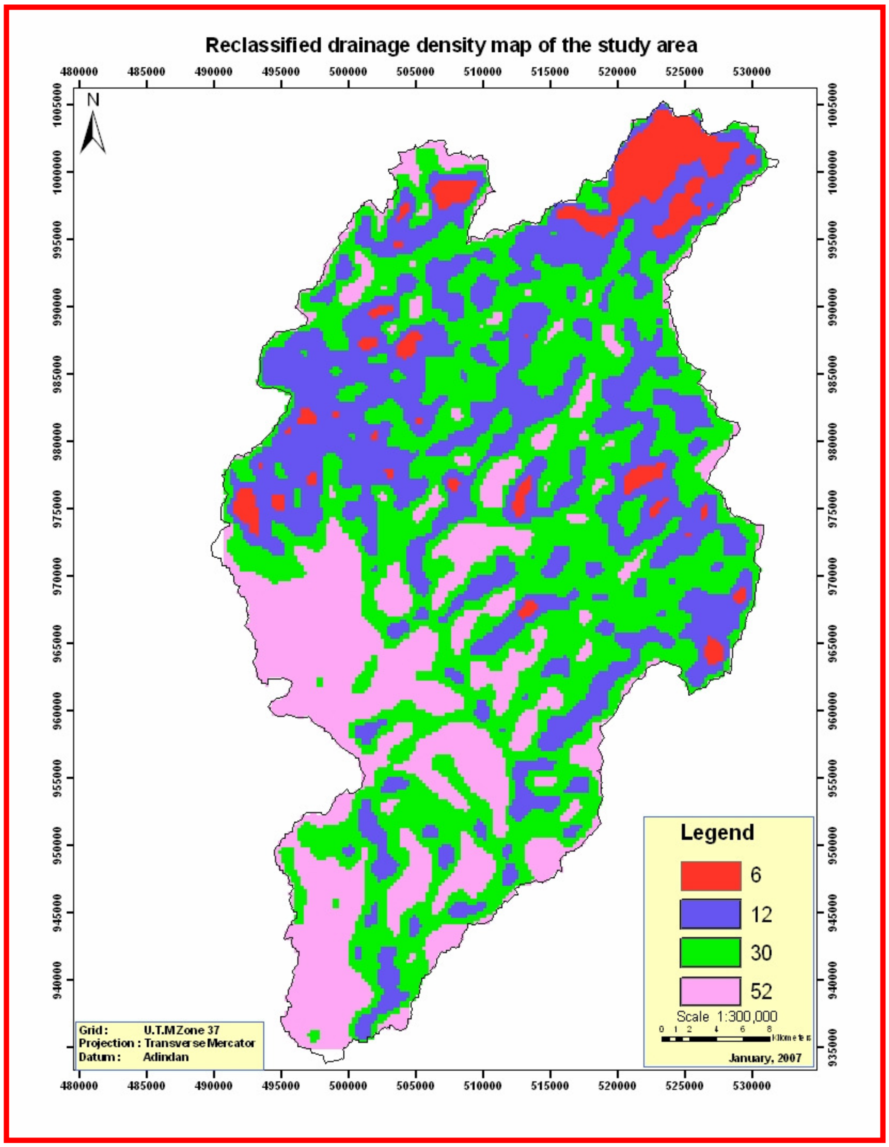

Figure 3.4 Reclassified drainage density map.

3.2.2 Slope Steepness

Slope Analysis

As the terrain slope plays an important role in characterizing the nature of the terrain, landforms and hydrological conditions, the slope amount map has been prepared using contours digitized from topographic maps. In relation to groundwater flat areas where the slope amount is low are capable of holding rainfall, which in turn facilitates recharge whereas in elevated areas where the slope amount is high, there will be high run-off and low infiltration. The slope amount map has then been taken as one of the inputs in GIS analysis for delineating the prospective groundwater zones and method of producing the slope amount map is described below

Method

Steps followed to prepare the slope amount of the study area are described below:

I. Digitization of contours and spot heights from georeferenced toposheets having scale 1: 50000 in separate layers.
II. Defining the heights in the attribute tables of the concerned layers.
III. Creation of Triangulated Irregular Network (TIN) model from the digitized contours and spot heights (Fig 3.5a).
IV. Derivation of Slope Amount from the TIN model using Arcmap Spatial Analysis and reclassification in to appropriate classes.

The slope amount derived from digitized contours and spot heights have shown that elevation decreases from the northern part to the southern part with slope 0º to 70º in flat and mountainous areas respectively (Table3.)

Table 3. Slope amount class in the study area

Slope Class	***Slope in Degree***
1	**(0-2)**
2	**(2-6)**
3	**(6-13)**
4	**(13-25)**
5	**(25-70)**

The Kontora mountain located in the western part has an elevation which ranges from 2900 m.a.s.l to 2400 m.a.s.l with slopes from 25º to 70º. The southern part is characterized by flat topography with a range of 2000 m.a.s.l to 1600 m.a.s.l elevation with 0º to 6º. Generally the area has high elevation in the north and low elevation in the south, which can as well be confirmed by the drainage system flow direction. The slope amount map classified in to five classes (Fig 3.5b) has been prepared.

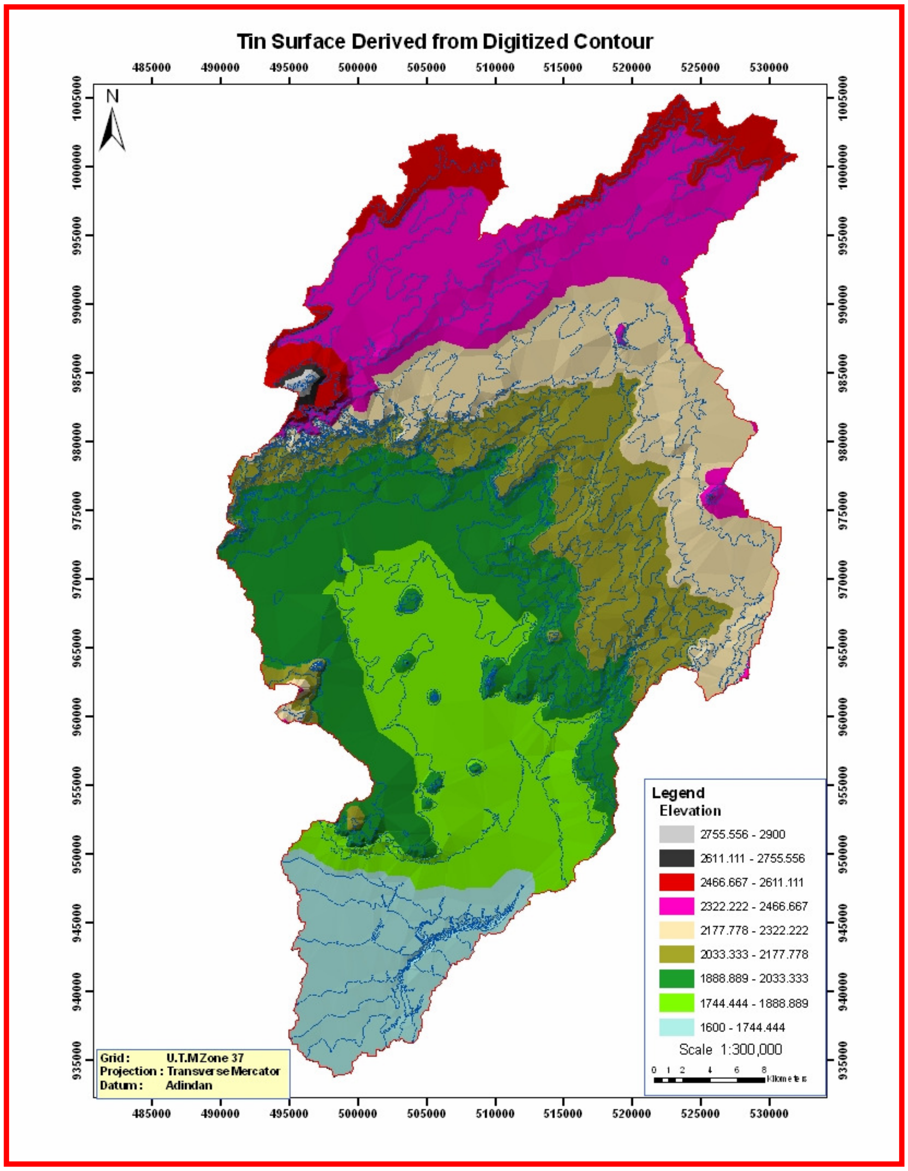

Figure 3.5a. Tin Surface derived from digitized contours.

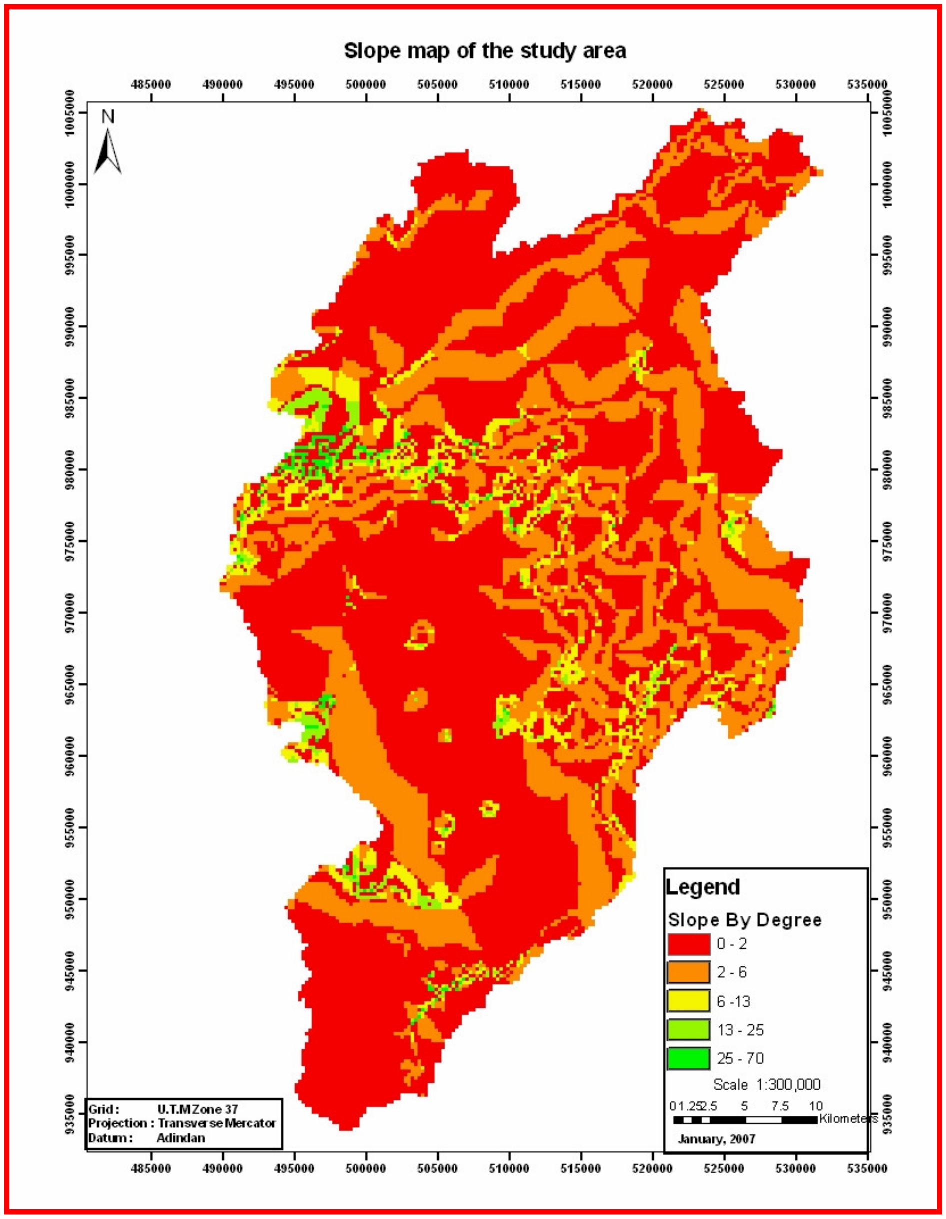

Figure 3.5b. Slope amount classes of the study area

Pair-wise comparison done and the weight calculated (Table 4) for slope angle was based on the fact that the flatter the topography (low slope angle) is the better are the chances for groundwater accumulation. The reclassified map was produced based on the weight calculated (Fig. 3.6).

Table 4. Weight for slope map of the study area.

	Flat	Gentle	Moderate	Steep	Very Steep	Weight	Weight * 100
Flat	1					0.4978	50
Gentle	1/3	1				0.2680	27
Moderate	1/4	1/3	1			0.1362	14
Steep	1/7	1/5	1/3	1		0.0642	6
Very Steep	1/9	1/7	1/5	1/3	1	0.0337	3

Consistency ratio = 0.05

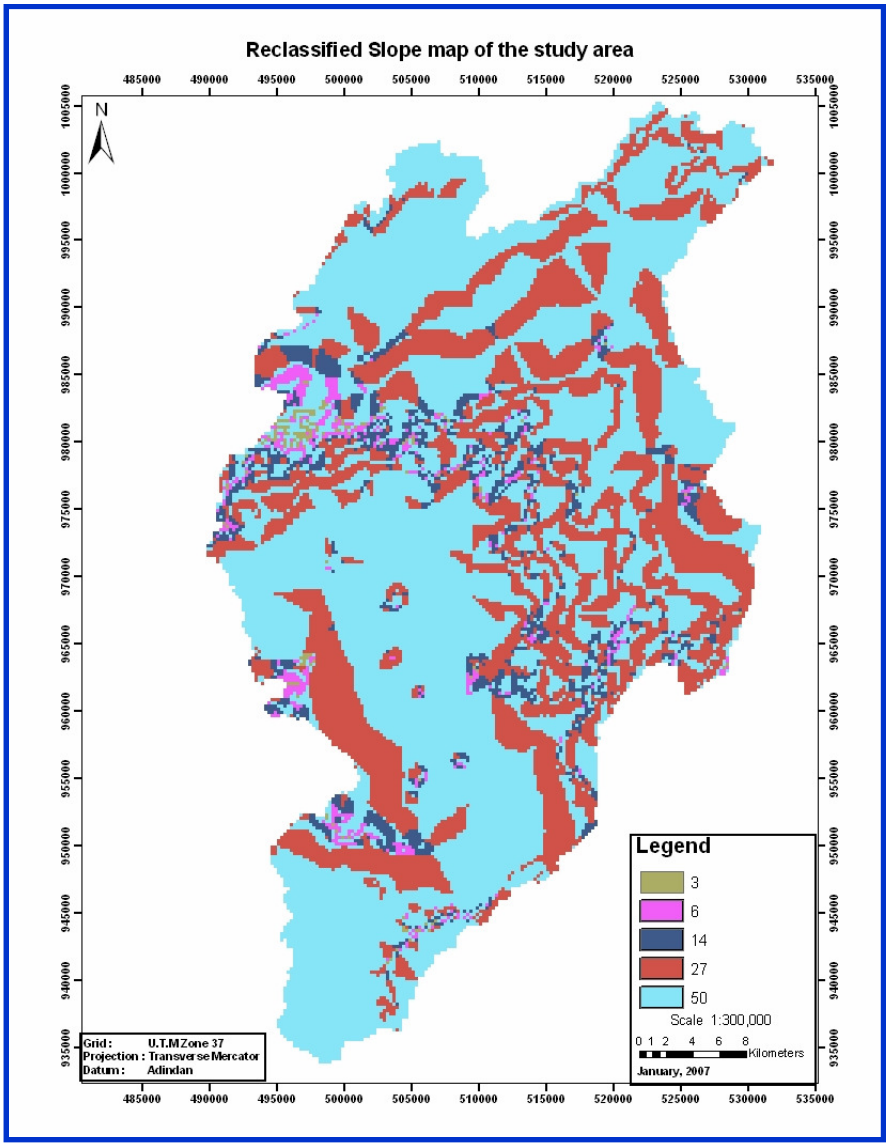

Figure 3.6 Reclassified slope map.

