DELINEATION OF GROUNDWATER POTENTIAL ZONES OF UPPER TUMET CATCHMENT, MENGE AREA, WESTERN ETHIOPIA USING REMOTE SENSING AND GIS

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Dedicated to
My mother, Dansure Gonfa
And
My father, Lemecha Boru
For their support, inspiration and blessing in my educational trek

Abstract

Low success rate of drilling productive wells is one of the challenges encountered in hard rock environment. The use of remote sensing data for the evaluation of groundwater resource in conjunction with ancillary ground information in GIS environment is becoming an effective method for the improvement of groundwater development success rate. In the present research thematic layers generated from satellite images, existing maps and field survey results were integrated in Geographic Information System (GIS) environment to delineate the groundwater potential zones in upper Tumet catchment, Menge area. Factor maps generated from satellite images include lineament, thermal lineament, soil moisture and vegetation anomaly and land use (lu)/land cover (lc) whereas those derived from existing maps were slope, drainage density and lithology. The zone of weathering thematic layer was generated from water point inventory data and Vertical Electrical Sounding (VES) survey interpretation results. In order to drive groundwater indicator parameters from satellite images, image pre-processing, enhancements and classifications were performed and various false color composite images were generated. Geologic and topographic maps were digitized and GIS analysis performed to drive thematic layers from existing maps. Field work was conducted for inventorying water points, to do VES survey and to collect point information for geometric rectification and ground truth. Information for 49 water points was gathered and 13 VES surveys were done. The collected ground truth was used during image classification. Data derived from different sources were reclassified to common scale and weighted. Multi-criteria evaluation using pairwise comparison matrix was used for weighting and ranking the thematic layers. In order to arrive at the groundwater prospect map raster based GIS modeling was conducted using Weighted Linear Combination (WLC) method. The resulting groundwater prospect map has five classes; namely Excellent, Very good, Good, Moderate and Poor. The model result revealed that large part of the study area has poor groundwater potential. The resulting model was evaluated using water point inventory data and the result was found to be in good agreement with the model output.

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I. Introduction

1.1 General

Water is one of the basic requirements for sustainable socio-economic development. Proper water resource evaluation, development and management guarantee food self sufficiency, assists in building healthy society and brings socio-economic well being.

Ethiopia is traditionally known as the “water tower of Africa”. But its usable water resources are not uniformly distributed through out its geographic boundary due to variations in factors controlling the quantity and quality of the resources. In general the highland areas are known for good surface and groundwater potentials whereas the peripheral lowland areas are known for the scarcity of the resource. As water is one of the limiting factors for settlement pattern the population density is very low in the peripheral lowlands and is congested in the highland areas.

Surface water resource in the peripheral areas is either lacking or is very limited in spatial distribution. In dry seasons apart from areas close to perennial water bodies the source of water for domestic use is rainwater harvesting community ponds and alluvial deposits along intermittent stream courses.

Groundwater is a dependable resource to be explored and developed to improve the socio-economic and cultural well being of the society living in this part of the country. But due to the complexity of factors controlling the occurrence of groundwater the success rate of drilling productive wells is low.

Remote sensing offers great opportunity in groundwater resource evaluation as it provides medium to high spatial, temporal and spectral resolution digital data that can be interpreted by integrating with the available ground information in GIS environment.

Remote sensing images provide synoptic view of vast area that helps to identify the spatial relationship between factors that control the occurrence and movement of groundwater. In addition satellite images are acquired at different times/seasons for the same area. These images can be used to identify zone of groundwater manifestation. Important groundwater prospect indicator parameters that can be drawn from satellite images are geology (lithology and structure), geomorphology, drainage density, slope, soil moisture, lu/lc, vegetation anomaly, etc.

The use of remote sensing and GIS in groundwater exploration improves the success rate of drilling productive wells. In Ghana, for example, the success rate of drilling productive wells by using this technique at the exploration stage in conjunction with traditional hydrogeological and geophysical methods has improved by 13% (Minor et al., 1995) as cited in Sander, 2007.

The study area is underlain by basement rocks. Occurrence of groundwater in basement terrain is limited to zones of fracturing and weathering. Successful identification of these groundwater bearing geologic layers requires application of different techniques and methods.

In this research remote sensing and GIS method is employed for the identification of groundwater potential zones in upper Tumet catchment, Menge area.

1.2. *Description of the Study Area*

1.2.1 Location and Access

The study area, Tumet catchment, is located in western extreme part of Ethiopia about 756km from Addis Ababa in Benishanguel Gumuz Regional State, Komosha and Menge weredas. Geographically it is bounded by 34^{0}32’51.18”E, 10^{0}12’48.44”N and 34^{0}54’57.55”E, 10^{0}29’53.46”N (Figure 1). It has a total surface area of 670km^2.

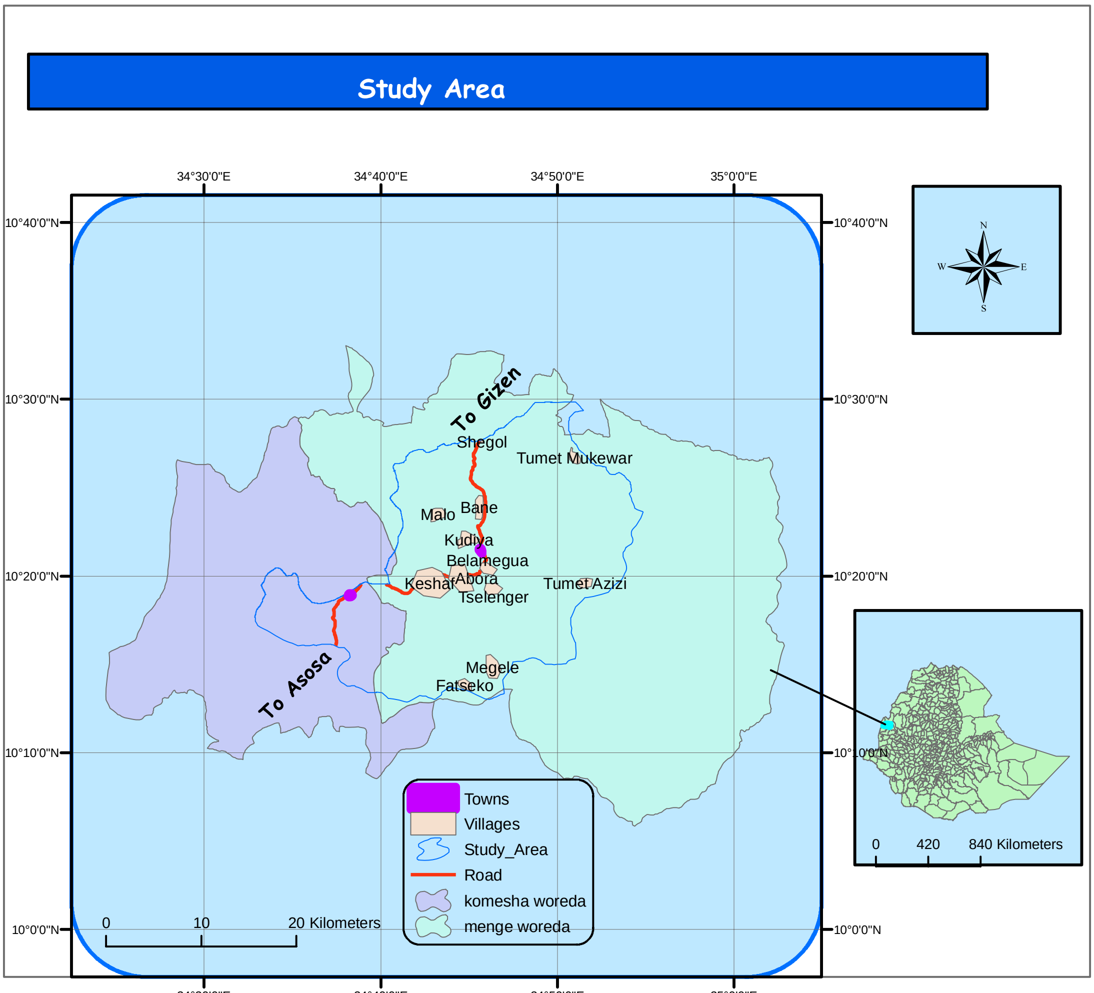


Figure 1 Location map of the study area

The area can be accessed through ground and air transportation. The ground access is via Nekemit-Gimbi-Asosa and then to the study area (Menge). The road from Addis Ababa to Asosa is partly asphalt and the remaining is under construction whereas the 56km from Asosa to Menge is all weather gravel road.

1.2.2 Climate

According to the National Atlas of Ethiopia, 1988, the climate of the study area is categorized under Tropical climate II. In this class the temperature of the coldest month is 18$^{\underline{0}}$c, annual rainfall is in the range of 680-2,000mm and elevation is up to 1750m above mean sea level (a.s.l.). The long year average annual temperature and mean maximum daily temperature calculated from 27 years data (1972-1999) is 24.1$^{\underline{0}}$c and 25.9$^{\underline{0}}$c respectively (Figure 2). The main rainy season is from middle of June to September with sporadic rain in almost all months of the year (Figure 3). The average rainfall calculated for the long year 1974-2004 for Menge station is 1339mm. Due to high altitudinal difference in the study area and lack of accuracy in data recoding of class 3 meteorological stations, the long year mean rainfall and temperature at Menge station might not be representative for the whole study area.