3.2.3 Soil Map

Soil map was prepared from soil database of FAO, 1997 (The digital Soil And Database of East Africa) in arcview shape file format, the study area soil map was clipped and seven soil types were identified (Fig.3.7): vertic cambisols, euric vertisols, luvic phaeozems, chromic luvisols, lithic leptosols, mollic Andosols, eutric fluvisols and haplic luvisols. Description of soils was made based on FAO/UNESCO " World reference base for soil resources 2006, A framework for international classification, correlation and communication".

Soil properties influence the relationship between runoff and rainfall since soils have differing rates of infiltration. Permeability and infiltration are the principal factors required to classify into hydrologic groups (Ethiopin Road Authority , Drainage Design Manual ,2002). Classification of soil types in relation to groundwater was done based on data on texture of soils obtained from (FAO, THE DIGITAL SOIL AND TERRAIN DATABASE OF EAST AFRICA (SEA), 1997) (Fig. 3.8, Table 5, Table 6).

Soil types in the study area are described as follows:

Leptosols

Leptosols are very shallow soils over continuous rock and are extremely gravelly and/or stony with various kinds of continuous rock or of unconsolidated materials with less than 20 percent (by volume) fine earth. Leptosols have a resource potential for wet-season grazing and as forest land. Erosion is the greatest threat to Leptosol areas, particularly in mountain regions in the temperate zones where high population pressure (tourism), overexploitation and increasing environmental pollution lead to deterioration of forests and threaten large areas of vulnerable Leptosols. Steep slopes with shallow and stony soils can be transformed into cultivable land through terracing, the removal of stones by hand and their use as terrace fronts. The excessive internal drainage and the shallowness of many Leptosols can cause drought even in a humid environment.

Andosols

Andosols accommodate the soils that develop in volcanic ejecta or glasses under almost any climate (except under hyperarid climate conditions). However, Andosols may also develop in other silicate-rich materials under acid weathering in humid and perhumid climates. They are typically black soils of volcanic landscapes parent material, volcanic glasses and ejecta (mainly ash, but also tuff, pumice, cinders and others) or other silicate-rich material. Andosols are easy to cultivate and have good rootability and water storage properties. Strongly hydrated Andosols are difficult to till because of their low bearing capacity and their stickiness.

Phaeozems

Phaeozems accommodate soils of relatively wet grassland and forest regions in moderately continental climates. They have dark, humus rich surface horizon and are porous, fertile soils that make excellent farmland. Phaeozems are in use for the production of soybean and wheat and other small grains. Phaeozems in the temperate belt are planted with wheat, barley and vegetables alongside other crops. Vast areas of Phaeozems are used for cattle rearing and fattening on improved pastures. Wind and water erosion are serious hazards to these soil types.

Fluvisols

Fluvisols accommodate genetically young, azonal soils in alluvial deposits. They develop in alluvial plains, river fans, valleys and tidal marshes on all continents and in all climate zones; many Fluvisols under natural conditions are flooded periodically. A dry period also stimulates microbial activity and promotes mineralization of organic matter. Many dry land crops are grown on fluvisols as well, normally with some form of water control.

Luvisols

Luvisols are soils that have a higher clay content in the subsoil than in the topsoil as a result of processes (especially clay migration) leading to an argic subsoil horizon. Luvisols have high-activity clays throughout the argic horizon and a high base saturation at certain depths.

Pedogenetic differentiation (especially clay migration) of clay content with a lower content in the topsoil and a higher content in the subsoil without marked leaching of base cations or advanced weathering of high-activity clays. Most Luvisols are fertile soils and suitable for a wide range of agricultural uses.

Cambisols

Cambisols combine soils with at least an incipient subsurface soil formation. Transformation of parent material is evident from structure formation and mostly brownish discoloration, increasing clay percentage, and/or carbonate removal. They are soils with at least the beginnings of horizon differentiation in the subsoil evident from changes in structure, color, clay content or carbonate content. Cambisols are characterized by slight or moderate weathering of parent material and by the absence of appreciable quantities of illuviated clay, organic matter. Cambisols with groundwater influence in alluvial plains are highly productive paddy soils.

Vertisols

Vertisols are churning, heavy clay soils with a high proportion of swelling clays. These soils form deep wide cracks from the surface downward when they dry out, which happens in most of the years. The name Vertisols (from Latin vertere, to turn) refers to sediments that contain a high proportion of swelling clays, or products of rock weathering that have the characteristics of swelling clays. Their physical soil characteristics and, notably, their difficult water management cause problems. Buildings and other structures on Vertisols are at risk. The vertical root system of cotton can resist damage by cracking of vertisol but tree crops cannot resist the cracking. The heavy soil texture and domination of expanding clay minerals result in a narrow soil moisture range between moisture stress and water excess. Excess water in the rainy season must be stored for post-rainy season (water harvesting) on Vertisols with very slow infiltration rates.

Weight calculated for each soil unit was done by the pair-wise comparison of each soil group by taking their clay content, which was explained in FAO, THE DIGITAL SOIL AND TERRAIN DATABASE OF EAST AFRICA (SEA), 1997. (Fig. 3.8, Table 5, Table 6). The reclassified map was produced based on the weight calculated (fig.3.9).

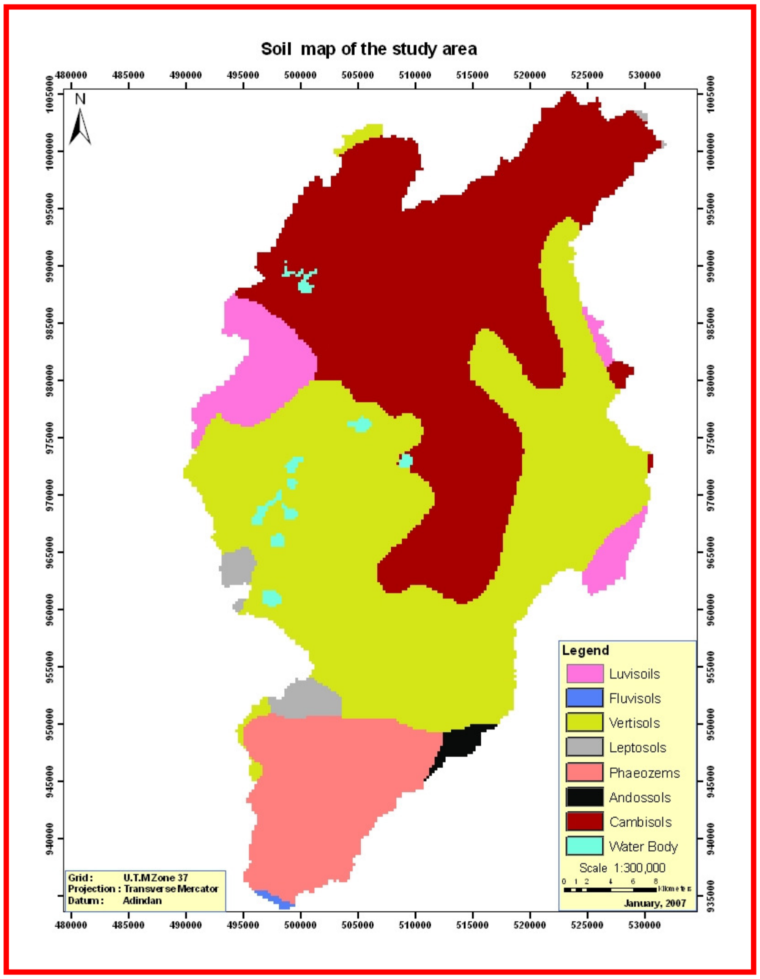

Figure 3.7 Soil map of the study area

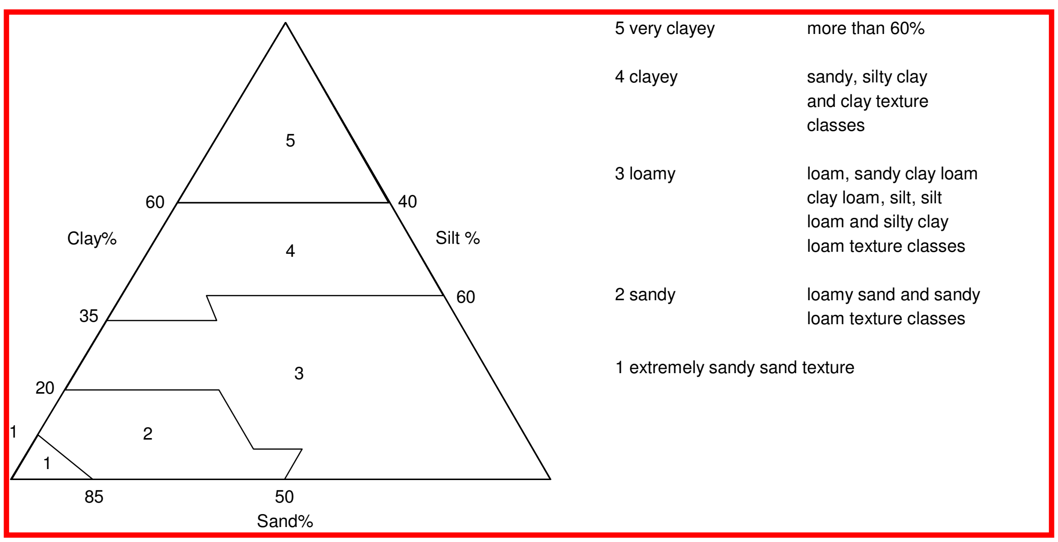

Figure 3.8 Texture class of soil based on sand , silt and clay content (THE DIGITAL SOIL AND TERRAIN DATABASE OF EAST AFRICA (SEA), 1997).

Table 5. Texture class of soils (THE DIGITAL SOIL AND TERRAIN DATABASE OF EASTAFRICA (SEA), 1997)

Code	Texture
1	Extremely sandy
2	sandy
3	loamy
4	Clayey
5	Very clayey

Table 6. Soil type in order of increasing permeability

No.	Soil Type	Code
1	Leptosols	3
2	Andosols	3
3	Phaeozems	4
4	Fluvisols	4
5	Luvisols	4
6	Cambisols	5
7	Vertisols	5

Increasing Permeability

Table 7.Weight for soil map of the study area

	Lake /WaterBody	Leptosols	Andosols	Phaeozems	Fluvisols	Luvisols	Cambisols	Vertisols	Weight	Weight * 100
Lake /WaterBody	**1**								0.3632	36
Leptosols	**1/3**	**1**							0.2371	24
Andosols	**1/4**	**1/3**	**1**						0.1533	15
Phaeozems	**1/5**	**1/4**	**1/3**	**1**					0.0985	10
Fluvisols	**1/7**	**1/5**	**1/4**	**1/3**	**1**				0.0631	6
Luvisols	**1/7**	**1/7**	**1/5**	**1/4**	**1/3**	**1**			0.0405	4
Cambisols	**1/8**	**1/7**	**1/7**	**1/5**	**1/4**	**1/3**	**1**		0.0264	3
Vertisols	**1/9**	**1/8**	**1/7**	**1/7**	**1/5**	**1/4**	**1/3**	**1**	0.0178	2

Consistency ratio = 0.09

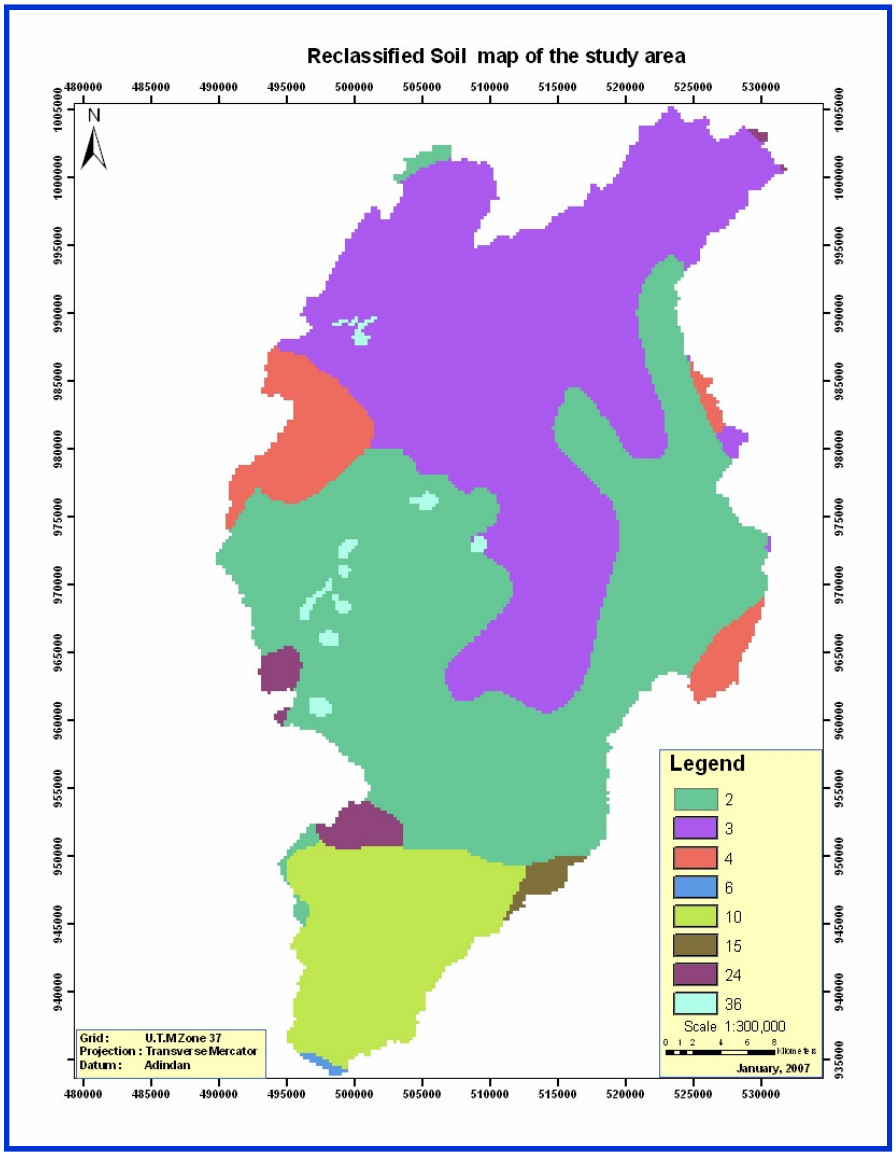

Figure 3.9 Reclassified soil map.

3.2.4 Land Use/Land Cover

Introduction

One of the parameters that influence the occurrence of sub-surface groundwater occurrence is the present condition of land cover and land use of the area. The effect of land use / cover is manifested either by reducing runoff and facilitating, or by trapping water on their leaf. Water droplets trapped in this way go down to recharge groundwater. Land use/cover may also affect groundwater negatively by evapotranspiration, assuming interception to be constant.

Land Use/Land Cover Mapping

The land use/cover map of the area was readily interpreted from Landsat image by using visual interpretation, unsupervised classification, supervised classification and print outs of band 453,432 543 in RGB combination.