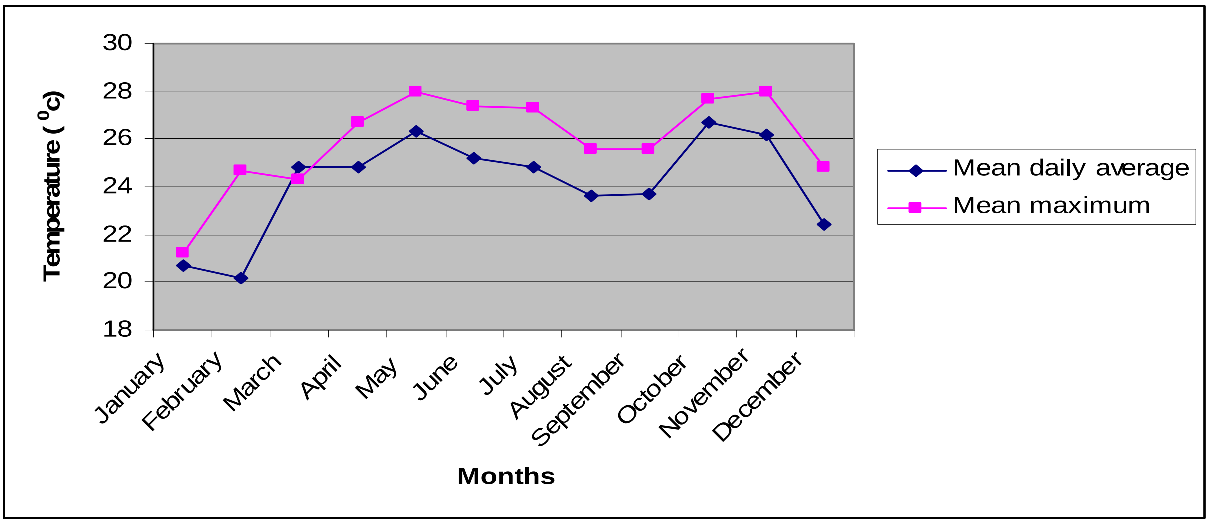


Figure 2 Long year (1972-1999) average and maximum temperature at Menge station

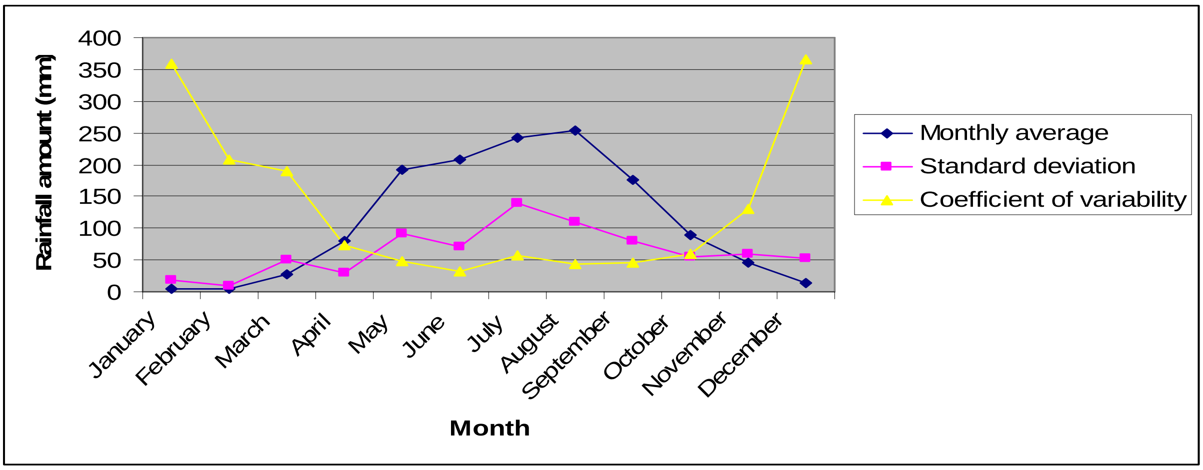


Figure 3 Long year (1974-2004) monthly average rainfall at Menge station

1.2.3 Physiography and Drainage

The study area is part of the western Ethiopia lowland locally characterized by rugged and mountainous to gentle and flat topography with escarpments and hills at places. It can be divided into two physiographic zones; namely the south- southwestern mountain chain and the north-northeastern plain of Tumet stream catchment. The southwestern border of the study area is characterized by rough morphology with steep slopes and narrow valleys whereas the north and eastern parts are flat plains. The study area has a relief with a general orientation in SW-NE direction. The altitudinal elevation ranges between 1920 and 860m a.s.l. The elevation differences have considerable effects on the climatic conditions, soil and vegetation distributions of the area.

The drainage patterns are generally dense, dendritic and sub-parallel. Generally, the streams drain toward northeast and ultimately join the main Tumet which is the tributary of Dabus River. All the streams crossing the study area are intermittent.

1.2.4 Vegetation and Land use

The study area is covered with thick mostly deciduous vegetation. Menge Woreda which has a total surface area of about 1,461km^2 has a forest cover of 87,657 hectares. The major type of forest species in the Woreda is Aflcombrerum Terminus. Of the total land area of the Woreda only 8,124 hectares is used for agricultural activities (source: Menge Woreda Agricultural office).

Komosha Woreda has a total land area of 11,200 hectares. Of this 5,012 hectare or 44.75% is covered by forest. The major forest types are ‘Wanza’, acceccia, ‘shola’, bamboo and mango trees. The total land used for built up and agricultural activities are 0.82 and 30% respectively (source: Komosha Woreda Agricultural Office).

1.3. Literature Review

The first regional hydrogeological study that encompasses the study area is the hydrogeological map of Ethiopia by Tesfaye Chernet (1993). According to this map (scale 1:2,000,000) rock units in the western Ethiopia are classified into three hydrogeologic units; namely the Precambrian basement classified as regional aquicludes, the Wollega basalt having moderate permeability and productivity and unconsolidated sediments consisting of alluvium, elluvium, collivium and lacustrine, which are classified as extensive aquifers with intergranular permeability

Tamiru Alemayehu (2006) classified the igneous and metamorphic rocks of Ethiopia including those in western Ethiopia as hard rocks that are devoid of primary water bearing structures. According to this work groundwater occurrence and movement in hard rocks takes place along open fracture system and in upper weathered mantle. Recharge in hard rocks dominantly takes place from streams where the open fractures cross or closely follow the surface water channel/course or through the weathered pervious portion of the unit. Moreover Tamiru Alemayehu (2006) has described that the groundwater in basement terrain of Ethiopia is characterized by regionally extended aquifer in near surface zone. In the same work the author identified geological and physiographic features that are important for groundwater occurrence and movement in basement rock namely;

- Major and minor fracture zones or lineation resistant topographic troughs or ridges that do not confirm to the regional trends,
- Contact zones between two or more rock types,
- Features such as pegmatites, dikes which frequently contain zones of low permeability or highly fractured zones of high permeability,
- Zones of regoliths.

The hydrogeological map of Asosa-Kurmuk sheet by Alamerew et al. (2003) is another regional hydrogeological work that includes the study area. According to this work the rock units within the study area are classified into two hydrogeologic units; namely (1) the moderately productive fractured aquifers that incorporate the alkaline olivine basalt exposed as pockets within the study area and (2) the dominant basement unit that cover most of the study area and classified as low productive fissured aquifer. The basement unit exposed in the study area consists of Precambrian stratified rocks (Amphibolite and quartzofeldspathic schist, metasediments and quartzofeldspathic and graphitic schist) and Precambrian intrusive rocks (metagrandodiorite and metagranite). The porous aquifers which developed locally along intermittent stream valley and at the base of mountains are mentioned to be not mappable at the scale of 1:250,000.

The Benishangul Gumuz regional water bureau also described the local geology, mineralogy, degree of weathering and fracturing, vegetation conditions etc and used as criteria to locate water well drilling sites for communities residing in the study area.

1.4. Objective and Scope of the Study

1.4.1 Objective

The objective of this research work is to delineate groundwater potential zones in upper Tumet catchment by integrating information from earth resources satellite data, topography, hydrogeologic and geological maps, water points inventory data and geophysical surveys using GIS analysis tools.

1.4.2 *Scope of the Study*

- Interpretation of earth resource satellite data to map lineament, thermal lineament, soil moisture and vegetation anomaly, and Lu/lc,
- Slope and drainage density analysis using topographic maps,
- Generate depth of weathering surface from water point inventory data and VES survey interpretation results.

1.5 Materials and Method

Landsat ETM+ and TM5 sensors digital data, topographic map of 1:50,000 scale, geological and hydrogeological maps of scale 1:250,000, Global Positioning System (GPS) and SAS Terrametr 300C geophysical instrument were used in the study. Software's used include ArcGis 9.1, ERDAS 8.6, ENVI 4.2, Global Mapper 7, Idrisi and RESIST 1987. ERDAS and ENVI were used for image analysis, RESISIT for interpretation of VES Survey data, Global Mapper for mapping lineament using SRTM data and ArcGIS to combine ground based and remotely sensed data and for preparation of thematic maps.

The methodology employed in the research was

- Collect secondary data like geologic, hydrogeologic, and topographic maps and generate factor maps like drainage density, slope and lithologic maps through digitization and GIS analysis,

- Spatial, spectral and radiometric enhancement of satellite images for generation of thematic layers like thermal lineament, lineament, vegetation anomaly and lu/lc,
- Mapping of zone of weathering from water point inventory and VES survey results,
- Integration of vector and raster thematic layers to classify the study area based on the groundwater potential,
- Validate the model result using water point data.

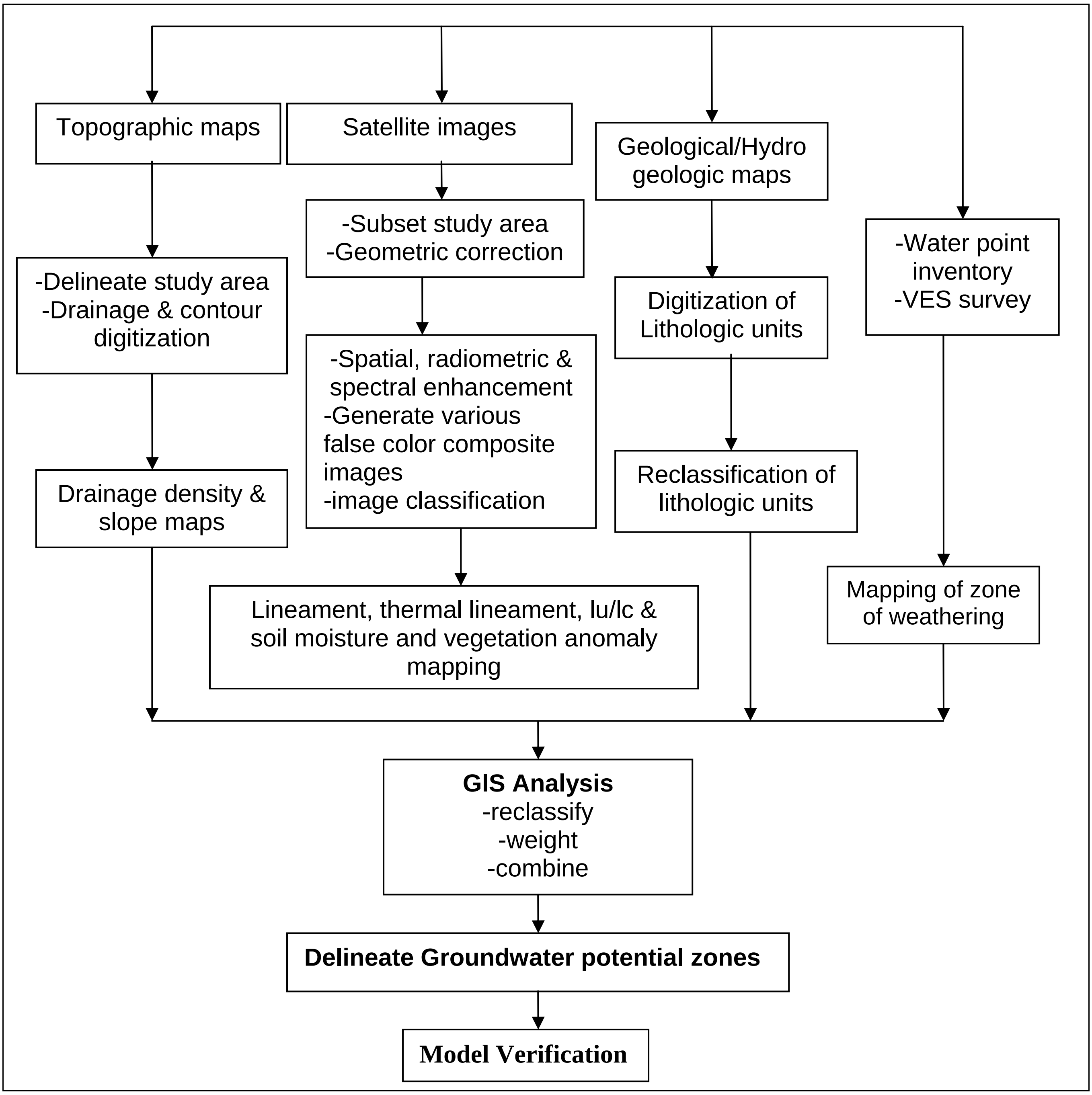


Figure 4 Work flow diagram

II. Geology and Hydrogeology

2.1 Lithology

The geology of western Ethiopia is dominantly crystalline basement rocks which are believed to be part of the low grade Arabian-Nubian low grade Shield. The low-grade volcano-sedimentary belt is bounded by the high grade gneissic terrains to the east and west. Internally the belt can be divided into three N-S running zones. The central zone consists of mafic to felsic metavolcanics with interbedded pelitic to psammitic metasediments and lesser associated cherts and marbles. These rocks are intruded extensively by pretectonic batholitic plutons, mostly intermediate to felsic in compositions. The eastern and western zones mostly consist of mafic metavolcanics with intercalated pelitic to psammitic metasediments and associated meta-plutons. The two outer zones are distinguished from the central zone by the presence of bodies of dismembered ultramafic rocks (serpentinized dunites, serpentinite, talc-carbonate schists and tremolite schist). All the three zones are extensively intruded by syn- to post-tectonic granitic bodies (Amenti Abraham, 1989).

The lithologic units exposed in western Ethiopia are divided into 5 major lithologic groups (Yohanis Belete et al, 2004), namely

- Gneiss and associated high grade metamorphic rocks,
- Low-grade supra-crustal metamorphic rocks which are mainly of metavolcanic, metasediments and associated ultramafic rocks,
- Syn- and post-tectonic intrusives of acidic to intermediate composition,
- Mesozoic sediments, and
- Cenozoic volcanic rocks.

The main lithologic units exposed within the study area include various types of schists, pre-to post-tectonic intrusives and Tertiary basaltic rocks (Figure 5). The schists include interlayered metasediments and metavolcanics, which are intruded by granodiorite and granite. The basalts, characterized by columnar joints, occur as isolated cover rocks in the southwest and southern parts of the study area. The different lithologic units of the basement rocks exposed in the study area are described by Demrew Yirgu (2007).

Metasediments

This unit is exposed around Menge, Abeyndu and Bela Gulu localities within the study area. It varies in composition, texture, structure and degree of weathering and deformation from place to place. Generally, it comprises graphite schist, chlorite schist, talc-chlorite schist, amphibole-biotite-feldspar-quartz schist, amphibole-biotite schist, muscovite-feldspar-biotite-amphibole schist, chlorite-biotite schist, quartz-muscovite schist, biotite schist and quartz-muscovite-sericite schist. The unit varies from weakly deformed massive varieties to strongly deformed schistose and foliated varieties. At place it is intensely weathered.

Metavolcanics

This unit is exposed around Belmegoha, Bela Gali, Abeyndu and Afigala areas. It generally varies from dark to dark-grey in color and basic to intermediate in composition. Mineralogically it is composed of biotite, amphibole, feldspar, chlorite and quartz. The unit varies from strongly deformed and layered to massive varieties, and is generally fine-grained. At places it exhibits weathered and friable appearances.

Metagranodiorite

The metagranodiorite is the dominant unit that covers large parts of the study area. Generally, it is dark-grey in color, medium- to coarse-grained and mainly composed of biotite, amphibole, feldspar, quartz and epidote. It is massive to weakly deformed and varies from fresh and hard variety to weathered and friable ones. At places, the unit is deeply weathered resulting in reddish-brown saprolite containing mineral fragments of feldspar, quartz and biotite.

Metagranites

The metagranites mostly occur as small lensoidal bodies. Generally the unit is coarse-grained, light to light-grey in color and mainly composed of K-feldspar and minor quartz and muscovite. The unit is generally massive except few localities where it exhibits strong deformational fabrics.

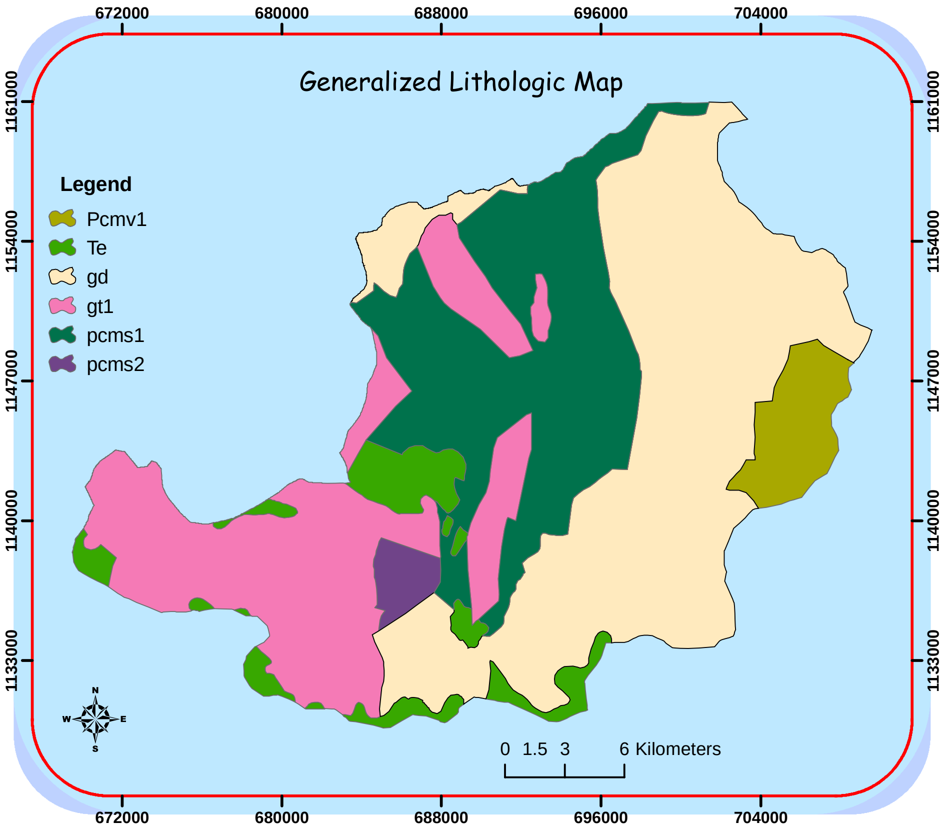


Figure 5 Lithologic Map of the study area (modified from Tefera, 1987)

Pcmv1-Amphibolite, lesser quartzite & quartzofeldspathic & graphitic schists, Te-Basalt, gd-Metagranodiorite, gt1-Metagranite, pcms1-Bioitie, graphite & chlorite schists, quartizite, metasandstone, metaconglomerate & quartzofeldspathic schist, pcms2-quartzofeldspathci & graphitic schists, greenschists & quartizite, lesser phyillite, biotite schist, metasandstone, & metaconglomerate

2.2 Geologic Structures

According to the descriptive note of the hydrogeolgical map of Asosa Kurmuk (Yohanis Belete et al, 2004) north-northwest and north-northeast trending lineaments are prominent in the area. The majority of stream courses in the area are controlled by these lineaments. Major structural and tectonic features that trend N-S, E-W, N-E, and N-W are also mentioned to be common.

Demrew Yirgu (2007) described that two phases of deformations are recognized in the area. The oldest and prominent phase of deformation is marked by penetrative axial planar foliation. This well developed and prominent foliation is a common characteristic feature of metavolcanic and metasedimentary and sporadically the metaintrusive complexes. This foliation is truncated by micro and meso structures. The regional penetrative foliation mainly strikes to NNW and locally to NNE and N-S with moderately low to sub-vertical dip towards SW, NE, SE and E directions. The second phase of deformation is defined by local shearing phenomena. The shearing is a progressive deformation that developed on the first phase of deformation. It is marked by the existence of indicators such as mylonitization, mineral grain rotation, boudinage and anastomising fabrics of the rock. The shearing is noted to be local and minor structure.

2.3 Hydrogeology

The western lowlands of Ethiopia are predominantly underlain by crystalline basement rocks, which are compact and dense materials. The importance of these rocks as sources of groundwater depends on the degree of fracturing, the extent to which the fractures are filled with secondary minerals and intensity of weathering. Hence, these crystalline basement rocks are regionally classified as aquicludes.

The hydrogeological map of Asosa-Kurmuk sheet scale 1:250,000 (Demis Alamerew et al, 2003) classified the hydrogeological units in western Ethiopia into 4 groups, namely;

- Precambrian marble
- Non-carbonate Precambrian stratified and intrusive rocks
- Mesozoic sandstone, and
- Tertiary volcanic rocks.

Except for pockets of Tertiary volcanics around the western and southwestern corners, the study area is underlain by the hydrogeologically less important non-carbonate Precambrian stratified and intrusive rocks. The basaltic rocks are affected by columnar jointing. Hence it has primary porosity resulted from cooling joints.

Based on the degree of metamorphism the basement rocks can be classified into two; namely low-and high-grade rocks. As compared to the low-grade rocks the high-grade metamorphic rocks show little degree of fracturing and weathering. Weathering in fine-grained metamorphic rocks such as slates and schists may extend up to depths of 100m while in hard high-grade rocks such as quartzites and gneisses it is much less pronounced or may be absent (IHE, 1997). Weathering enlarges the joints and fractures by disintegrating the constituent minerals and result in the formation of local secondary aquifers that may be important sources of groundwater.

According to their hydrogeological significance the rocks in the study area are classified into three aquifer aquitard systems (Yohanis Belete et al., 2004)

(1) Moderately productive fissured aquifers: - Under this unit is classified the Tertiary volcanics exposed as pockets around the western and southwestern corners of the study area.

(2) Low productive fissured aquifers: - Under this class are grouped the Precambrian stratified and intrusive rocks. The Precambrian stratified rocks consists of amphibolite and quartzofeldspathic schist, metasediments and quartzofeldspathic and graphitic schist.

   a. Amphibolites and quartzofeldspathic schist: - The amphibolite is massive and fine grained and hence has low permeability. The quartzofeldspathic rock is fine grained, unlaminated and intercalated with less pervious rocks such as felsic rocks, quartizite, etc which reduces groundwater percolation within the rock association. The group is low in their water bearing and permeability because of the physical rock property.
   b. Metasediments:-Common rock type in this group are biotite, graphite and chlorite schists, quartizite, quartzofeldspathic schist, meta-arkos and meta-conglomerate. Pelitic schists and amphibolite schists occurs as minor intercalations. The hydrogeological importance of the unit depends on interlayering thickness that varies from cm to m, thickness of weathered zone, grain size variation and end product of weathering of the rocks in the interlayering. Existence of primary sedimentary structures in the unit such as graded bedding enhances groundwater permeability, storativity and recharge.
   c. Metagranodiorite: - The unit is coarse in grain size and massive to foliated. Prominent basic minerals are biotite and amphibolite. The unit is characterized by variable intensity of weathering, increase in

thickness of weathered zone when composition is dominated by basic minerals or when assimilated with other rocks such as diorite.

d. Metagranite: - This unit is coarse in grain size, weakly to strongly foliated and highly to moderately weathered. Alternation products include sericite, epidote and chlorite which are products of feldspars and biotite. The unit forms high topography and have thick weathered part (silty sand to fine sand) which makes it good water bearing.

(3) Aquitards:-Under this group are classified fine grained metasediments such as phyllite, felsic schist, mafic schist, green schist with beds of graphite schist, quartizite and talc schist. The rocks in this group are fissile, fine grained and thinly to highly foliated. Mineral alterations common to most of these rocks are epidotization and chloritization. Most of the rocks in the group contain magnetite, hematite, calcite and chlorite as accessory minerals. Quartz veins and mafic to feslic dykes of variable dimension are found together with this group. The group weather to clay rich soil; even the moderately weathered rocks have higher proportion of alteration minerals that seal fractures. Secondary minerals also seal original vesicles. As a result permeability, storativity and aquifer yield of the group is low.

Moreover alluvial aquifers are important water supply sources for the local community. Dug wells excavated along intermittent streambed give year round water supply. The thickness of the deposits is more than 10m at some places as observed in pits excavated for placer gold mining along Tumet and Shegol stream banks (Figure 6).

Figure 6 Alluvial deposits from pit excavated for gold panning

III. Application of Remote Sensing and GIS in Groundwater Exploration

3.1 Preamble

Remote sensing data with its advantages of spatial, spectral and temporal availability covering large area is a very effective tool in assessing, monitoring and conserving groundwater resources within short time. It provides quick and useful baseline information on the parameters controlling the occurrences and movements of groundwater such as lithology, structure/lineament, geomorphology, soil, lu/lc, etc (Kumar & Tomar, 2006).

Satellite data have the following advantages to be applied in groundwater exploration (SD FAO, 2006).