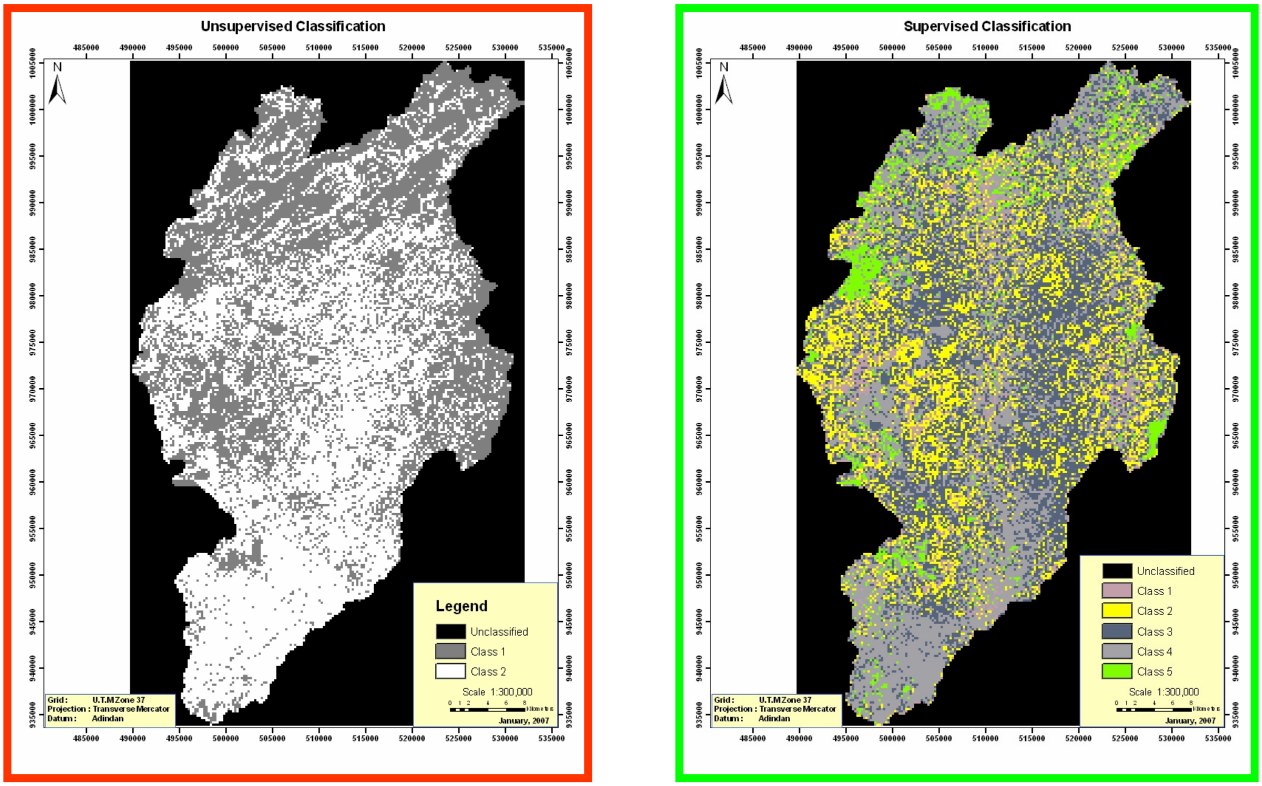

Figure 3.10 Study area images of year 2000 G. C., unsupervised classification (left) and supervised classification (right).

For identification of vegetation cover band ration of band 4 to band 3 was done. After detailed analysis the result was compared and corrected by data collected from different locations of the area. Comparison of Landsat image and topographic map of year 1975 has shown that there is remarkable expansion of settlements since 1974, which negatively affect the groundwater recharge of the area. The Yerer mountain that is located west of the study area is covered by dense forest, it is protected by local administration, the largest portion of the area located in the central part is agricultural land.

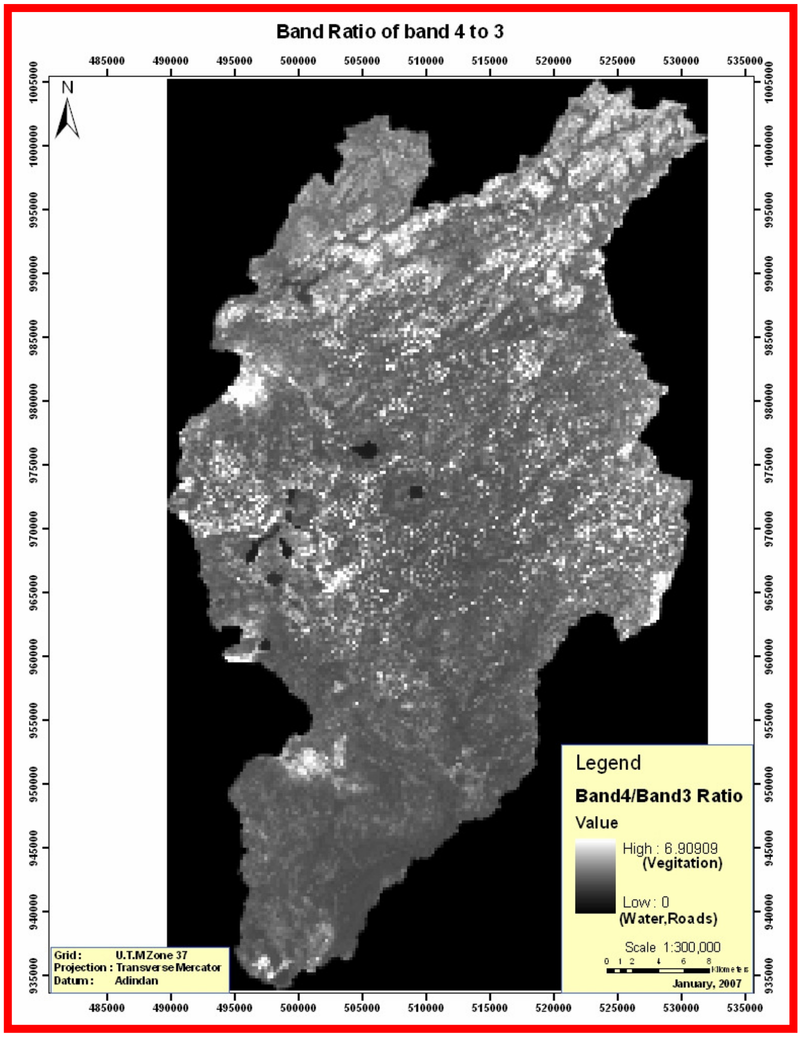

Figure 3.11 Study area images of year 2000 G. C., band ratio of Band4/Band3.

The original vegetation is more preserved in the elevated areas than the flat areas, especially in the stream valleys and foot of elevated areas where there is seepage of water or shallow groundwater. This is due to the fact that people had made the natural forest to disappear on the flat lands in order to grow Teff, one of the most important crops in central areas. Moreover, there are discouraging situations in which deforestation is still going on through improper utilization of the forest: clearing or cutting of the vegetation for trading and for new farmland, especially in the new resettlement areas. Flat and marshy areas are covered by elephant grasses and short trees, whereas big trees and mixed forest cover the riverbanks and stream valleys. The results of the various land use/land cover of the study area is given in (Fig 3.12).

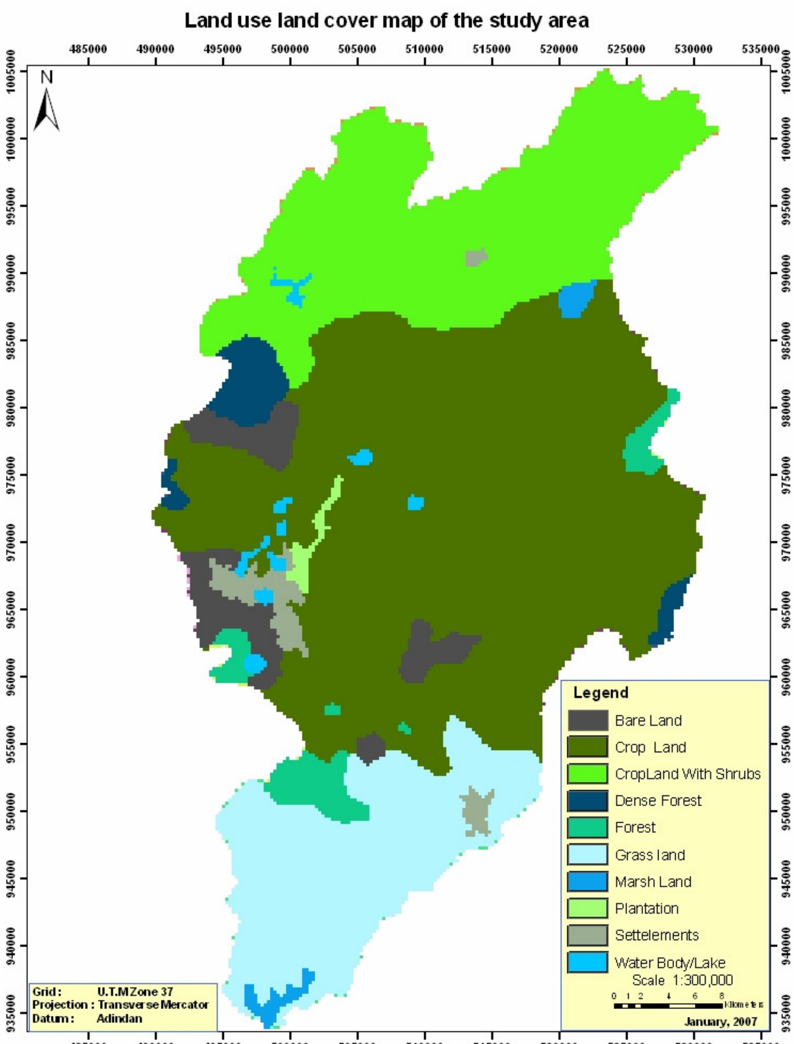

Figure 3.12 Land use land cover map of the study area.

The areal extents of various land use/land cover categories mapped in the area are given in Table 8. It is evident from this table that the cropland takes largest share of the area. It covers an area of 859,168,826 sq.m out of the total area of 1,725,476,175 sq.m.

Classification of land use/cover for analysis was done based on their character to infiltrate water in to the ground and to hold water on the ground. Generally settlements are found to be the least suitable for infiltration and after pair-wise comparison of each class weight for each class was calculated (Table 9). Reclassified map was produced based on the weight calculated (Fig. 3.13).

Table 8. Areal extent of various Land use/Land cover categories

ID	Land Use/Land cover	*Area (Sq.m)*
1	Bare land,	72931863
2	Crop Land	859168826
3	Crop land With Shrubs,	391647335
4	Dense forest,	37765623
5	Forest	45737008
6	Grass land,	254445324
7	Marsh Land,	13170623
8	Plantation,	7980797
9	Settlements,	28201049
10	Water body/Lake	14427722
	Total	1,725,476,175

Table 9. Weight for land use land cover map of the study area.

	Water body/Lake	**Marsh Land**	**Planta tion**	**Open Forest**	**Dense Forest**	**Crope Land**	**Crop Land With Shrubs**	**Grass Land**	**Bare Land**	**Settle ments**	**Weight**	**Weight * 100**
Water body/Lake	1										0.2286	23
Marsh Land	0.9	1									0.2089	21
Planta tion	1/2	0.9	1								0.1929	19
Dense Forest	1/3	1/3	0.9	1							0.1328	12
Open Forest	1/4	¼	1/5	0.9	1						0.0879	9
Crop Land With Shrubs	1/5	1/5	1/6	1/5	0.9	1					0.0575	6
Crope Land	1/6	1/6	1/7	1/6	1/5	0.9	1				0.0376	4
Grass Land	1/7	1/7	1/8	1/7	1/6	1/5	0.9	1			0.0247	2
Bare Land	1/8	1/8	1/8	1/8	1/7	1/6	1/5	0.9	1		0.0161	2
Settle ments	1/9	1/9	1/9	1/8	1/8	1/7	1/6	1/5	0.9	1	0.0131	1

Consistency ratio = 0.08

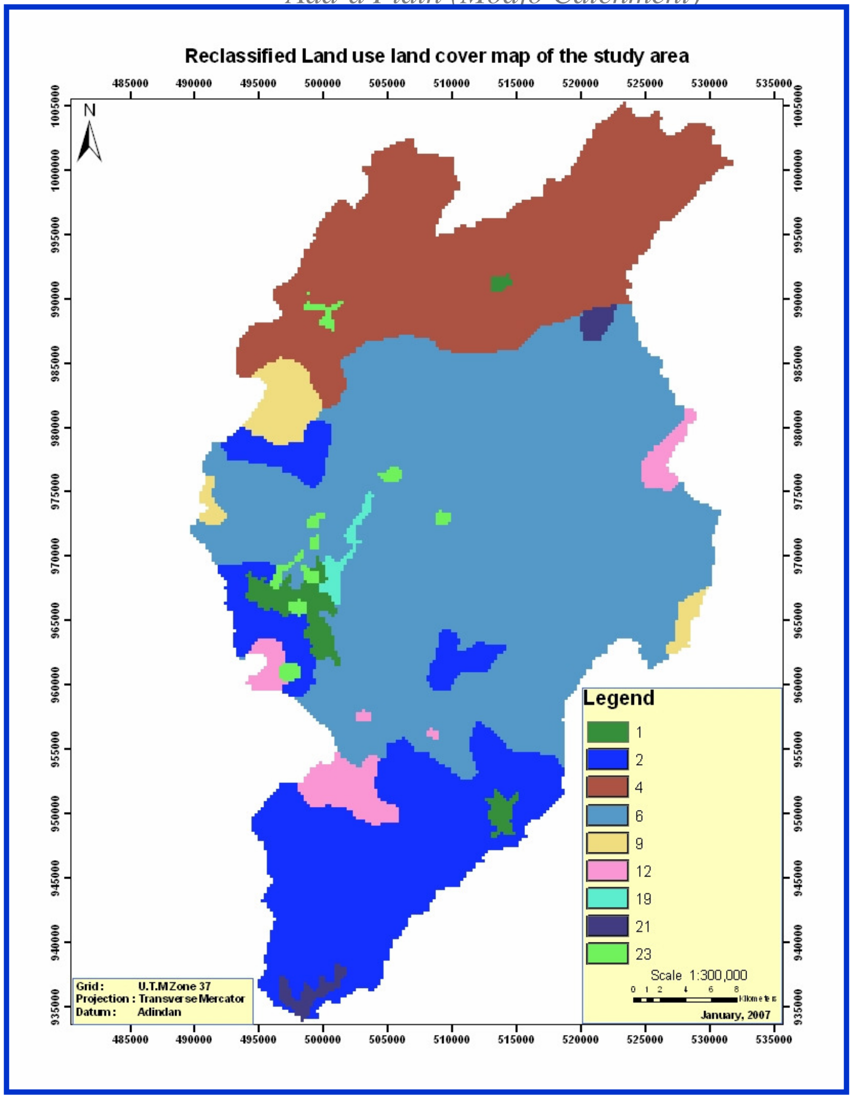

Figure 3.13 Reclassified land use land cover map.

3.2.5 Annual Rain Fall

Rainfall is one of the primary sources of groundwater and is expressed as the depth of precipitated water in inches, measured by rain gauge for selected periods of time. The period desired depends upon the interest of investigator. Intensity of rainfall is less important to groundwater. The relation ship of rainfall to groundwater occurrence is modified by factors like topography, vegetation and surface geology; all these factors affect the quantity of water that gets underground. All the water that precipitated may be absorbed in a flat sand dune area. With respect to different surface condition which affect the amount of water that goes to the ground, annual rainfall should be taken in order to average the amount of water that percolates in to the ground regardless of surface condition. In general the high rainfall amounts imply the possibility of high groundwater potential zone.