- Provide synoptic coverage and therefore give an exhaustive view of vast areas at the same time,
- They can be acquired for the same area at a high rate of repetition thus permitting selection of the most appropriate seasonal data,
- The data can be obtained for any part of the world.

The use of remote sensing from aerial platform in groundwater exploration dates back to the 1960's when Lattman and Parizek (1964) as cited in Sander, 2007 mapped lineament on stero-pairs of aerial photographs in carbonate terrain on the eastern United States and showed the correlation between well productivity and distance to the identified features.

Since then many research and development oriented projects have employed remote sensing from both space and aerial platforms for the identification of groundwater occurrence indicator parameters. Data obtained from remote sensing can be combined with traditionally collected ground information for the identification of potential groundwater zones in GIS environment. The effectiveness of the methodology has been tested using geophysical exploration and drilling works in different parts of the world (SD FAO, 2006).

In Ethiopia the use of image from aerial platform dates back to the 1950's when aircraft was flown to take photograph of the Blue Nile basin for the production of

1:250,000 scale topographic map and for the study of the water resources of the basin. However the use of image data from space platform for groundwater potential study is limited to research projects.

Recently Tewodros Rango (2005) used remote sensing and GIS for groundwater potential zone identification in hard rock terrain of Bale Mountains. In this work thematic layers like drainage, lineament, elevation, slope, land cover, soil, rainfall, and biological factor (burrowing rodents) generated from satellite image and existing maps were combined in GIS environment for mapping groundwater potential zones within the study area. Similarly Sisay Libasse (2006) applied similar approach to generate thematic maps such as geology, geomorphology, lineament, soil, rainfall, lu/lc, slope and drainage for producing groundwater potential map of northern Ada'a plain (Mojo catchment).

Remote sensing images can be used to produce different thematic maps that are important for the evaluation of groundwater resource. In this research remote sensing data was used for the identification of lineament, thermal lineament, lu/lc, vegetation and soil moisture anomaly from Landsat ETM+ and TM5 sensor images. Remotely sensed data by its wide area coverage and multi-spectral nature help in identification and mapping of these factors with selective ground checks. The parameters generated from remote sensing images were combined with other groundwater potential indicator parameters like lithology, drainage density, and slope derived from existing maps and zone of weathering map generated from water point inventory data and VES survey interpretations to produce the groundwater prospect map of the study area. The major activities carried out to accomplish the aforementioned tasks are briefly described as follows.

3.2 Delineation of the Study Area

The study area is located on 4 topographic maps (1:50,000 scale); namely Komosha, Menge, Undule and Asosa which were scanned, geo-referenced and arranged in mosaic. The study area was digitized following Tumet stream catchment boundary using ERDAS image processing software. The topographic map which is originally in Transverse Mercator projection was projected to UTM/WGS 1984 for overlay with Landsat ETM+ & TM5 sensor images which are obtained in the same projection.

3.3 Subseting Satellite Images and Maps

The Area of Interest (AoI) layer digitized from the topographic map was used to subset the study area from the full scene of the satellite images. The geologic and hydrogeologic maps used in the study were also scanned, geo-referenced and projected to the same coordinate system after which the study area was subseted similar to the satellite images.

3.4 Image Restoration (Pre-processing)

Most of the information for this project was extracted from satellite images. As raw satellite data contain significant distortion they can’t be used as maps. Hence, to extract maximum information from the satellite images, it is necessary to compensate for the distortion introduced during image acquisition. This process of image restoration which precedes any image manipulation and analysis is termed as pre-processing.

Image restoration (pre-processing) processes are designed to recognize and compensate for errors, noise, and geometric distortions introduced into the data during the scanning, transmission and recording processes. The objective is to make the image resemble the original scene (Sabins, 1987).

Geometric correction was made on topographic map, satellite images and geologic and hydrogeologic maps using Ground Control Points (GCP’s) collected from the study area. The procedure involves selection of distinguishable GCP's (road and river intersections, bridges) on the topographic maps and assigning appropriate reference information obtained from field using GPS. After 20 GCP’s were entered computer program was used to resample the original pixels into new referenced geographic location. The corrected topographic map was used to make an image to image rectification on the satellite images and other maps. The purpose of the geometric rectification was to allow accurate overlay of point data collected using GPS on the satellite images and other maps used in the study.

3.5 Image Processing

Landsat 7 ETM+ sensor digital data acquired on November 11, 2001 and Landsat TM5 image of January 13, 1987 having path and row numbers of 171/053 were used in this study. The ETM+ sensor image has 9 bands of which 6 are multi-spectral (bands 1, 2 & 3 visible, band 4 is NIR, and bands 5 & 7 are SWIR) having spatial resolution of 28.5m, 1 panchromatic (band 8) having spatial resolution of 14.25m & and 2 thermal (bands 61 and 62) high and low gains respectively and having spatial resolution of 57m. The raw ETM+ sensor image has an absolute positional accuracy of 50m. All the 9 bands were used in the analysis.

Landsat TM5 image has 7 bands of which 6 are multi-spectral (bands 1, 2, 3, 4, 5 and 7) and 1 is thermal (band 6). All the 7 bands have spatial resolution of 28.5m. The spatial resolution of the thermal band is 120m during acquisition but re-sampled to 28.5m.

Both the ETM+ and TM5 images were obtained in "tif" file formats. All bands (multi-spectral, thermal and panchromatic) were layer staked using ERDAS and ENVI formats.

Various image enhancements and color composites were generated using the staked layers to determine the best enhancement techniques and band combinations to extract thematic layers such as lineament, thermal lineament, vegetation and soil moisture anomaly and lu/lc.

3.5.1 Image Enhancement

Enhancement is the process of improving the visual interpretability of an image by increasing the apparent distinction between the features in the scene (Lillesand et al., 2004).

Various types of enhancements were applied to the raw Landsat images to increase their visual interpretability. The major enhancements performed were spatial (non-directional edge, convolution and resolution merge), radiometric (histogram equalization), and spectral (principal component, Tasseled cap, NDVI and Vegetation indices, and RGB to IHS, IHS to RGB).

Non-directional edge and convolution were applied for detecting lineaments. In order to improve the spatial resolution of the multi-spectral bands, the high resolution panchromatic band (band 8) of ETM+ sensor was fused with the multi-spectral bands of ETM+ and TM5 sensor images. The resulting image has spatial resolution of that of the panchromatic band which is 15m. The fused images were partly used in the interpretation of non-changing parameters like lineament. The TM5 image was acquired before construction of the gravel road crossing the study area from Asosa to Kurmuk. However merging TM5 multi-spectral band with ETM+ panchromatic band helped to recognize and locate the position of the newly constructed road on the TM5 image.

Spectral enhancements are modifications of the pixel values of an image. They can be used to improve interpretability, reduce information redundancy, and extract information from the data which is not readily visible in its raw form. The spectral enhancements utilized in the actual information extraction in this study were principal components analysis, ratio images and the tasseled cap transformation.

3.5.1.1 Principal Component Analysis

Principal Components Analysis (PCA) is a spectral enhancement which can be used to compress the information content of a multi-spectral data set (Sabins, 1987). PCA uses mathematical algorithms to transform n bands of correlated data into n principal components which are uncorrelated, such that the coordinate axes of the components are mutually orthogonal (corner). The first principal component (PC-1) describes most of the variation of the brightness values for the pixels of the original bands (Jensen, 1986). Subsequent components explain less and less of the data, with the final PC usually corresponding to atmospheric noise in the data rather than any ground features (Sabins, 1987). The main benefit of principal components analysis is that it can reduce the amount of data (bands) without losing much of the information and typically reducing redundancy (Jensen, 1986). PCA helps to transform the original raw remote sensor data into new more interpretable data.

Thematic layers generated using different enhancement techniques and band combinations were draped over individual principal component image and their false color composites to identify similar features which were not clearly visible on the original image.

In addition, attempts were made to produce geological map using remote sensing image of TM5 using band combinations 742, false color composite of principal component image (123) in RGB order and decorrelation stretch of the principal component image but the resulting map was of lesser detail than the existing geological map. The aim of the mapping effort was to delineate the alluvial deposit which has hydrogeological significance.

3.5.1.2 Image Rationing

Image rationing is an enhancement technique whereby Digital Number (DN) values of image in one spectral band is divided by the corresponding pixel value in another band. The usefulness of image ratio is to minimize the effect of varying illumination caused by topography.

Natural Difference Vegetation Index (NDVI) and Vegetation Index were used during lu/lc analysis of the study area.

3.5.1.3 Tasseled Cap Transform

The tasseled cap transform is a guided and scaled principal component analysis, which transforms the 6 Landsat TM bands into 3 bands of known characteristics; soil brightness, vegetation greenness, and soil/vegetation wetness (Frankovich, 1999). The technique decreases the information redundancy and the number of layers used in the analysis.

In the present study tasseled cap transform was used with the TM5 sensor data for detecting vegetation and soil moisture anomaly.

3.6 Classification

Classification is the procedure of automatically categorizing all pixels in an image into lu/lc classes or themes. The spectral pattern present within the image data for each pixel is the numerical basis for categorization (Murty, 2005). Supervised and Unsupervised classifications are used in satellite image data categorization. In supervised classification the analyst trains the computer by specifying numerical descriptors of the various lu/lc types present within the scene. This will be followed by automatic categorization of each pixel present in the scene into the lu/lc training data it mostly resembles. In unsupervised classification the computer aggregates the image data into natural spectral grouping and the analyst latter affixes lu/lc identity by comparing with ground reference data.

Image classification was used to classify lu/lc and soil moisture and vegetation anomaly thematic layers in the study area. Supervised, unsupervised and hybrid classification methods were employed.

3.7 GIS Analysis

GIS is a process that contains a set of procedures that facilitate the data input, data storage, data manipulation and analysis and data output for both spatial and attribute data to support decision making activities (Grimshaw, 1994) as cited in Jacek Malezewaski (1999).

GIS has two major functions namely fundamental (or basic) and advanced. Fundamental functions are functions like measurement, (re)classification, overlay operations, connectivity operations and neighborhood operations. Advanced functions are statistical and mathematical modeling functions (Malezewaski, 1999).

In this study both the fundamental and advanced capabilities of the system were utilized. GIS was used to

- input and store spatial and attribute data captured through GPS and digitization,
- make different analysis on input data to produce intermediate and final factor maps,
- create continuous surface from point data (geo-statistical analysis),
- integrate data from different sources (remote sensing, existing maps & field survey),
- conduct multi-criteria analysis to determine class and factors maps weight,
- to perform mathematical modeling to categorize the study area based on the groundwater potential, and
- produce output thematic layers.

In multi-criteria analysis Analytic Hirerarchy Process (AHP) developed by Saaty (1980) cited in Malezewaski (1999) was used to determine individual class and factor maps weight. The assignment of class and factor maps weight was based on Saaty's 9 point continuous scale (Figure 7).

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		

Figure 7 Saaty's 9 point continuous weighting scale

Weighting the relative importance of two components (factors) involved in determining suitability was conducted at a time. The pairwise comparison matrix determined in this way was entered into the WEIGHT module of IDRIS for windows. The module calculates the principal eigenvector of a square reciprocal matrix which is the weight of the component. The procedure requires the Consistency Ratio (CR) to be less than 0.1. Therefore whenever the CR is above the limit pairwise comparison was repeated until it is within the required limit.

IV. Analyses of Groundwater Indicator Parameters

4.1 Preamble

Parameters that indicate the groundwater potential of an area includes geological factors (lithology and structures), hydrological factors (water availability for recharge), geomorphologic features, topographic and drainage factors, lu/lc, etc.

The order of importance of these parameters varies from place to place. For example, in areas where the lithology is unconsolidated sediment the geologic control for occurrence of groundwater is less important as compared to hydrologic factor.