For analysis of rainfall effect in groundwater occurrences, two data sources, one from National Meteorological Service (10 years record from the year 1989-2002 of three stations that are located in Debre Zeit, Modjo and Nazreth and the other from Woody Biomass in arc view shape file was obtained. Due to uneven distribution of the stations in the study area both data were used and were interpolated with output grid cell size of 150 m using IDW techniques. After interpolation the project area raster map was clipped, classified and the final rainfall map was produced (Fig 3.14).

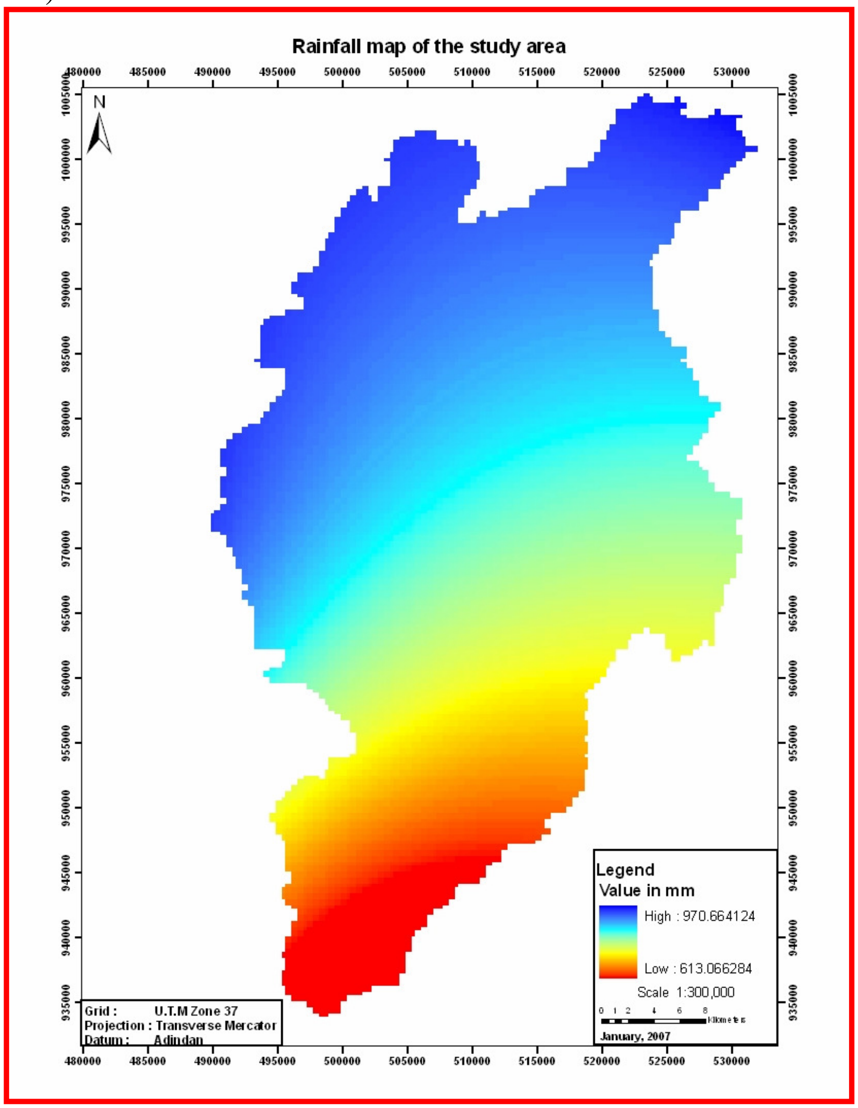

Figure 3.14 Average rainfall map of the study area

Generally it has been observed that high amount of rainfall is related to high occurrence of groundwater and based on this fact pair-wise comparison was done and weight was calculated accordingly (Table10). Reclassified map of rainfall was then produced based on calculated weight.

Table 10. Weight for annual rain fall map of the study area

.	High	Moderate	Low	Weight	Weight *100
High	1			0.6694	67
Moderate	1/3	1		0.2426	24
Low	1/7	1/3	1	0.0879	9

Consistency ratio = 0.01

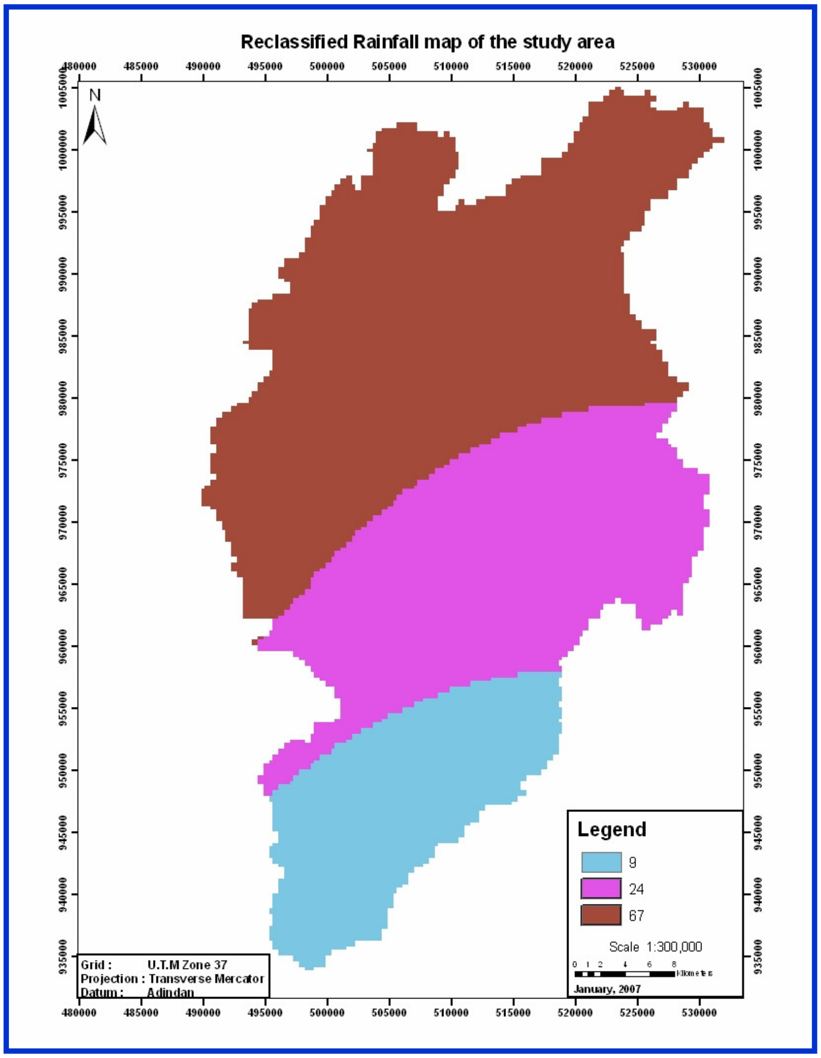

Figure 3.15 Reclassified rainfall map.

3.2.6 Lineaments

Lineaments are linear features caused by the linear alignment of regional morphological features such as streams, escarpments, and mountain ranges, and tonal features that in many areas are the surface expressions of fractures or fault zones (Lillesand, T.M., and Kiefer, R.W., 1994). Lineament analysis of remote sensing data constitutes an important part of studies related to tectonics, engineering, geomorphology and in the exploration of natural resources such as groundwater, petroleum and minerals (e.g. Koopmans 1986, Kar 1994, and Philip 1996).

Mapping of lineaments from various remote sensing imagery is a commonly used step in groundwater exploration. In relation to groundwater exploration, since lineaments are the results of faults and fractures they infer that they are the zone of increased porosity and permeability, which in turn has greater significance in groundwater studies occurrence and distribution.

Structural features can be interpreted from satellite imagery. In such imagery they are identified on the basis of break of slope, truncation of terraces knick points, abrupt change in stream course, lithology, vegetation, texture, drainage density etc.

Mapping of lineaments in the study was done by visual interpretation of various digitally enhanced single band (Fig.3.16a) and multi band images that involves standard band combinations, principal component analysis and directional filtering.

The lineaments were identified by visual interpretation and interactive digitization (Fig.3.16c) in the images. A final lineaments map was constructed from the digital enhancement of individual single band and multiband images together with ground truth and previous work. An attempt was made to avoid linear features that do not correspond to geological structures eg. roads and crop fields by using ground data.

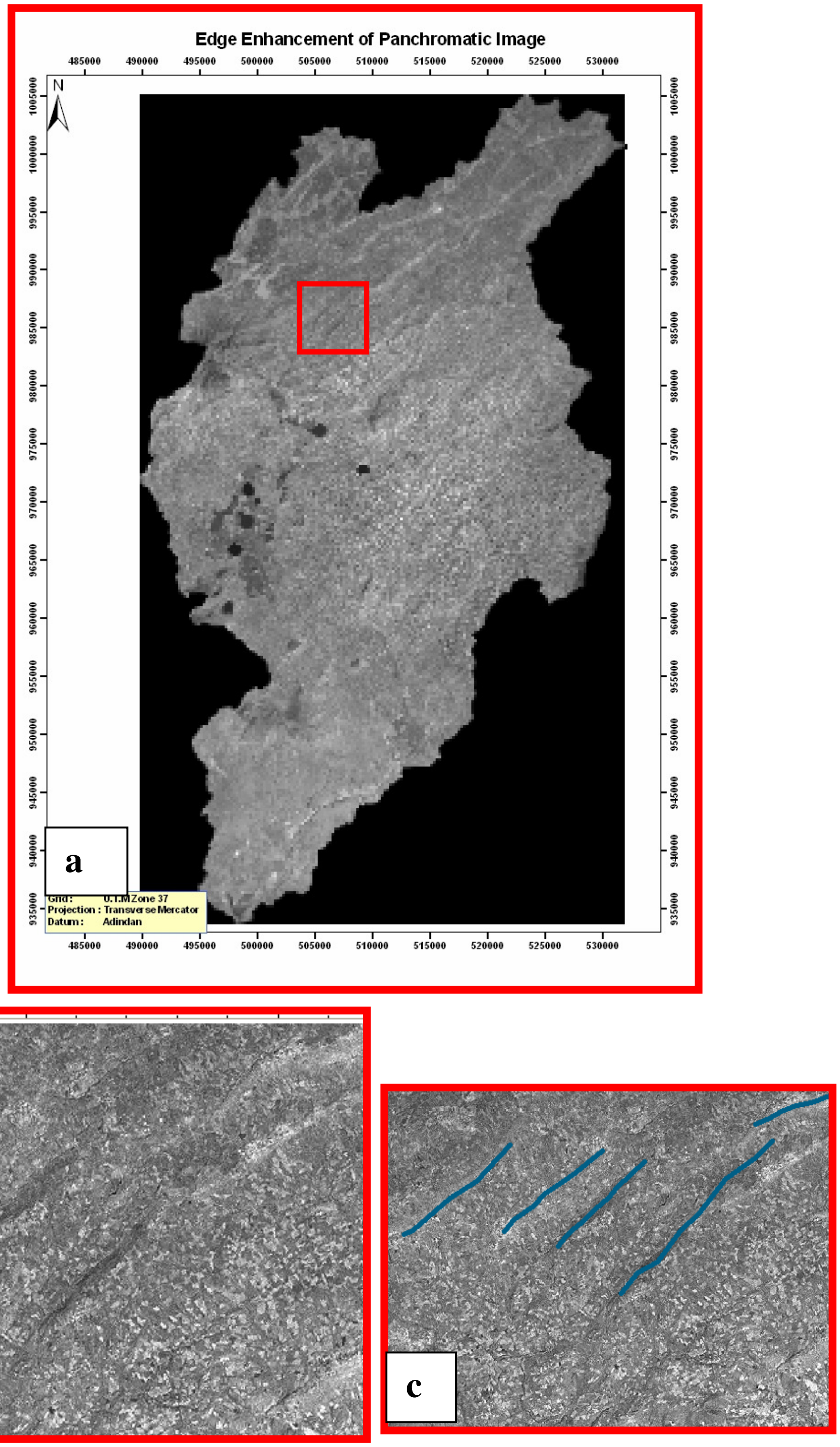

Figure 3.16 Edge Enhancement of Panchromatic image (a), magnified lineaments (b) digitized lineaments (c).

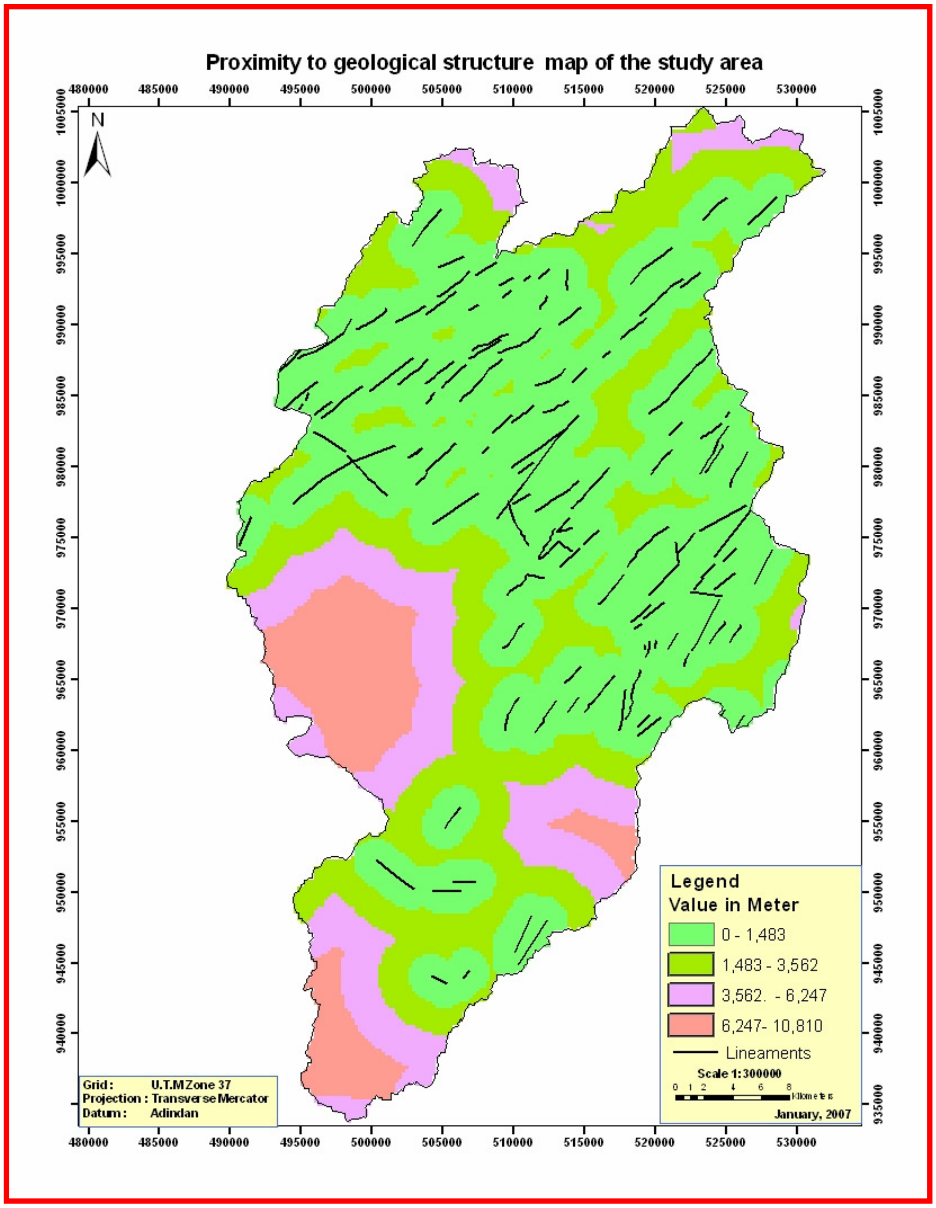

Figure 3.17 Proximity to geological structure map.

For analysis of lineaments in relation to groundwater prospective zones, distance analyses were carried out and 4 classes were produced (Fig 3.117). Reclassified map of lineament (Fig.3.18) was then produced based on the weight calculated (Table 11) after a pair-wise comparison done based on the fact that areas closer to lineaments are the highest zone of increased porosity and permeability which in tern have greater chance of accumulating groundwater.

Table 11. Weight for proximity to geological structures map.

Distance	Very Close	Close	Far	Very Far	Weight	Weight * 100
Very Close	1				0.5812	58
Close	1/3	1			0.2599	26
Far	1/6	1/3	1		0.1195	12
Very Far	1/9	1/7	1/5	1	0.0394	4

Consistency ratio = 0.07

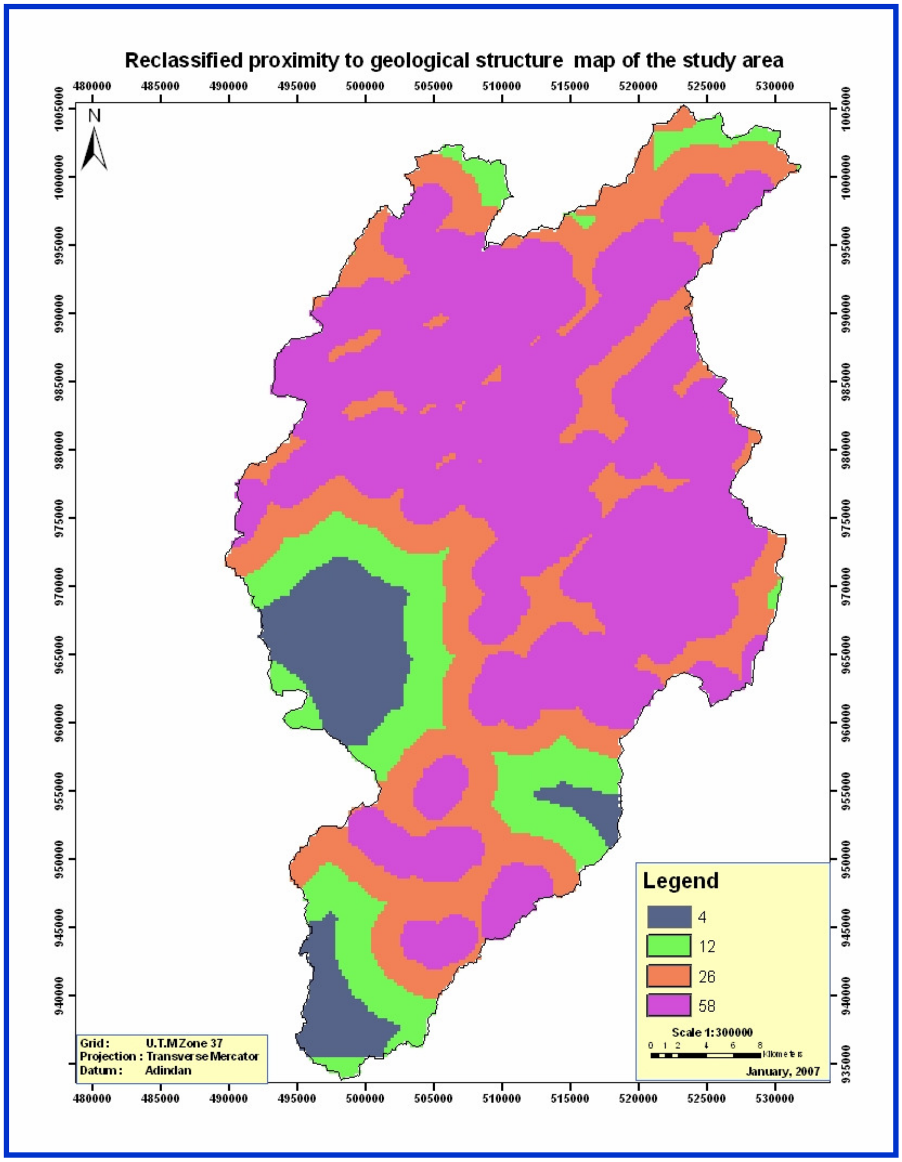

Figure 3.18 Reclassified proximity to geological structure map

3.2.7 Geomorphology

Landforms are the most common features encountered by any one engaged in geological field works. If they are properly interpreted they throw light upon the geologic history, structure and lithology of a region (William D, Thornbury 1986). For the evaluation of groundwater resources, a geomorphological terrain classification leading to the delineation of hydromorphological is useful, taking both morphological and lithological factors in to consideration (Verstappen, 1983). DEM and SRTM data allow creating a detailed description of landforms that is useful for groundwater potential assessment (Semere, 2003).

In groundwater exploration geomorphology plays an important role in identification of favorable zone for groundwater. More promising groundwater is in flood plains, alluvial fans and valley fills that are associated with thick alluvial and weathered materials to give high porosity and permeability. Pediments generally are not favorable for groundwater potential zones (Verstappen, 1983).

To classify topographic regions into landform types DEM generated from digitized contour and spot heights, SRTM V-3 data and Landsat imagery was used. Draping of Landsat imagery on SRTM has made it possible to visualize elevated geomorphic units (Fig.3.19). Field checking of geomorphic features was also done for final mapping and five geomorphic units were mapped (Erosional Hills, Upper Plateaus, Middle Plateaus, Lower Plateaus, Mesa hills and Plain) (Fig 3.20).

Geomorphic units, which are classified as Erosional Hills, are observed in the east and western part of the area. In the western part volcanic complex of Bede Gebaba is elongated NNE with a quasi-circular shape and maximum relief of 400m above the surrounding topography. The volcanic unit exposed in the northwestern part of the area, which is represented by Yerer volcanic, occurs occupying a series of NE-SW aligned ridges and domes within 1000m differences from the plain.

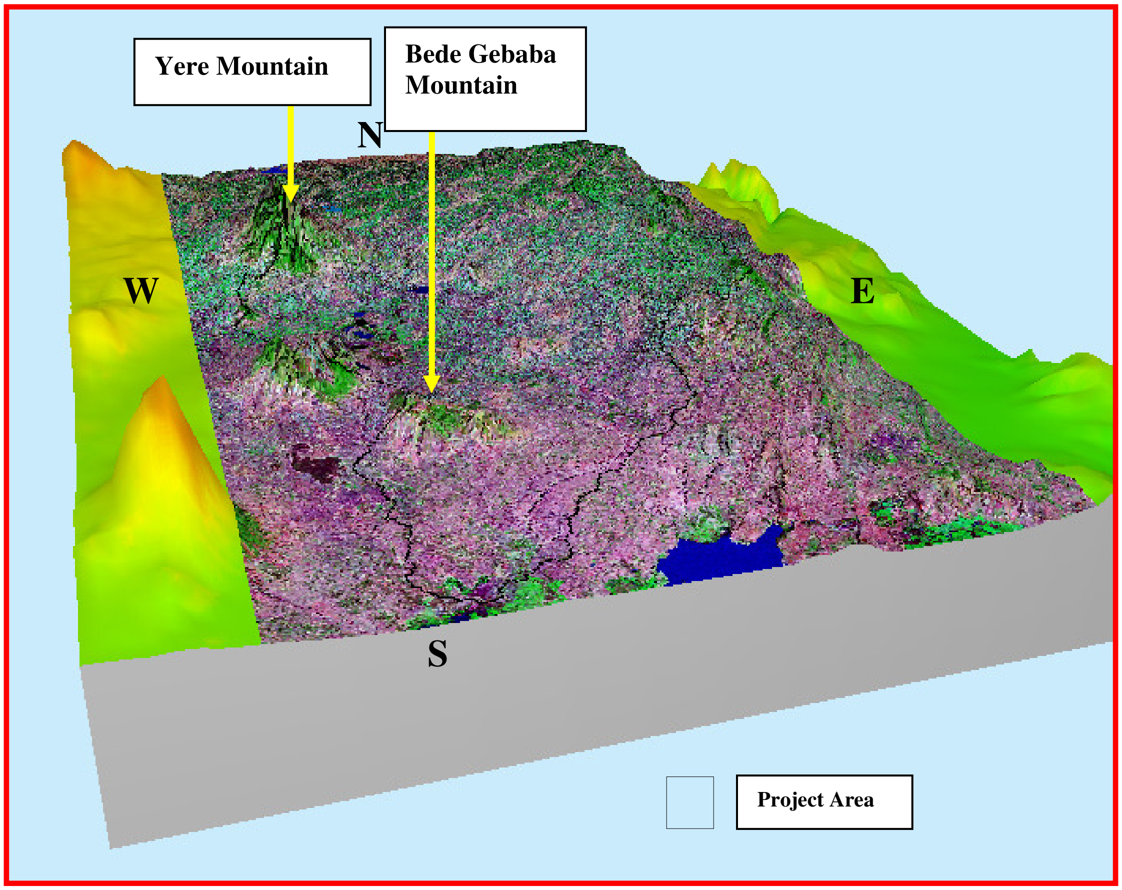

Figure 3.19 Landsat imagery draped over SRTM data

The Mesa Hills are geomorphic units, which are flat at the top bordered by steep sided escarpment on all sides; they are extensively exposed in the central part of the study area forming NNE trending belt in the rift axis complex of volcanic that represent the most recent basic lava flow.

The geomorphic units Upper Plateau, Middle Plateau and Lower Plateau are geomorphic units, which are elevated, and flat with considerable length, are exposed in the upper, middle and lower part of the study area respectively. The Upper Plateau and the Middle Plateau are similar volcanic rocks composed of welded to poorly welded rhyolitic ignimbrites, sub-horizontal to slightly tilted basalt, and fall deposits that are affected by NE-SW trending lineaments. Despite similarity in structure and composition of the Upper Plateau and the Middle Plateau classification of these geomorphic units was done based on their height difference that the Upper Plateau are more elevated than Middle Plateau. The Lower Plateau is mainly composed of fine-grained deposits, generally brown-yellowish, thinly stratified and often contain abundant volcanic matrix.

Plain geomorphic unit presents in the western part of the study area where debris and sediments eroded from elevated area are deposited (Plate 2). Most of agricultural activities are exercised in this geomorphic area due to its favorability for ploughing and moisture content.

Plate 2. Partial view of Ada'a plain geomorphic unit .

Weight calculated for geomorphic units was done according to the landform type. Lower Plateau and plains were considered best targets of groundwater occurrence through facilitating recharge and as a circulation of water by way of interflow at shallow depth, above the groundwater level (Verstappen, 1983). The pair-wise comparison done based on this fact is shown in (Table 12). It can be seen that the highest value 24 and 15 were calculated for lower plateau and plain respectively. In contrast for Erosional Hills and Mesa Hills 2 and 4 were calculated respectively, as they are poor geomorphic units for groundwater accumulation (Table 12). Reclassified map shown in figure 3.21 was produced based on the weight calculated.

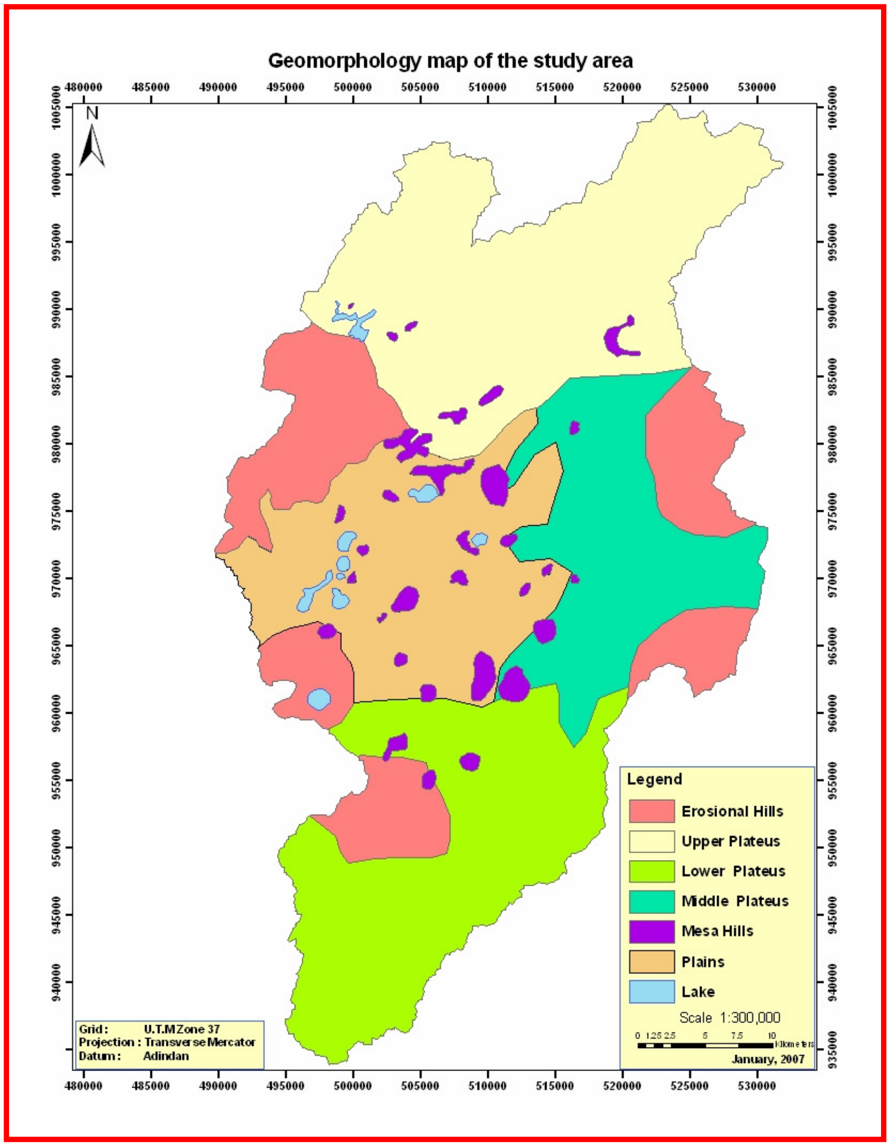

Figure 3.20 Geomorphology map of the study area.

Table 12. Weight for geomorphology of the study area.