Satellite image can be used for the recognition of parameters that indicate the occurrence of groundwater and for mapping zones of groundwater manifestation using indicators like vegetation and soil moisture anomaly.

The parameters identified from satellite images can be integrated with ancillary ground based data collected from different sources for the identification of potential groundwater bearing zones.

4.2 Lineament

Lineaments are significant lines of landscape caused by joints and faults revealing the architecture of rock basement (Hobbs, 1904) as cited in Sander, 2007. Lineaments are zones of increased porosity and permeability in hard rocks. Mapping of lineaments is one of the key factors in understanding groundwater occurrence and movement in hard rock terrain. Lineaments can be recognized on satellite images by image color, texture, tone, pattern, break of slope, abrupt change in stream course, lithology, vegetation, etc.

Mapping of lineaments can be carried out from topographic maps, digital elevation models (DEM), satellite images and aerial photographs. High resolution satellite images like Quick Bird and IKONOS are best images for mapping lineament accurately. But due to high cost these images are not commonly used. Medium resolution Landsat, SPOT, IRS and ASTER missions are the most commonly used imageries.

In this research lineament mapping was done using Landsat ETM+ and TM5 sensor images. Various edge detection and enhancement algorithms and non directional and directional filters applied for recognition of lineament enhanced major streams crossing the study area only. This is presumably due to vegetation cover and burial of the lineaments by the regolith. So lineaments indicated on the geologic map of the study area were digitized and draped over the satellite image at the beginning to have idea about lineament on the satellite images. Then after linearity resulting from spectral variability was used as base for the identification and mapping of lineaments.

Mapping of lineaments was done with visual observation and interactive digitization of original and edge enhanced band 4, panchromatic band (band 8), 1st and 3rd principal component images, and false color composites (432 & 453) and false color composite of principal component 1, 2 and 3 in RGB order. The lineaments mapped from one band or band combination was draped over the others to identify those which can be distinguished with the band or band combination under consideration. In addition to the satellite images, Shuttle Radar Terrain Model (SRTM) data was used for lineament mapping.

After completing the digitization of lineaments from the satellite images and SRTM data they were overlaid with the geologic map to see the consistency. It was found that the majority of the bigger linear features identified from the satellite images and SRTM data were also indicated on the geologic map. But there were many newly mapped lineaments especially those smaller in length. The smaller lineaments were considered to be weathering lineaments whereas the bigger once are tectonic lineaments.

In order to distinguish anthropogenic linear features such as foot path which is dominant in the study area the mapped lineament vector map was overlaid on the scanned old topographic map of the study area after which the non-geologic linear features were omitted. The final lineament map was overlaid with the drainage map digitized from the topographic map and it was found that most of the mapped lineaments correspond to the drainage line which confirms that the drainages are structurally controlled as in most hard rock environment (Figure 6).

The influence of lineaments on groundwater can not be directly judged from remote sensing images. But their spatial location can help to infer their hydraulic characteristics. Lineaments located along topographic high can be potential recharge areas whereas those intersecting with surface water body can be potential discharge as well as recharge area.

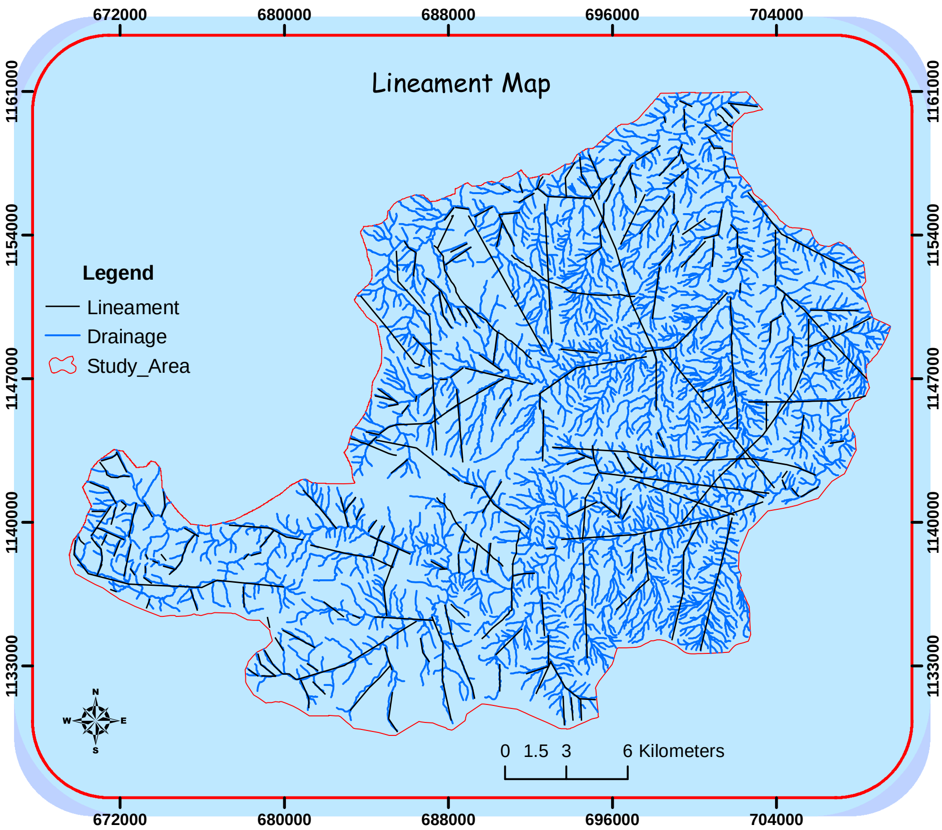


Figure 8 Lineament draped over drainage map

The digitized lineament map was imported to ArcGIS where lineament density was calculated with spatial analyst tool (Figure 9). The lineament density map was reclassified into 5 classes and the relative importance of each class was determined using pairwise comparison matrix (Table 1). The Consistency Ratio (CR) was determined to be 0.05.

The boreholes drilled in the study area were overlaid on the lineament density map to evaluate the degree to which lineaments controls the sitting of wells. The result revealed that 2 dry and 2 productive wells are located on an area classified under very low lineament density, 4 of the productive wells are classified in an area with low lineament density and 1 well on an area classified as moderate lineament density. This shows that lineament is not the only controlling factor for the occurrence of groundwater in the study area.

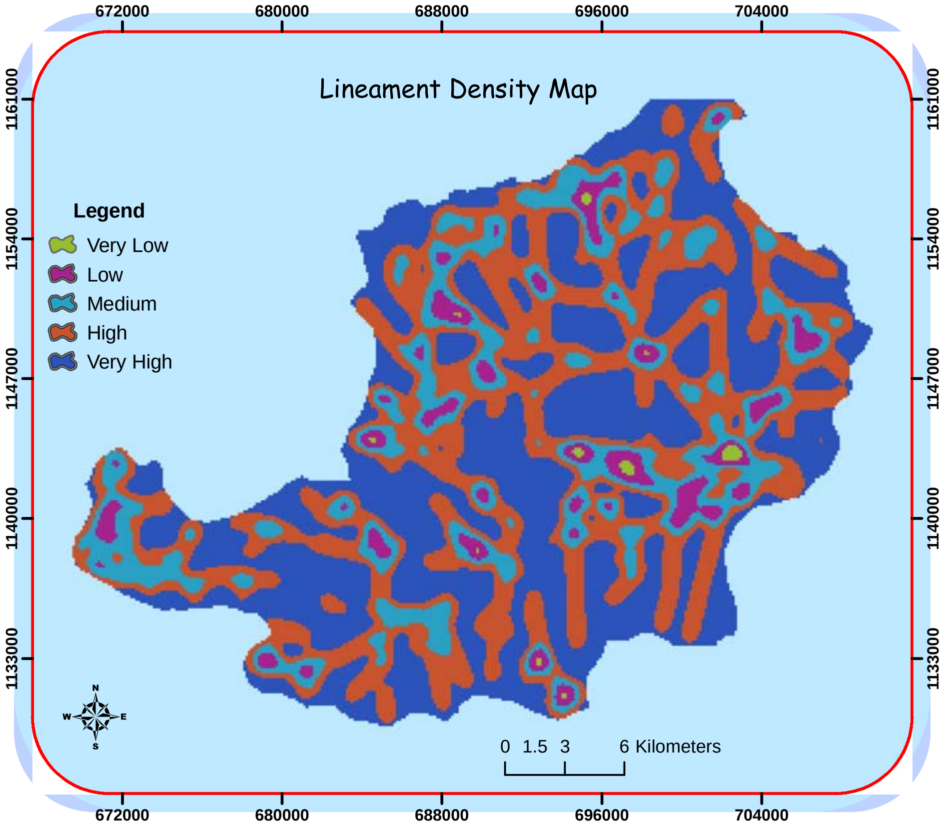


Figure 9 Reclassified lineament density map

Table 1 Class weight of reclassified lineament density

	Lineament Density (m/km2)	Very High	High	Medium	Low	Very Low	Weight	Weight %
Very High	2.80-1.55	1					0.5128	51.3
High	1.55-1.08	1/3	1				0.2615	26.2
Medium	1.08-0.69	1/5	1/3	1			0.1290	12.9
Low	0.69-0.28	1/7	1/5	1/3	1		0.0634	6.3
Very Low	0.28-0	1/9	1/7	1/5	1/3	1	0.0333	3.3

4.3 Thermal Lineament

Thermal sensors record the radiant temperature of terrain materials. The radiant temperature recorded by the thermal sensors is related to the surface kinetic temperature and thermal properties of the terrain materials (Drury, 1987).

Thermal image can be acquired at any time of the day or night. The earth's surface emits thermal radiation equally day and night. The tone of thermal images expresses surface temperature and not reflectance. On thermal IR images the brightest tones represent the warmest radiant temperature and the darkest tones represent the coolest temperature (Sabins, 1987).

Moisture content affects the thermal characteristics of surface materials. Dry and moist soils that have similar composition and texture can have different thermal responses. The effect of evaporative cooling dominates the radiant temperature signature of damp ground. Green deciduous vegetation has a cool signature on daytime images and a warm signature on nighttime images. During the daytime transpiration of water vapor lowers leaf temperature, causing vegetation to have cool signature relative to the surrounding soil (Ali, 2006). Lineaments that have groundwater manifestation can be recognized from IR images using the effect of evaporative cooling similar to the damp soil and green vegetation.

The main elements of interpretation of thermal images are tone, texture, pattern, shape and context. Daytime images express topography and geologic structures very well in doing so they obscure variations due to different thermal properties of the surface (Sabins, 1987). The images used in this research were daytimes which were acquired around 4:30a.m.

Thermal lineaments were digitized from Landsat ETM+ and TM5 sensor images thermal band (band 6) by visual observation of the linear boundary between features having different thermal response. Digitization was conducted before and after applying various spatial enhancements such as non directional edge enhancement and various kernel size high pass and edge enhancement filters. Spatially enhanced images were spectrally enhanced so that it is convenient for visual identification and interactive digitization.

The mapped thermal lineaments in the study area didn't seem to be purely associated to zone of groundwater manifestation but influenced by the following factors;

- boundary of different rock units having variable thermal property &
- boundary of different lu/lc classes

The lineaments digitized from thermal bands were smaller in size and less in number as compared to lineaments digitized from multi-spectral band. Those linear features observed in both bands have sometimes shift in spatial orientation (Figure 10). Thermal lineaments are likely to be tectonic lineaments as most of them coincide with bigger size lineaments digitized from multi-spectral images. Thermal images show clear linear contrast in the northeastern part of the study area which has relatively low topographic influence.

The thermal lineament map prepared from the thermal bands of Landsat ETM+ and TM5 sensors was used to generate thermal lineament density map (Figure 11) which was reclassified into 5 classes. Class weight was assigned based on multi-criteria evaluation techniques using pairwise comparison matrix (Table 2). The CR is 0.05.