	Lake	Lower Platue	Plains	Middle Platue	Upper Platue	Mesa Hills	Erosional Hills	Weight	Weight * 100
Lake	1							0.3683	37
Lower Platue	1/2	1						0.2422	24
Plains	1/3	1/2	1					0.1543	15
Middle Platue	1/4	1/3	1/2	1				0.1005	10
Upper Platue	1/5	1/4	1/3	1/2	1			0.0655	7
Mesa Hills	1/8	1/5	1/4	1/3	1/2	1		0.0415	4
Erosional Hills	1/9	1/8	1/5	1/4	1/3	1/2	1	0.0277	2

Consistency ratio = 0.02

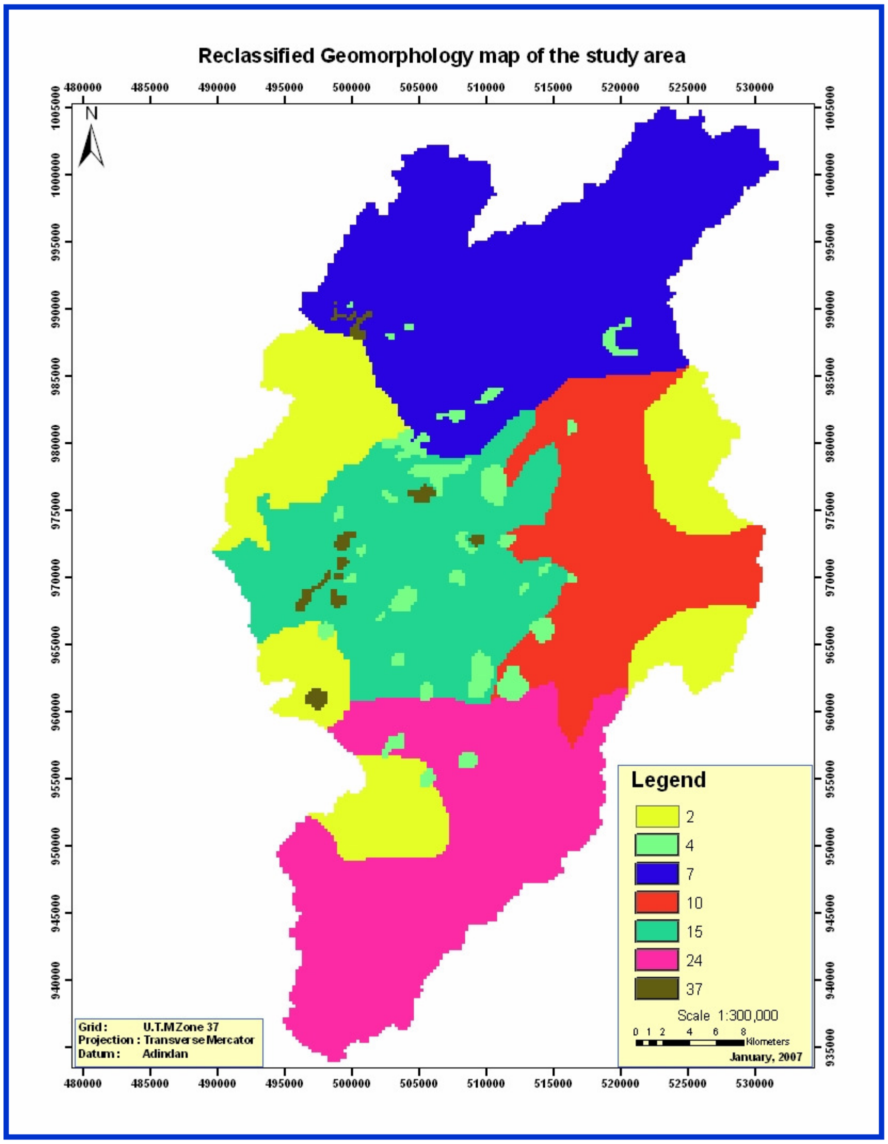

Figure 3.21 Reclassified geomorphology map.

3.2.8 Geology

It is well understood that geology plays an important role in the distribution and occurrence of groundwater (Krihnamurthy and Srinivas, 1995). In the present study geological mapping was done using previous data from different studies as well as field verification. The study area is underlain by a variety of volcanic and sedimentary rocks that exhibit ages ranging from Miocene to present. The volcanic lithologies occupy the vast portion of the study area. Sedimentary rocks and deposits cover the remaining portion of the area.

The stratigraphic sequence of rocks in the study area, Modjo river catchments, established based on geological mapping that allow the recognition of nine volcanic units that were grouped into four volcanic complexes. These complexes define three main structural sectors: the western rift margin, the main rift floor and intra-rift depression, respectively (F.Mazzarini et al.,1999). Stratigraphic relationships between the recognized units have been further constrained by isotopic and geochemical investigation conducted by various researchers (example Cherenet et al., 1999). This study also confirmed these stratigraphic sequence described by F.Mazzarini et al., (1999).

Volcanic rocks of the area include Addis Ababa ignimbrite, central volcano, Nazret unit, Tulu Rie basalt unit, Chefe Donsa unit, Bishoftu volcanic unit and Bede Gababa Volcanic Unit (BGV). Lacustrin deposit and alluvial cover also exposed in the study area (fig. 3.22) These rock units are described in the following section and names used by Abebe et al., (1999) is adopted to describe the lithologies exposed in the study area.

Addis Ababa Ignimbrite (AAI)

This unit is exposed in north western part of the study area and make up the minor portion of the volcanic rocks. It occurs along the foot of eastern escarpment of the Main Ethiopian Rift (MER). It is found resting on Addis Ababa basalt. This unit comprises different flow units, consisting of pale green to pale-yellow welded and crystal rich ignimbrite. K-Ar age dating conducted on samples from this unit has given an age ranging from 5 to 3.3Ma (Cherenet et al.,1999). This unit is moderately to strongly welded, characterized by well developed vertical joins and fractures which provide for high to moderate permeability (Adane, 1999).

Central volcano

Central volcano unit is represented by Yerer volcanic unit within the western rift margin complex and found in the northern part of the study area. It occurs occupying a series of NE-SW aligned ridges and domes within the largest Yerer volcanic edifies with relief of 1000m difference from the plain. This volcanic edifies is 14km wide along E-W direction. Rock samples taken from this unit were dated by K-Ar method and gave an age of 3.9 to 3.3Ma (Cherenet et al.,1999).

The Yerer volcanic unit mainly comprises lava flow with subordinate pyroclastic deposit in the central and eastern sectors. Porhritic trachyte is the main lava flow constituting this unit. It is composed of plagioclase, anorthoclase, oliven and clino-pyroxene phenocryst set in ground mass made up of alkali-feldspars, pyroxene and Fe- and Ti- oxides. The ground mass exhibits trachytic texture. To the top it consists recent spatter cones and associated basaltic lava. Due to their massive nature they have low permiabilty (Adane, 1999).

Nazret units

The Nazret unit is widely present in the north-eastern and eastern parts of the study area. The units are affected by the NE-SW trending lineaments, it consists sequence of welded rhyolitic ignimbrites, with four flow units that have thicknesses varying from 5 to 15 m. Also, the unit comprises numerous rhyolitic (Adadi, Ruketi, and Aminos) and trachytic domes (Gara Bokan, Dikub). The age of Nazret unit is between 9.5 and 3Ma (Kazmin and Berhe.,1978).

This unit is a basal unit grouped under the intra rift complex and may constitute the upper part of Nazret Group of (Kazmin and Berhe.,1978) with respect to age constraints. Fresh ignimbrite along the banks and floor of the Modjo River is interbedded with lacustrine deposit. Each ignimbrite layer has an average thickness of about 2 meters. This unit includes various welded and often jointed columnar ignimbrites. Basically, two types of ignimbrites have been identified: the slightly welded ignimbrite (top) and intermediately welded ignimbrite (bottom), separated by paleosoil and lacustrine deposits. Welded ignimbrite with well developed vertical joint and fracture provide high to moderate permeability (Adane, 1999).

Tulu Rie Basalt (TRB)

Tulu Rie basalt is present in the eastern and northern section of the study area. It consists sub-horizontal to slightly tilted basalt that belongs to the intra rift complex. It covers the Nazeret unit and forms the upper part of NE trending escarpments. The maximum observed thickness is 20 m at Tulu Rie Basaltic ridge at the southeastern catchment. They are mainly olivine basalts with rare plagioclase phyric basaltic andesites. The basalts show porphyritic to aphyric texture, and oliven is the main phenocryst mineral phase. The Tulu Rie Basalt was dated at 2.7-1.8Ma and for its stratigraphic position and composition was regarded as part of Bofa basalt of Kazmin and Berhe (1978). This unit when it is massive has low permeability where as with well-developed structural features they are good and productive aquifers (Adane, 1999).

Chefe Donsa Unit (CD)

This map unit is exposed in the south-eastern, eastern and north-eastern parts of the study area and belongs to the intra rift complex. It occurs mainly along the border of the central plain of the study area. Chefe Donsa unit consists of fall deposits and poorly welded ignimbrites of rhyolitic composition. In the southwest, the lacustrin deposit in southeast overlies this unit, while in the eastern and northeastern parts, it overlies Nazret unit and Tulu Rie basalt. Fission track analysis applied to juvenile material (obsidian fragments) from the upper pumice falls in a section close to Chefe Donsa village yielded age of 2.2Ma (Abebe, 1999). Observed thickness of the unit varies from few meters up to 40m close to Chefe Donsa village, where the most complete section is exposed. It consists of four fall deposits each separated by paleosoils of up to one meter thick. In the eastern most section of the study area the Chefe Donsa unit is made up of pyroclastic fall with a thickness of about 12m. Generally this unit has low permeability due to its massive nature (Adane, 1999).

Bede Gababa Volcanic Unit (BGV)

Bede Gababa Volcanic unit is found in the central part of the study area. It is a volcanic complex with a quasi-circular shape, slightly NNE elongated and with a maximum relief of 400m above the surrounding topography. The lacustrine deposit rests above BGV and its morphology is dominated by the occurrence of several coalescent calderic structures (Abebe, 1999).

The central part of Bede Gebaba volcanic unit comprises spatter cone and basaltic lava flow. The most recent products are represented by rhyolitic obsidians for which a radiometric age of 0.36 to 0.07Ma (Leeds University, Leeds) has been estimated. Pumices and lavas show a comparison ranging from rhyolites (Plate 4) to minor trachite. Subaphyric obsidian is common, sometimes are devitrified (Abebe, 1999).

The lavas contain microphenocrysts and the rare phenocrysts of sanadine and quartz as well as scattered plagioclase and clinopyroxene set in glassy to micricrystalline groundmass (Gaspasron et al., 1999). The Bede Gababa unit, due to its composition of ryolites and trachytes, which have massive nature, has very low permeability (Adane,1999).

Plate 3. Massive Ryolite composition of Bede Gebaba volcanic unit

Bishoftu Volcanics (BV)

This unit is found extensively in the central part of the study area forming a NNE trending belt in the rift axis complex. Bishoftu volcanics represent the most recent basic lava flow of the Debrezeit area (Tsegaye Abebe. et al., 1999), which was also reported as the younger volcanics by Grasparon et al (1993).

In the BV there are two groups represented by spatter and cinder cones with associated tabular lavas and phreatomagmatic deposits, respectively. The latter, consisting mainly of pyroclastic surges and highly fragmented deposits associated with maars are chiefly concentrated in the central part of the central section where the highest thickness of the lacustrine sediments frequently intercalated with the phreatomagmatic products. The composition of lavas and juvenile glass ranges from alkali basalts to olivine basalts and trachyandesites. (Abebe, 1999)

Plate 4. Pyroclastic deposit exposed in Erob Gebeya.

Vesicular basalt is found associated with and/or sandwiched between pyroclastic (Plate 4) and lacustrine deposit and covering the volcanic tuff in some parts of the area. It is dark gray in color, vesicular, massive and sometimes scoracious and at places secondary minerals, dominantly zeolites and calcite fill the vesicles. According to (Adane, 1999), this unit has high porosity and permeability due to secondary structures and the interconnection of the pore spaces.

Lacustrine Deposits

The deposits are exposed in NE elongated depression in the central section of the area. Modjo town and the surrounding areas are supposed to have been covered by ancestral lake during the pluvial period of the Quaternary. Lacustrine environment started after the Bede Gebabe volcano unit and continued during the eruptive activity of Bishoftu (Abebe, 1999). The lacustrine sedimentations are the results of deposition in this large ancestral lake (Mohr, 1967 and Abebe, et al., 1999) and they are interbedded with Pliocene-Pleistocene ignimbrite in lakes region and on the rift shoulders in general, and within Modjo and the surrounding areas in particular (Mohr, 1966). These fine-grained deposits are generally brown-yellowish, thinly stratified and often contain abundant volcanic matrix. Their thickness ranges from less than 5 m up to 8 m. In these successions, volcanic layers are frequent and become predominant and coarse grained in the neighboring of the maars. Due to their fine-grained composition and compactness, these deposits have low porosity and permeability (Adane, 1999).

Alluvial Cover

This unit outcrops in NW west part of the study area covering a small portion of the whole area. They consist regolith, red soils, talus and alluvium (Abebe, 1999). Due to their loose nature, alluvial sediments are porous and permeable. Moreover, their grain size constitution varies from coarse to silty and clayey, giving rise to the occurrence of highly yielded unconfined, confined and semi-confined aquifer together with local perched ones (Tamiru, 1992).

The pair-wise comparison of geologic unit was done in terms of their importance with respect to groundwater occurrences by considering their characteristic such as rock type and thickness, fracture density, compactness, the type and degree of cementation etc. The weight 21 was calculated for bishoftu volcano unit due to high porosity and permeability (Table 13) where as weight 2 was calculated for both Bede Gebaba and Central volcano units due to their massive structure, composition and their highest elevation that leads to poor infiltration. The reclassified map produced based on the weight calculated is shown in figure 4.23.

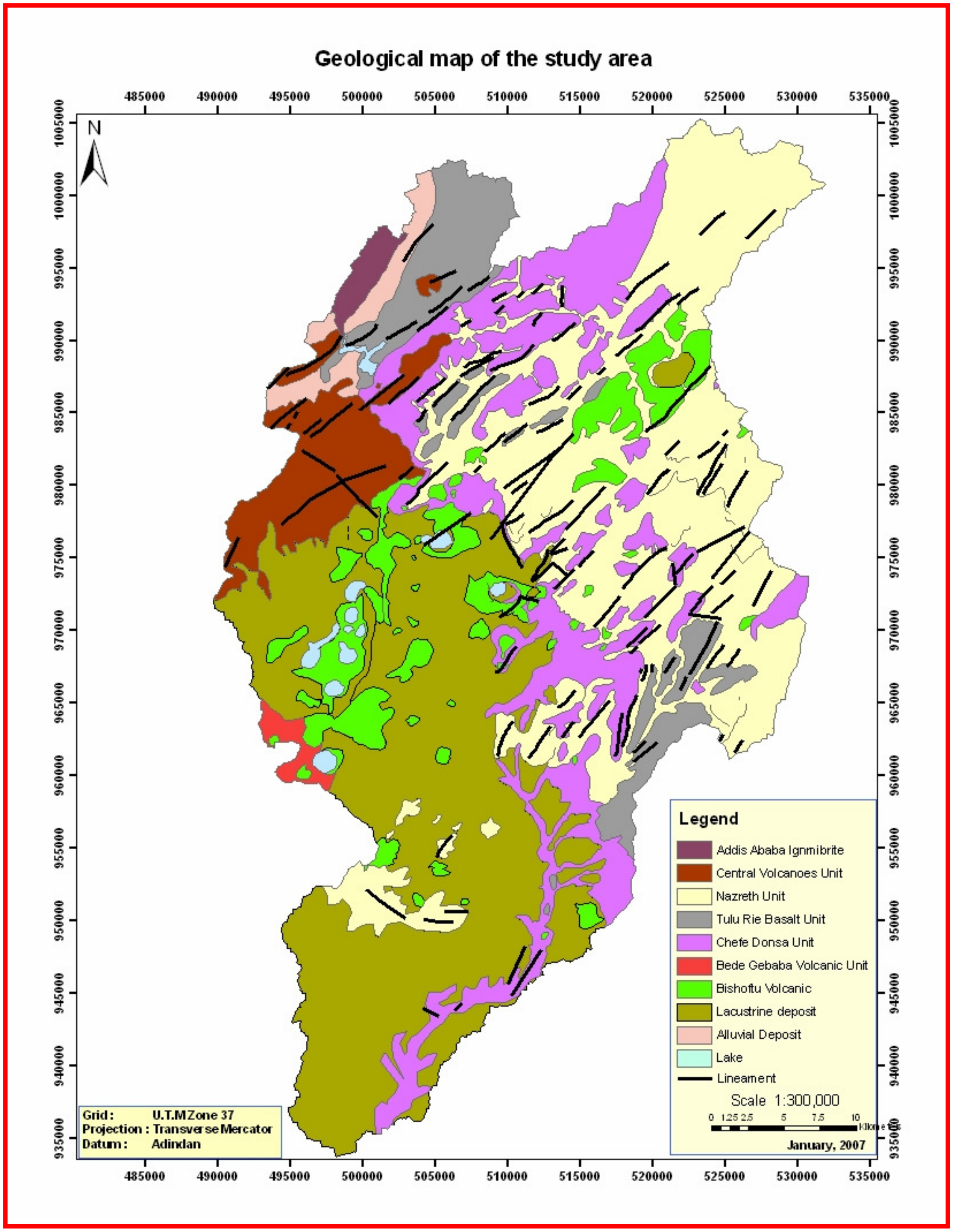

Figure 3.22 Geological map of the study area (Modified After Abebe et.al 1999).

Table 13. Weight for geological map

	Water body/Lake	Bishoftu volcanics	Alluvial cover	Addis Ababa Ignimbrite	Tulu Rie Basalt	Nazret Unit	Chefe Donsa	Lacustrine deposits	Central volcano	Bede Gababa Volcanic	Weight	Weight * 100
Water body/Lake	1										0.2884	29
Bishoftu volcanics	0.3	1									0.2100	21
Alluvial cover	0.28	0.3	1								0.1505	15
Addis Ababa Ignimbrite	0.27	0.28	0.3	1							0.1084	11
Tulu Rie Basalt	1/4	0.27	0.28	0.3	1						0.0785	8
Nazret Unit	1/5	1/4	0.27	0.28	0.3	1					0.0498	5
Chefe Donsa	1/6	1/5	1/4	0.27	0.28	0.8	1				0.0431	4
Lacustrine deposits	1/7	1/6	1/5	1/4	0.27	0.28	0.3	1			0.0295	3
Central volcano	1/8	1/7	1/6	1/5	1/4	0.27	0.28	0.3	1		0.0217	2
Bede Gababa Volcanic	1/9	1/8	1/7	1/6	1/5	1/4	0.27	0.28	0.3	1	0.0152	2

Consistency ratio = 0.09

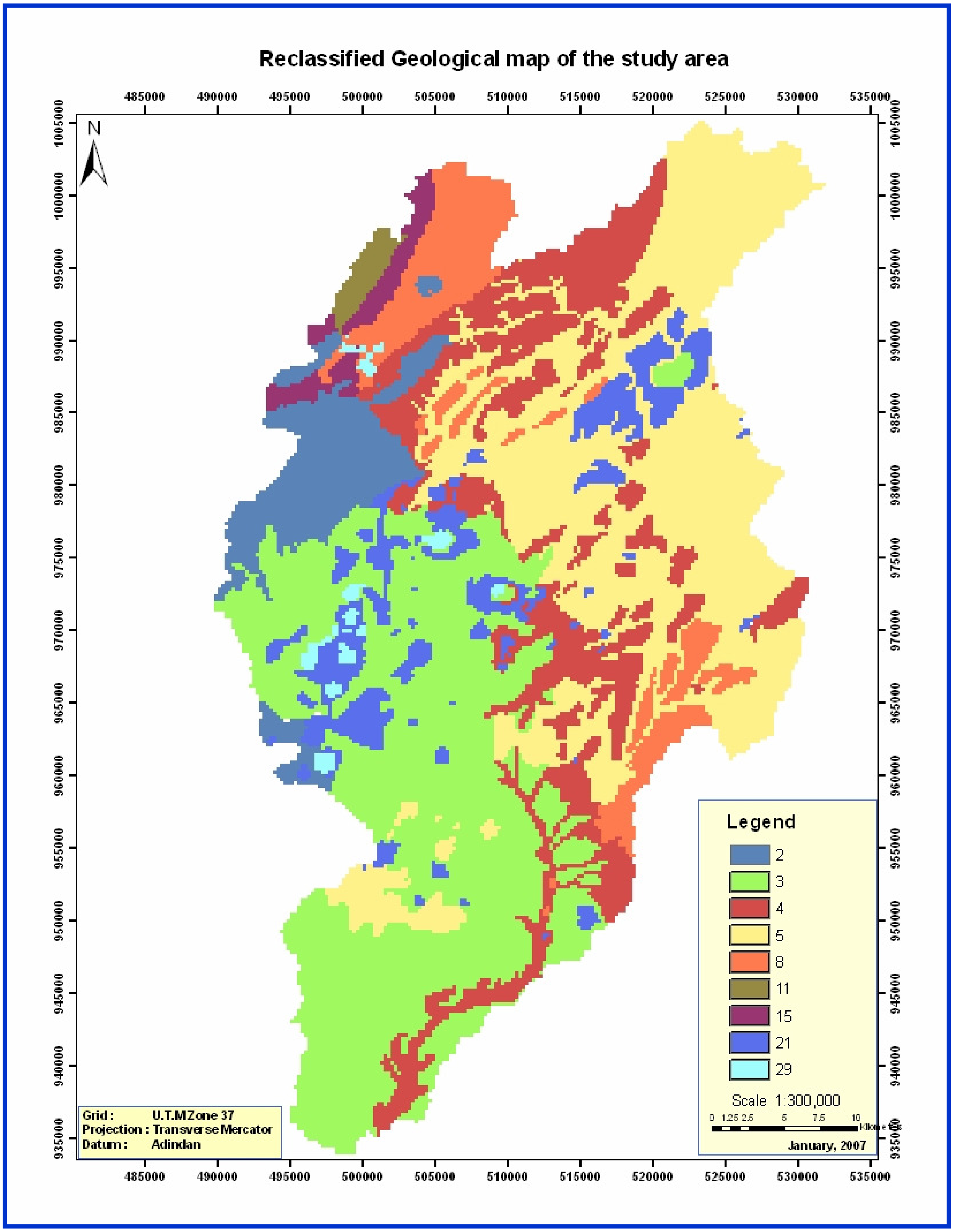

Figure 3.23 Reclassified geological map

4. INTEGRATED ANALYSIS IN GIS ENVIRONMENT

4.1 Introduction

The main objective of the study is to generate groundwater potential zone of the study area based on different thematic maps by considering their relevance to groundwater occurrence. In order to produce the potential groundwater zone map detailed GIS analysis of eight thematic maps was conducted. A groundwater model was constructed using ArgGIS model builder engine (Fig 4.1). Using the model all maps were rasterized, reclassified and given appropriate weight in order to integrate them for multi criteria evaluation (MCE).

The following steps have been followed to produce groundwater potential zone:

I. Selection of data for an input based on their groundwater controlling parameters.

II. Using the model personal geodatabse and feature dataset was prepared and each data set that was produced from previous work, remote sensing imagery, digital elevation model (DEM), topographic maps and field observation were imported into geodatabase to have the same spatial reference.

III. All the data sets were then converted into raster grid in the model in order to perform different GIS analysis between data layers such as overlay analysis.

IV. All the data sets were reclassified based on their importance to groundwater potentiality (availability).

V. Prior to integration of the data sets, individual class weights and map scores were assessed based on Satty's Analytic Hierarchy Process (AHP) (Table 1); in this method the relative importance of each individual class with in the same map and factor maps are compared each other and important matrices are produced with calculated weight using WEIGHT module of IDRSIS32. The matrices have consistence known as consistency ratio (CR). Satty recommends that matrices with CR rating greater than 0.1 should be re-evaluated. The weights derived from this method were normalized after multiplying them by 100 and rounded to integer value to avoid complexities of computation in further analysis.

VI. Eight matrices for pair-wise comparison of each data set in a single map with calculated weight of each data set was produced and the factor maps were reclassified based on the weight calculated.

VII. After a pair-wise comparison of each factor maps based on their influence to groundwater occurrence a single matrix (Table 14) with calculated weight of each factor map was produced.

4.2 GIS Modeling

In order to delineate potential groundwater site in the study area, all the data sets were integrated using the model constructed in ArcGIS model builder engine (Fig 4.1). The final map was produced by Weighted Linear Combination (WLC) where each class individual's weight was multiplied by the map scores and then adding the results:

$S = \Sigma Wi\ Xi$

Where S = Suitability

Wi = Weight for each map score

Xi = Individual map

4.3 Weighting

In order to apply multi-criteria evaluation (MCE), a set of relative weights was assigned for each map using WEIGHT module of IDRISI 32. The procedure mentioned in section 5.1 step vii was followed using continuous rating scale developed by Satty (1977) (Table 1). The weights calculated for each factor map were the results of pair-wise comparisons of each factor map based on their relative importance to groundwater accumulation.

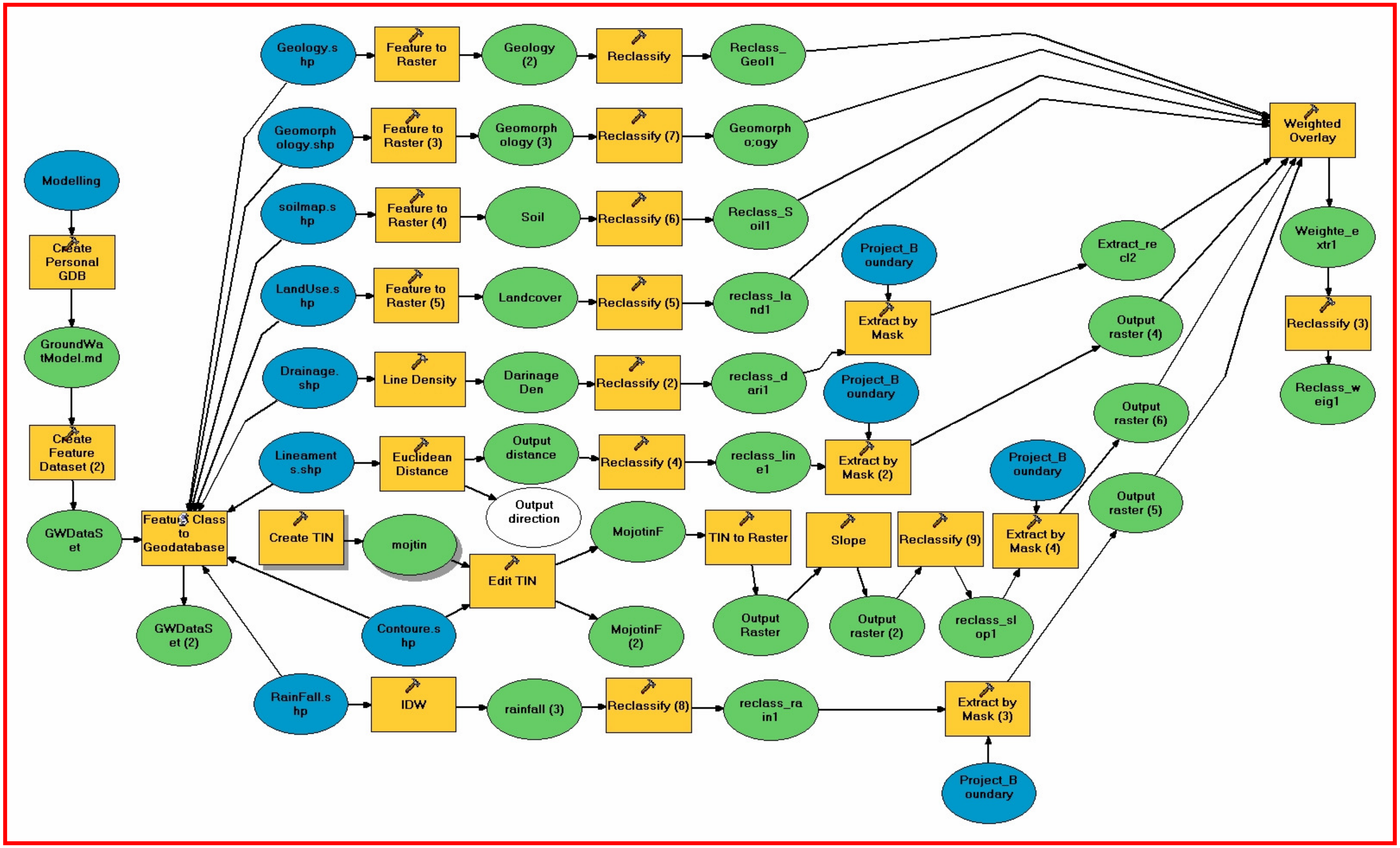

Figure 4.1 A model showing GIS analysis used to produce groundwater potential zone map

Geology, geomorphology and lineament were taken as the principal factors for the distribution, occurrence and flow of groundwater in the area. Geology is considered as the first principal factor since the distribution and magnitude of spring discharge, the degree of fracturing of the rock unit, the thickness of the formation, the grain size, the type and degree of cementation and the extent of the weathering are some of indirect evidences incorporated in geological properties and they define as to whether area is likely to be a low, moderate or high groundwater potential. Consideration of geomorphology as the second main factor was due to the fact that infiltration of water in to the ground depends on permeability of bedrocks, characteristics of soil and sediment cover, relief and vegetation, can be estimated by geomorphic classification using remote sensing imagery Verstappen, (1983). Lineaments, which are the third factors that controls groundwater occurrence, are incorporated in lithological characteristics area. The other factors (Slope, Soil, Drainage, Land use/cover, Rain fall) are factors that are incorporated in characteristic expressions of lithological, geomorphologic and structures. The result showed that the highest value 30 was calculated for geological factor where as the lowest value 2 was calculated for rainfall factor which is less variable, thought out the area (Table 14).