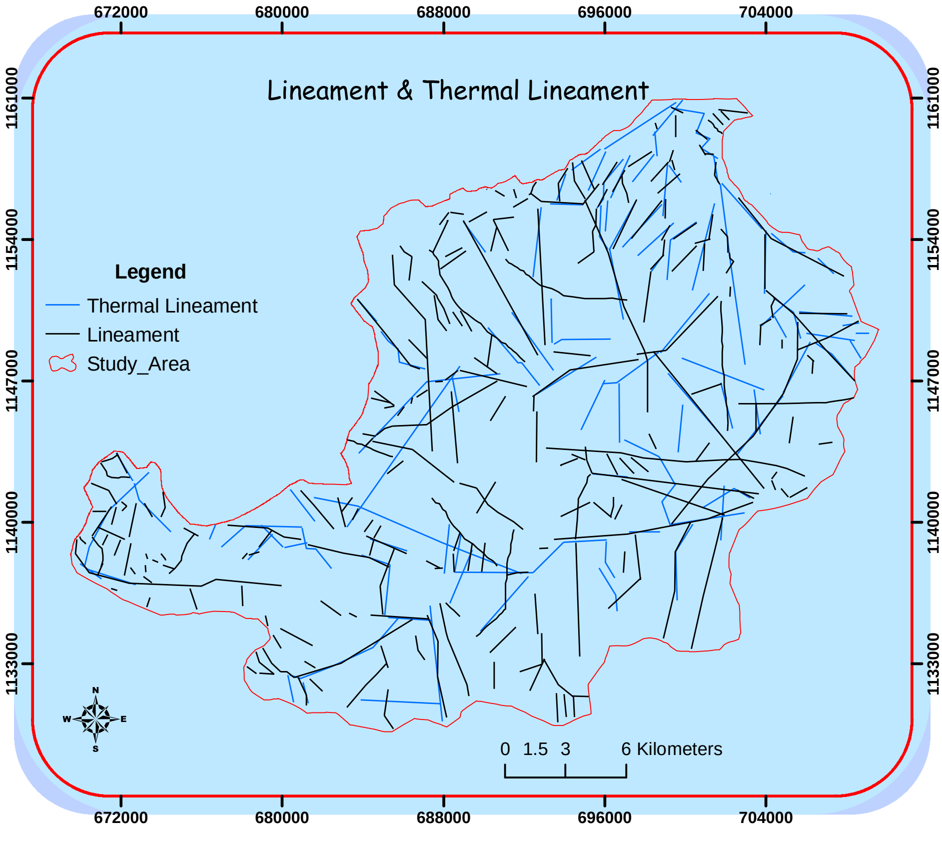


Figure 10 Thermal lineament overlain with multi-spectral lineament

Table 2 Class weight of thermal lineament density

	Thermal Lineament Density (m/km^2)	Very High	High	Medium	Low	Very Low	Weight	Weight %
Very High	2.61-1.52	1					0.5128	51.3
High	1.52-1.04	1/3	1				0.2615	26.2
Medium	1.04-0.64	1/5	1/3	1			0.1290	12.9
Low	0.64-0.23	1/7	1/5	1/3	1		0.0634	6.3
Very Low	0.23-0	1/9	1/7	1/5	1/3	1	0.0333	3.3

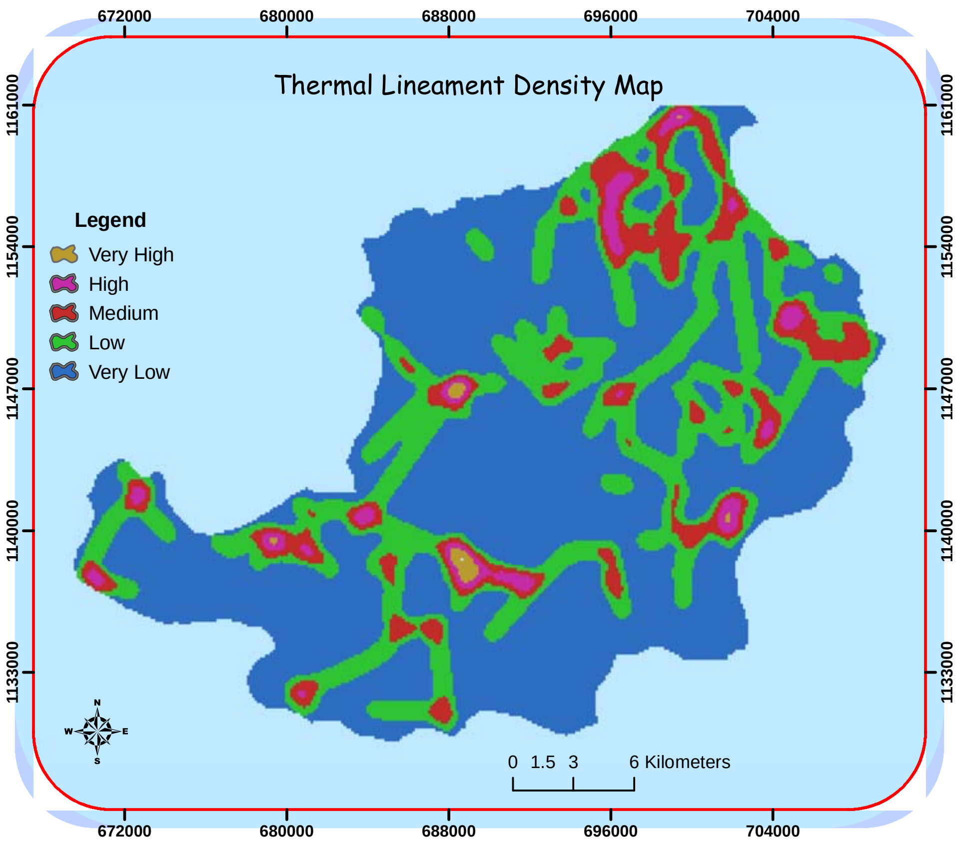


Figure 11 Reclassified thermal lineament density map

4.4 *Vegetation and Soil Moisture Anomaly*

Soil moisture refers to the presence of ground water or water held in the soil horizon during a specific period of a year. Soil can be continuously moist throughout the year or only for specified period according to the water supply condition from above and/or below. Depending on the moisture content level the soil supports different types of vegetation such as grass, or broad leaved native vegetation.

The type and density of natural vegetation that grow in any environment varies depending on the type of soil, amount, depth and quality of available water.

Identification of the type of vegetation that is present in an area can give an indication about availability, depth and quality of the groundwater.

Vegetation grows according to diurnal, seasonal, and annual phonological cycles (Jensen, 1986). Vegetation types and abundance vary according to the thickness of soil and amount of moisture it contains. Thin soil can support abundant vegetation in wet seasons but due to moisture deficit it can not sustain during dry seasons. The type of vegetation that grows in moist soil is different from and is more developed than those growing in moisture stressed soils.

In low land areas where temperature is high vegetation growth is seasonal due to moisture stress. Seasonal vegetation greens up in rainy seasons and dries a few months after the rain stops. The exception is associated to zones of groundwater manifestation. In areas of groundwater manifestation the vegetation remains green even in the driest season of the year and are more developed than the surrounding. In addition in areas where the soil layer doesn't support vegetation growth due to unsuitability of the soil nutrient moisture stressed and moist soils have different reflectance condition.

Digital processing of satellite images acquired during the driest month of the year can assist in mapping these anomaly zones which in turn helps in hunting for groundwater. But vegetation and soil moisture anomaly alone can't guarantee recoverable groundwater.

In order to map the soil and vegetation moisture anomaly of the study area Landsat TM5 sensor image for the month of January, one of the dry months in the study area, was spectrally enhanced using tasseled cap vegetation index. For Landsat TM5 data the tasseled cap index consists of three factors namely brightness (measure of soil), greenness (measure of vegetation), and wetness (interrelationship of soil and canopy moisture). The red component of the band combination 123 in RGB order i.e. soil brightness index (SBV) shows bare areas such as agricultural fields, beaches, and parking lots as the lightest features and green vegetation index (GVI), is an indicator of vegetation status since it displays areas with healthy, green vegetation as the lightest feature (Frankovich, 1999) and blue component indicates soil moisture (ERDAS Field Guide, 1999).

The study area is dominantly covered by deciduous vegetation. In the tasseled cap index the red component dominates the northern part of the study area which has the lowest elevation; the green component dominates along the bank of structurally controlled intermittent streams and in the middle part of the study area whereas the blue component dominates over the southern elevated part of the study area (Figure 12).

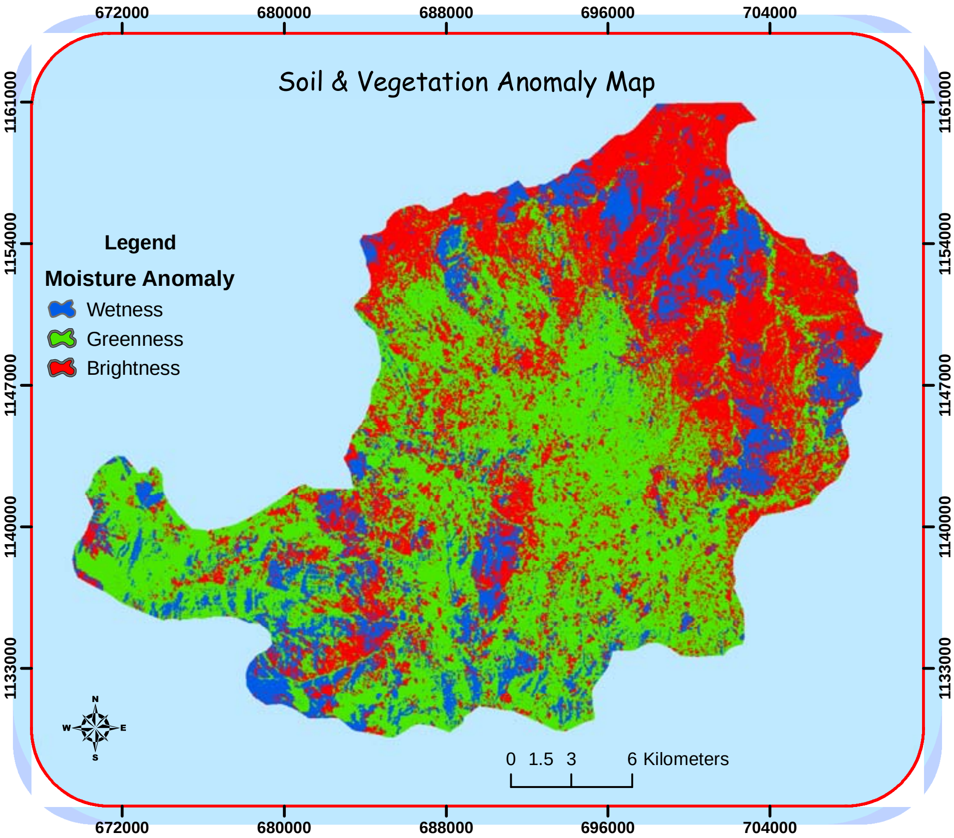


Figure 12 Reclassified soil moisture and vegetation anomaly map

The resulting map was imported to ArcGIS where class weight was given based on the pairwise comparison matrix (Table 3).

Table 3 Class weight of soil moisture and vegetation anomaly

	Brightness	Greenness	Wetness	Weight	Weight %
Brightness	1			0.0549	5.5
Greenness	9	1		0.6554	65.5
Wetness	7	1/3	1	0.2897	29

4.5 Land use/Land cover

Land use is man's activities and various uses which are carried out on land whereas land cover is the natural vegetation, water bodies, rock/soil, artificial cover and others resulting due to land transformation (Ali, 2006).

The amount of precipitation that reaches the ground surface to recharge groundwater depends on the nature and density of vegetation and existence of artificial cover such as buildings and pavements. Vegetation intercepts precipitation above the ground. The intercepted part of the precipitation is temporarily stored on the surface of the vegetation from where the water is either evaporated back into the atmosphere or falls to the ground.

The response of water level to precipitation in two wells installed under similar condition except for land cover has been studied by Zhang et al. (2005). The water level in the well located on land covered with grass was found to have lesser response to rainfall event than well on the bare land.

In an area where the vegetation cover is thick and the air temperature is hot the intercepted precipitation is exposed to fast evaporative loss before reaching the ground surface.

Buildings, pavement and other impermeable layers constructed on natural ground significantly reduce the amount of precipitation that reaches the water table. These structures favor runoff than recharge resulting in reduced groundwater potentiality.

In the study area the major type of lu/lc is natural forest and settlement with minor cultivable lands. Permanent coniferous and deciduous vegetation make up the forest resource of the area.

Lu/lc analysis was conducted using the ETM+ image because it represents the recent status of land use structure as it was the recent image used in the study. Band combinations 432, 453, PCA 123 in RGB order, NDVI and Vegetation index were used for lu/lc analysis. First the multi-spectral image was classified into 10 classes using unsupervised classification. Then by comparing the classified image with different color composite images, the original image and also based on ground truth collected during field visit the ten classes were combined into four classes. The resulting unsupervised classification image signature was used to make supervised classification resulting in hybrid type of classification (Figure 13).

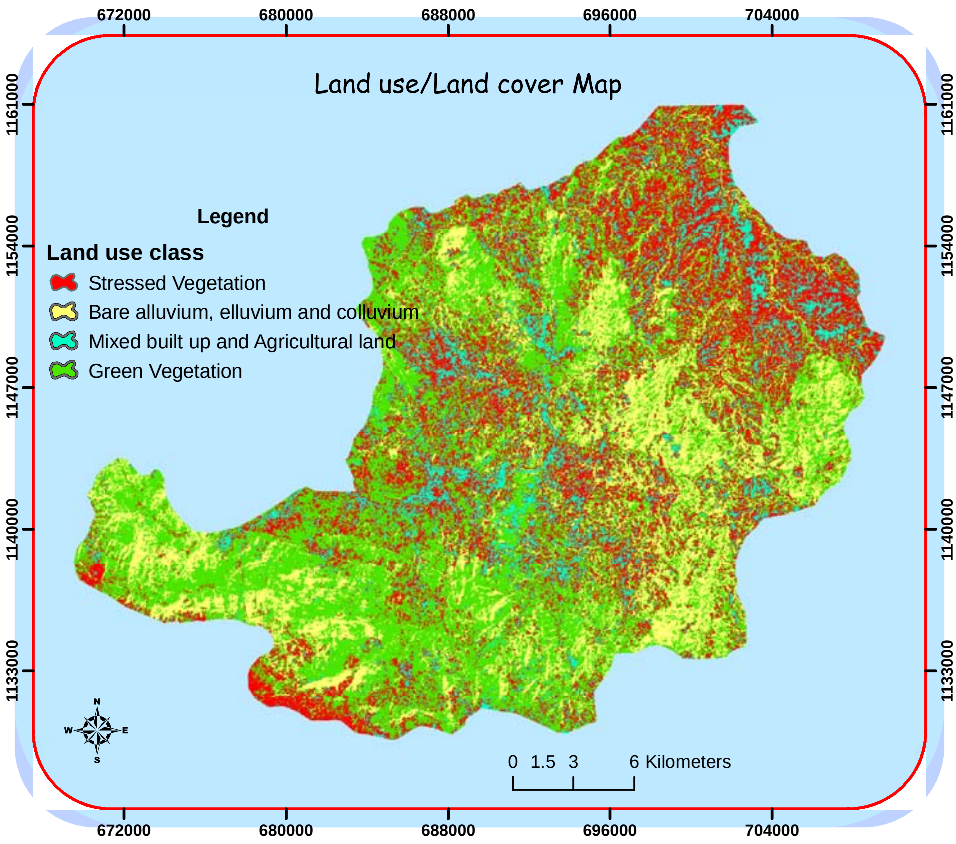


Figure 13 Reclassified lu/lc map

Accordingly the lu/lc classes identified are mixed built up (rural and urban residential areas and road) and agricultural land, bare alluvium, elluvium and delluvium, green vegetation and stressed vegetation. The resulting map was imported as GIS layer and class weight assigned based on pairwise comparison matrix result with CR of 0.04 (Table 4).

Based on the result of pairwise comparison matrix areas covered with green vegetation was found to be least important because it reduces recharge by increasing interception loss whereas areas of bare soil favors infiltration and were considered to be areas of good groundwater potential. Stressed vegetation doesn’t have well developed leaves. Therefore it has less interception capacity as compared to green vegetation identified from the same dry season image. In contrast stressed vegetation increases recharge by reducing overland flow. Therefore they were considered to be the second most important next to bare soil. Built up land increases soil compaction and hence reduces recharge. Farming favors recharge because it increases residence time of overland flow by creating damming effect during precipitation. In the study area built up and agricultural land are intermingled and hence were weighted as third important groundwater potential indicator factor.

Table 4 Class weight of reclassified land use/land cover

	Bare alluvial, elluvail and delluvial soil	Stressed Vegetation	Mixed land use	Green Vegetation	Weight	Weight %
Bare alluvial, elluvial & delluvial soil	1				0.5650	56.5
Stressed Vegetation	1/3	1			0.2622	26.2
Mixed land use	1/5	1/3	1		0.1175	11.8
Green Vegetation.	1/7	1/5	1/3	1	0.0553	5.5

4.6 Lithology

Lithology is one of the factors that indicate the groundwater prospect of an area. Different litholgic units have distinct porosity and permeability. The porosity determines the amount of water which can be held in storage and the permeability determines the ease of withdrawing the water for use (Stanley et al., 1966).

Lithology determines the type of porosity that the rock possesses. The dominant porosity that exists in unconsolidated sediments is intergranular, fracture porosity in consolidated rocks and double porosity in some consolidated volcanic and sedimentary rocks.

The lithologic units found to occur in the study area could be grouped into two major classes; namely the crystalline Precambrian basement rocks, which include metavolcano-sedimentary assemblages and meta-intrusives and the Tertiary volcanics. The crystalline basement rock lacks primary porosity whereas the Tertiary volcanics have primary porosity resulting from vertical cooling joints (Figure 14).

Based on their relative hydrogeological significance the crystalline basement rocks are classified into two; namely the low productive fissured aquifers (amphibolite and quartzofeldspathic schist, metasediments and quartzofeldspathic and graphitic schist, metagranite and metagranodiorite) and aquitards (phyllite, felsic schist, mafic schist, green schist with beds of graphite schist, quartizite, marble and talc schist).

Figure 14 Primary porosity formed by columnar joint in basalt

The digitized geological map of the study area shows the distributions of the reclassified lithologic units, namely low productive fissured aquifers, the aquitards and moderately productive Tertiary basalt (Figure 15). Weight was assigned to the three units based on their degree of importance as potential source of groundwater. Even though it underlies a small area the basalt that possesses primary porosity have higher potential to be source of groundwater followed by low productive fissured rocks and aqucludes (see also Table 5).

Table 5 Class weight of lithologic unit

	Basalt	Low Grade Rock	High Grade Rock	Weight	Weight %
Basalt	1			0.6370	63.7
Low Productive	1/3	1		0.2583	25.8
Aquitards	1/5	1/3	1	0.1047	10.5

4.7 Drainage Density

The drainage that develops in a given area depends on slope, the composition of the underlying bedrock and patterns of geologic structures such as faults/fractures, joints, folds, etc. Drainage network can be described according to its pattern and texture. Drainage pattern is the design formed by the aggregate of drainage ways in an area regardless of whether they are occupied by permanent or perennial stream (Ali, 2006).

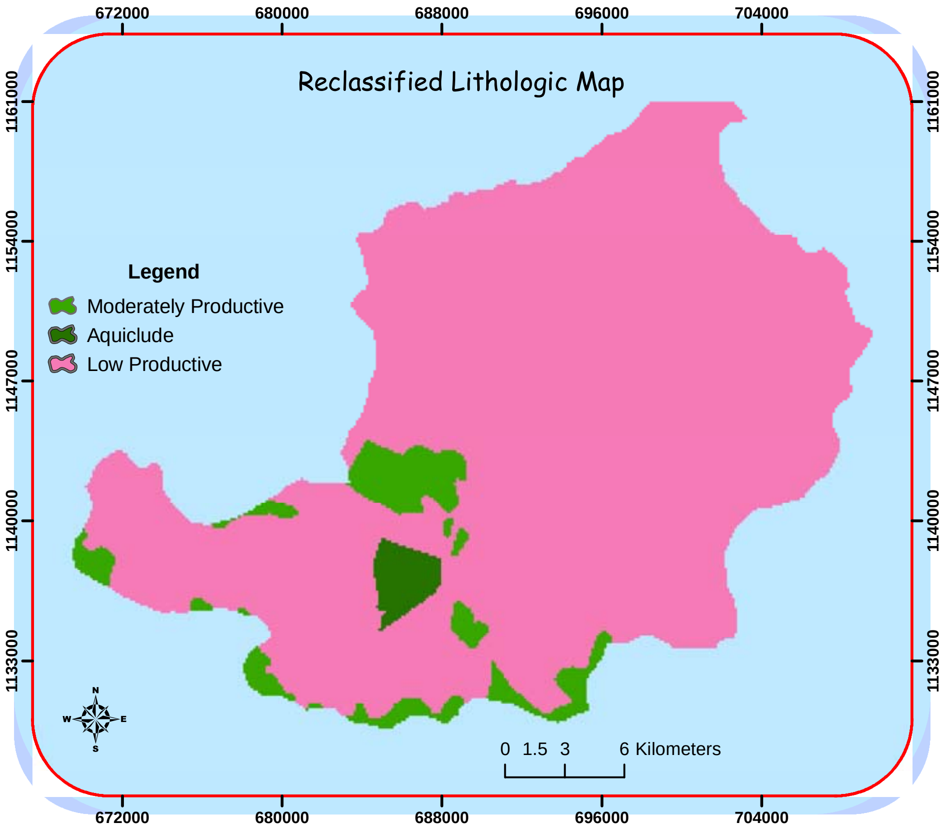


Figure 15 Reclassified lithologic map of the study area (modified from Tefera 1987)

Pattern is associated to the composition and structure of the bedrock over which the stream flows while texture is related to rock/soil permeability. The drainage texture that develops in an area gives important clues of the subsurface conditions, which help in deciphering groundwater conditions of the area. Fine drainage texture develops on bedrock where surface runoff exceeds infiltration and coarse drainage develops on permeable bed rock where infiltration exceeds surface runoff. In porous geologic formation surface drainage will be less developed or completely missing.

The less the rock is permeable the less the groundwater potential of the site will be and vise versa. Hence drainage texture/density can be used as an indicator of the groundwater potentiality of an area.

Tumet stream with its two principal tributaries streams Menge and Shegol forms the main drainage system of the study area. Tumet drains to Dabus River which is the tributaries of the Blue Nile (Abay) River.

The drainage network of the study area was digitized from topographic map of scale 1:50,000 produced by the Ethiopian Mapping Agency (EMA) using ArcGis 9.1. The drainage types that developed in the study area are recognized to be sub-parallel and dendritic. These types of drainage patterns develop in massive homogenous rocks having slight difference in resistance. In hard rock terrain surface drainage is generally aligned along fracture system (Tamiru Alemayehu, 2006).