Table 14. Weight for all factor maps

	Geol	Geom	Lin Dist	Slope St	Soil	Drain Dn	Land U/C	Rain Fa	Weight	Weight * 100
Geol	1								**0.2956**	**30**
Geom	½	1							**0.2214**	**22**
Lin Dis	½	1/2	1						**0.1892**	**19**
Slope St	¼	1/3	1/3	1					**0.1186**	**12**
Soil	1/5	1/4	1/5	1/3	1				**0.0729**	**7**
Drain Dn	1/6	1/5	1/5	1/4	1/3	1			**0.0514**	**5**
Land U/C	1/7	1/6	1/7	1/6	1/4	1/4	1		**0.0318**	**3**
Rain Fa	1/8	1/7	1/6	1/6	1/6	1/5	1/5	1	**0.0191**	**2**

Consistency ratio = 0.09

Key
Geol = Geology
Geom = Geomorphology
Land U/C = Land Use/Cover
Rain Fa = Rain Fall
Lin dist = Lineament Density
Drain Dn = Drainage Density
Slope st = Slope Steepness
Soil = Soil

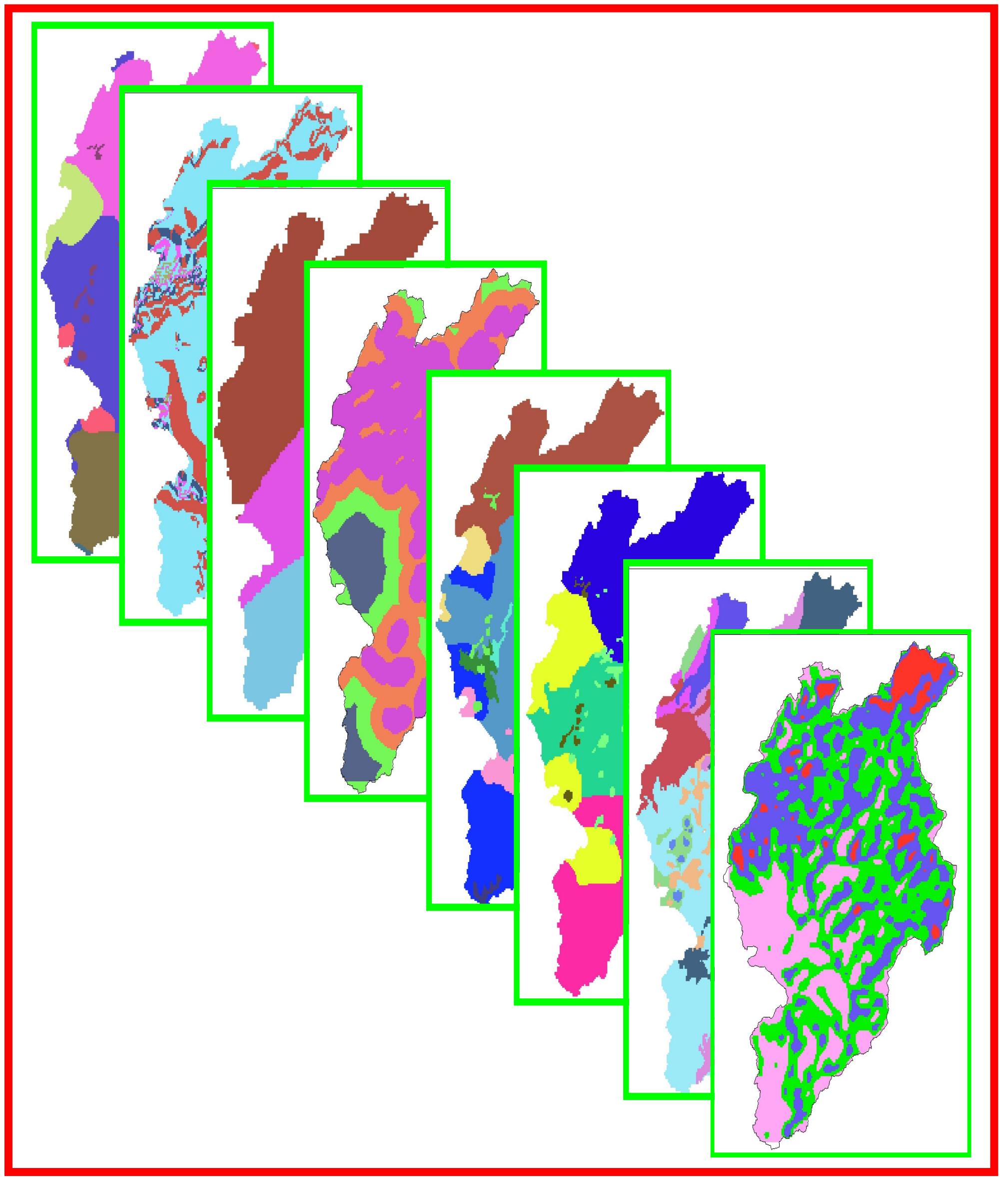

Figure 4.2 Thematic maps of Geology, Geomorphology, Lineaments, Slope, Soil, Drainage density, Land Use/Cover and Rainfall

4.4 Results

The delineation of groundwater potential zones by reclassifying into different potential zones; Very Good, Good, Moderate, Fair and Poor (fig 4.3) was made by utilizing the model designed using ARCGIS model builder engine. The map produced has shown that the groundwater potential of the study area is related mainly to geology, geomorphology and lineaments.

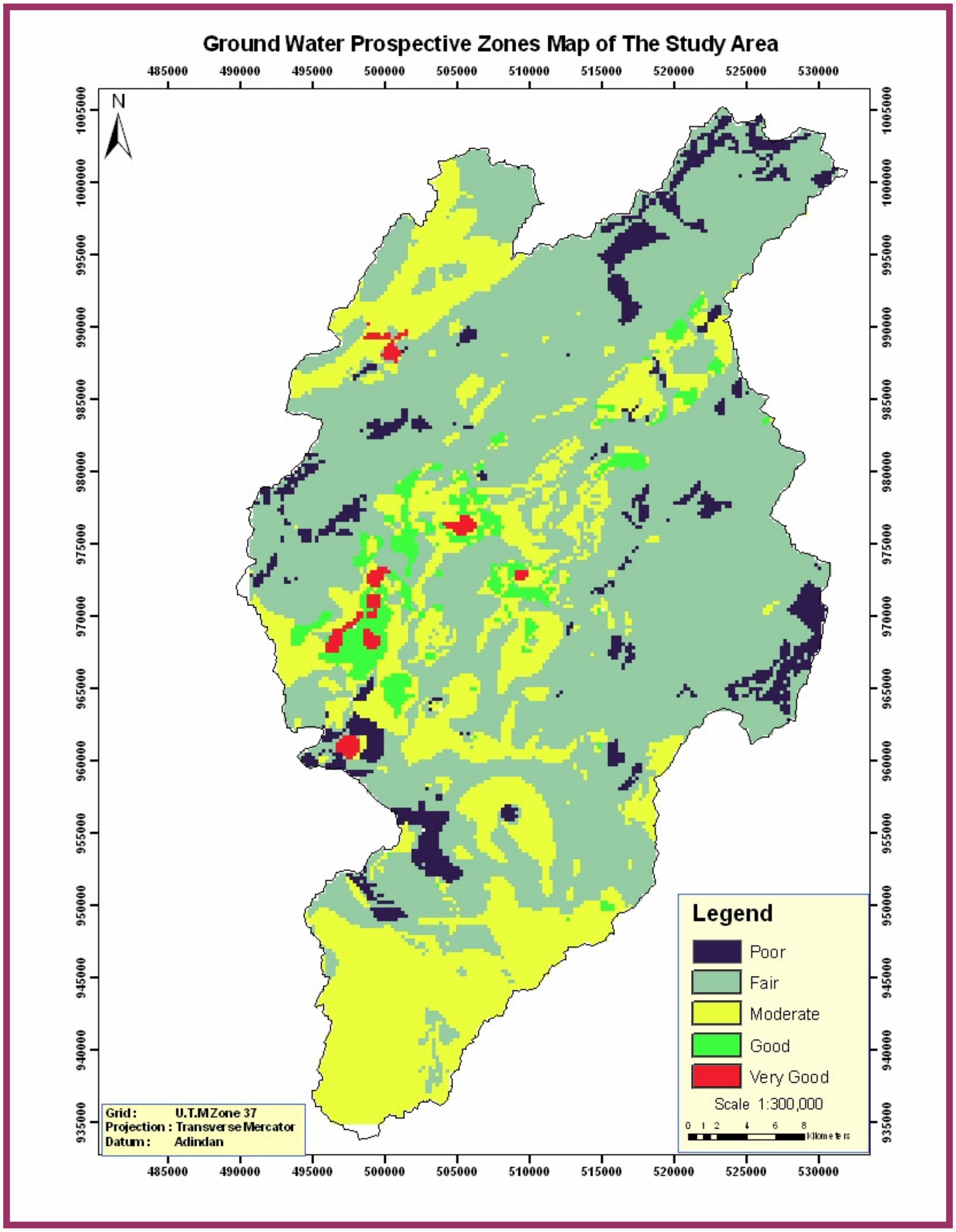

Figure 4.3 Ground water prospective zone analysed on the basis of Geology, Geomorphology, Lineaments, Slope, Soil, Drainage, Land Use/Cover and Rain Fall.

The validity of the model developed was tested against the borehole data, where out of 107 (With and without yield value) borehole data collected from the study area 50 are on very good and good zones, 37 on moderate zones, 14 on fair and 6 on poor zones (Fig. 4.4).

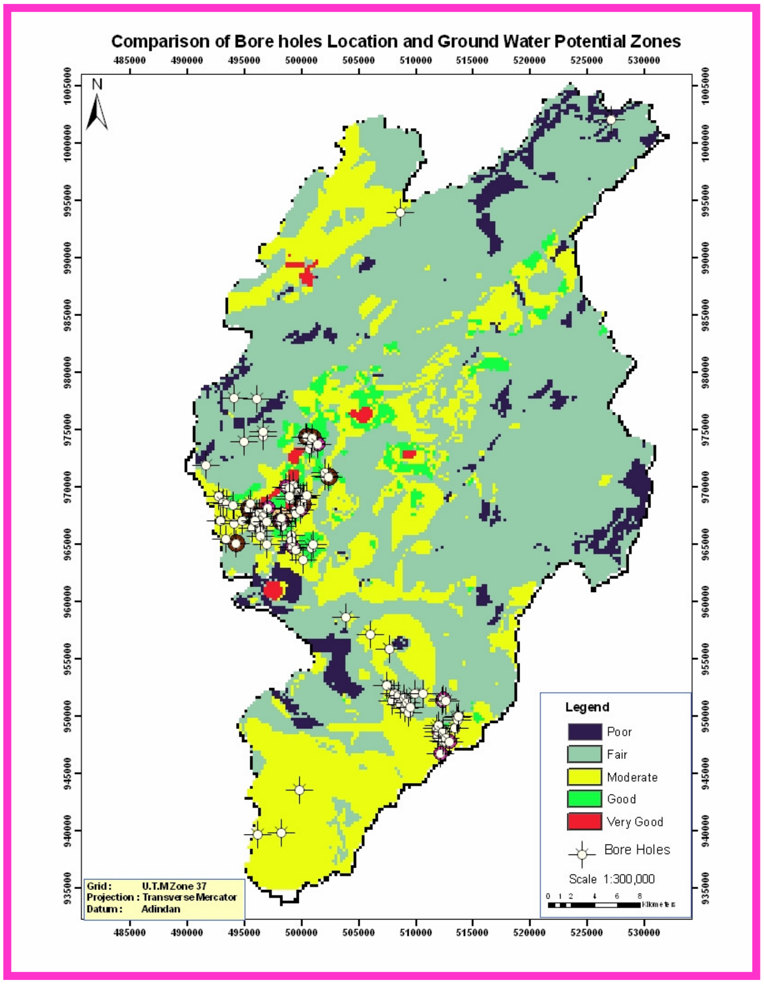

Figure 4.4 Distribution of bore holes in groundwater potential zones.

Moreover out of 52 bore holes (with yield data), bore holes with yield between 24 l/s to 69 l/s are on the very good and good zones which reflects the actual groundwater potential (Fig. 4.5). Although some wells exist in all groundwater potential zones, the best yielding wells lie in the very good and good groundwater prospect zone.

The model generated will help as a guideline for designing a suitable groundwater exploration plan in the future. The spatial distributions of the various groundwater potential zones obtained from the model generally show regional patterns of lineaments, drainage, landform and lithology.

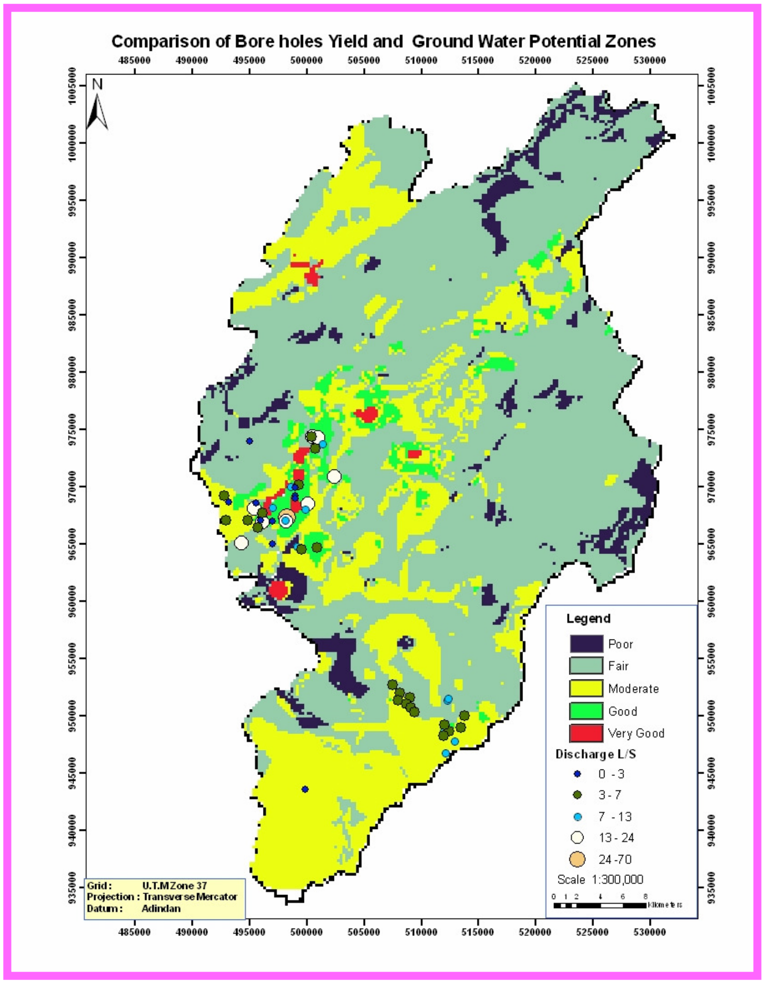

Figure 4.5 Relationship of bore hole yield and groundwater potential zones

Spatially the very good and good categories are distributed along areas near to lineaments and less drainage density and where the lithology is affected by secondary structure and having interconnected pore spaces. This highlights the importance of lineaments, geology and hydrogeomorphological units for groundwater investigations

Areas with moderate groundwater prospects are attributed to contributions from combinations of the land use/cover, lithology, slope, landform and soil. The low to poor categories of groundwater potential zones are spatially distributed mainly along ridges where slope class is very high, the lithology is compact/massive, clay soil composition and far from lineaments.

5. CONCLUSIONS AND RECOMMENDATION

5.1 Conclusion

Water is one of the main resources that are important for sustainable development of a country. The study area is most populated and industrialized part of the country, with the developmental activities and population growth, enough supply of water is vital.

The study area covers 1720 Sq.km, for delineation of groundwater potential zones; eight thematic maps from satellites images, exiting data and field data were produced with an integrated remote sensing and GIS techniques. The eight thematic maps that were selected for multi-criteria evaluation from the most influencing to least influencing were; geology, geomorphology, lineaments, slope, soil, drainage, land use/cover and rainfall.

Each data class in a single factor map were compared in pair-wise method and weight were calculated to each class using IDRISI 32 weight module, also all the eight factor maps were compared each other in pair-wise according to their influence to groundwater occurrence and they were reclassified based on the weight calculated. Final groundwater potential map was produce by using INDEX OVERLAY ANALYSIS.

In the study area occurrence of groundwater is controlled mainly by rock type, structures and landforms and to a lesser extent slope, soil, drainage, and rainfall. The most promising potential zone in the area is related to volcanic rock of Bishoftu, which is affected, by secondary structure and having interconnected pore spaces, with plain geomorphic feature and less drainage density. Most of the zones with fair to poor groundwater potential lie in the massive volcanic units of Bede Gebaba, central volcano and Nazreth unit, which are far from lineaments.

The overall results demonstrate that the integration of remote sensing, GIS, traditional fieldwork and models provide a powerful tool for the assessment of groundwater resources.

5.2 Recommendation

Remote sensing data are powerful tools to improve our understanding of groundwater systems. Despite unable to measure hydrogeological properties directly, they provide continuous detailed terrain information and allow the mapping of features significant to groundwater development there fore it is important to incorporate them in the data collection stage of groundwater exploration works.

Despite various satellite data with different spectral and spatial resolutions coupled with digital image processing techniques help to produce detailed maps, ground verification is crucial to increase the accuracy of the interpretation results.

Since geology, geomorphology and lineament mainly control the distribution occurrence and flow of groundwater, analysis of these parameters should be supported by high-resolution terrain data and satellite imagery.

When conducting MCE instead of assigning weight using random intervals, is important to calculate weight by professional judgments using pair-wise comparison for each data set in a single map as well for all factor maps to avoid confusions, individual biasness and to produce better results.

For fast, cost effective and accurate result in hydrogeological investigations integrated remote sensing and GIS approach is highly recommended.

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