The digitized drainage map was converted to raster format after which drainage density was calculated (Figure 16). The resulting drainage density was reclassified and given class weight according to pairwise comparison matrix with CR of 0.05 (Table 6). Accordingly low drainage density is associated with areas underlain by the metagranitoids and Tertiary basalts.

Table 6 Class weigh of drainage density

	Drainage density (m/km^2)	Very low	Low	Medium	High	Very high	Weight	Weight %
Very low	0-1.39	1					0.5128	51.3
Low	1.39-2.34	1/3	1				0.2615	26.2
Medium	2.343-.11	1/5	1/3	1			0.1290	12.9
High	3.11-3.95	1/7	1/5	1/3	1		0.0634	6.3
Very high	3.95-5.65	1/9	1/7	1/5	1/3	1	0.0333	3.3

4.8 Slope

Slope determines the hydrological characteristics of the catchment. Higher slope results in higher hydraulic gradient which favors overland flow than percolation by reducing residence time of the precipitation.

In order to generate slope map, contour lines were digitized from the mosaic of topographic map. The digitized contours were used to generate Triangulated Irregular Network (TIN) from which the slope map of the study area was generated (Figure 17). The generated slope map was reclassified into 5 classes (flat, gentle, moderate, steep and very steep) and assigned class weight based on degree of importance calculated using pairwise comparison matrix with CR of 0.05 (Table7). The classification result revealed that most part of the study area is flat and gentle with weighted percentage of about 51 and 26 respectively.

Table 7 Class weight of slope

	Slope (Degree)	Flat	Gentle	Moderate	Steep	Very steep	Weight	Weight %
Flat	0-2.94	1					0.5128	51.3
Gentle	2.94-9.49	1/3	1				0.2615	26.2
Moderate	9.49-18.64	1/5	1/3	1			0.1290	12.9
Steep	18.64-32.71	1/7	1/5	1/3	1		0.0634	6.3
Very Steep	32.71-83. 73	1/9	1/7	1/5	1/3	1	0.0333	3.3

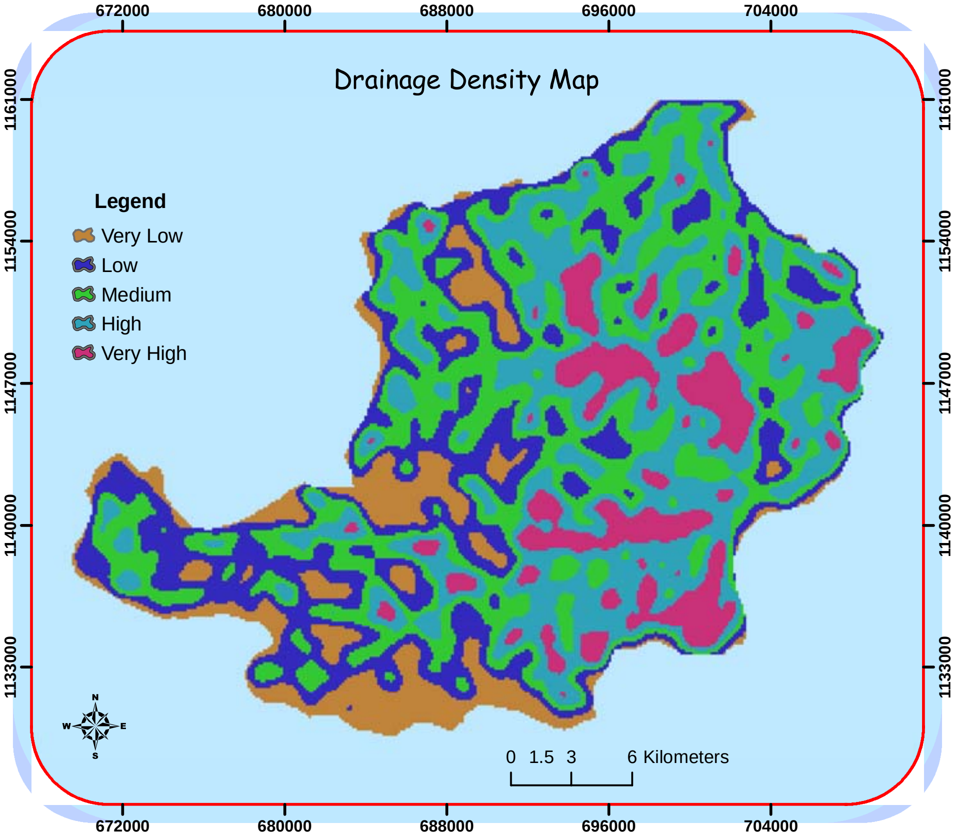


Figure 16 Reclassified drainage density map

4.9 Zone of Weathering

The geology of the study area is dominantly basement rock overlain by weathered material or regolith produced as a result of insitu weathering of the underlying bed rocks. The importance of the basement rocks as an aquifer depends on the degree of fracturing and weathering. Fractures don't constitute large volume of rock and, therefore, the porosity of fractured rocks is generally small. Weathering at near surface and deeper along zone of fracturing can significantly improve the water holding and bearing characteristics of the hard rocks. A borehole that penetrates large thickness of regolith can have better yield as compared to the one that penetrate fractured zone only.

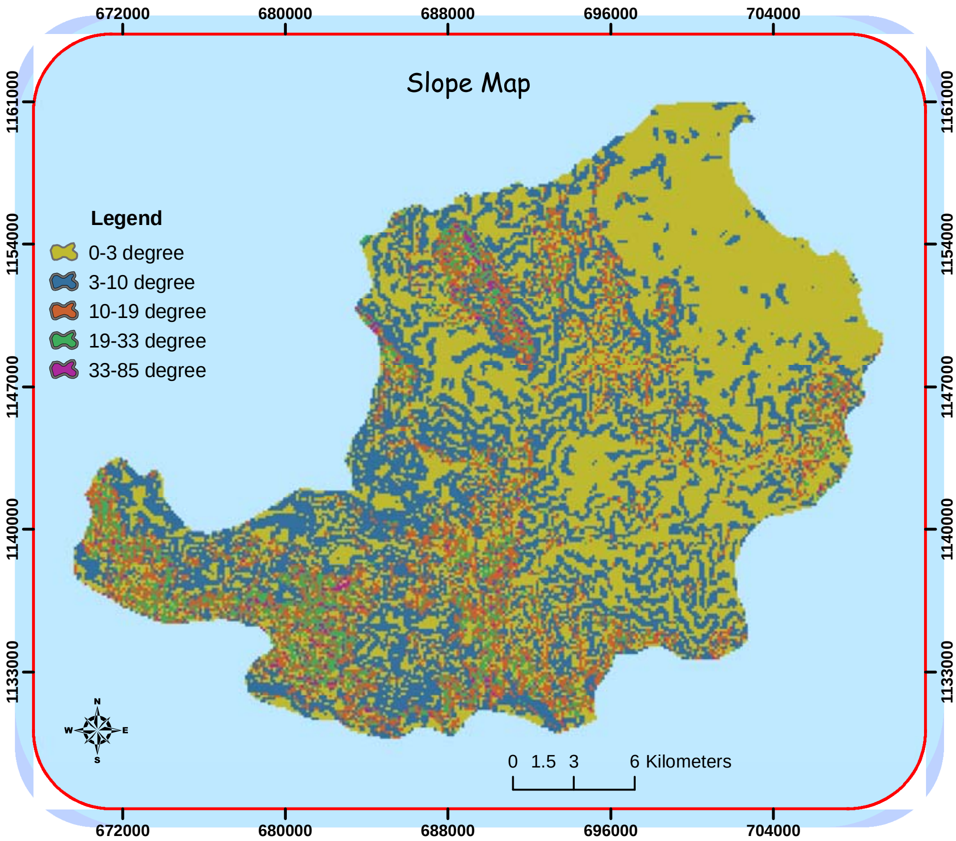


Figure 17 Reclassified slope map

In the study area hand dug wells that tap water from the upper weathered mantle alone provides year round water supply. The depths of these wells are extended when there is a serious shortage of water due to drawdown. Increase of depth from 7 to 18m was reported. This shows that dug wells don't penetrate full thickness of the weathered portion of the basement rock. The reasons for partial penetration are;

- Excavations are done with human labor which makes deep penetration difficult.
- Rise in water level. When water column is above certain level it is difficult to continue digging.
- The other factor is the season of excavation. Dug wells excavated shortly after rainy season strikes shallow groundwater at relatively shallower depth than wells excavated in dry season in the same area.

In the study area where the rainfall duration is long and air temperature is hot the zone of weathering is an important source of groundwater that can be put into use economically through shallow well drilling and hand dug well excavation. Therefore depth of weathering is found to be an important factor in the delineation of groundwater potential zones.

Mapping of the zone of weathering for the study area was done based on depth of dug wells and thickness of weathered portion obtained from VES survey interpretation result.

4.9.1 Geophysical Survey

Geophysical studies involve measurements of basic physical parameters to infer subsurface conditions. Geophysical methods are classified as active and passive. Active geophysical methods measure naturally occurring soil/rock property, like magnetics, gravity, etc whereas passive methods measure the reaction of formations to specific disturbance, like electrical, seismic, etc (Moss & George, 1990).

Electrical method is the most widely used geophysical method in groundwater exploration. In this method current is injected into the ground and the potential induced by the current flow is measured. Different geological materials have different response to the introduced current.

Two techniques of electrical resistivity survey are most commonly used in groundwater exploration; Sounding and Profiling. In sounding, the electrodes are moved farther apart for successive readings. With increasing distance, the current will penetrate more deeply, and thus the potential difference reflects the electrical properties of materials at increasing depth. In resistivity profiling, the spacing between electrodes is kept constant, and the array is moved from place to place over the study area. Profiling is designed to show resistivity difference at certain constant depth.

For the current study VES survey was used using Schlumberger electrode configuration with an electrode spacing varying between 330 and 500m. The purpose of the electrical sounding survey was to determine the thickness of depth of weathering.

A total of 13 VES surveys were conducted taking into consideration the geological variability, catchment size and accessibility. Data was collected using SAS Terrameter 300c geophysical instrument. The field data recorded includes the current and potential electrode separations and the resistance at each separation distance.

The recoded resistance value was converted to apparent resistivity by multiplying with a constant (Annex 1). The interpretation of the survey finding was done using “RESIST” geophysical software, developed by the MSC research project at International Institute for Geo-information Science and Earth Observation (ITC) in 1988.

The interpretation result (Annex 2) could not be compared with lithologic log result to establish relationship between layer resistivty and degree of weathering due to lack of well log data. Therefore it was assumed that the thickness of top most layers having relatively low resistivity values represents the thickness of weathered layer (Table 8).

Table 8 Depth of weathering calculated from VES survey

No	Site Name	Depth of weathering (m)	Remark
1	Abjendu	32.4	
2	Shegol	9.1	
3	Belmagoha	7	
4	Kudiya	5.2	
5	Tumet Bariya	5.6	
6	Tumet Mukewar (Menge stream)	1.7	
7	Tumet Mukewar (Tumet stream)	2.7	
8	Jebrona	5.3	
9	Rob Megele	2.6	
10	Bela Gali	3.4	
11	Keshaf	2.3	
12	Malo	0.9	

The interpretation result of VES survey showed that maximum depth of weathering was at Abjendu site. The VES points were overlaid with the lineament map to see relationship between depth of weathering and lineaments. The result revealed that the point of maximum depth of weathering is located around the intersection of two major lineaments (Figure18).

At Jebrona and Tumet Mukewar where VES was done near dug wells contrasting results were obtained. The depth of weathering from VES interpretation was found to be shallower than depth of dug wells. In another locality, Shegol, the depth of machine drilled shallow well is 46.5 but the interpretation result revealed possibility of drilling up to 69m before encountering massive basement rock (Figure 19).

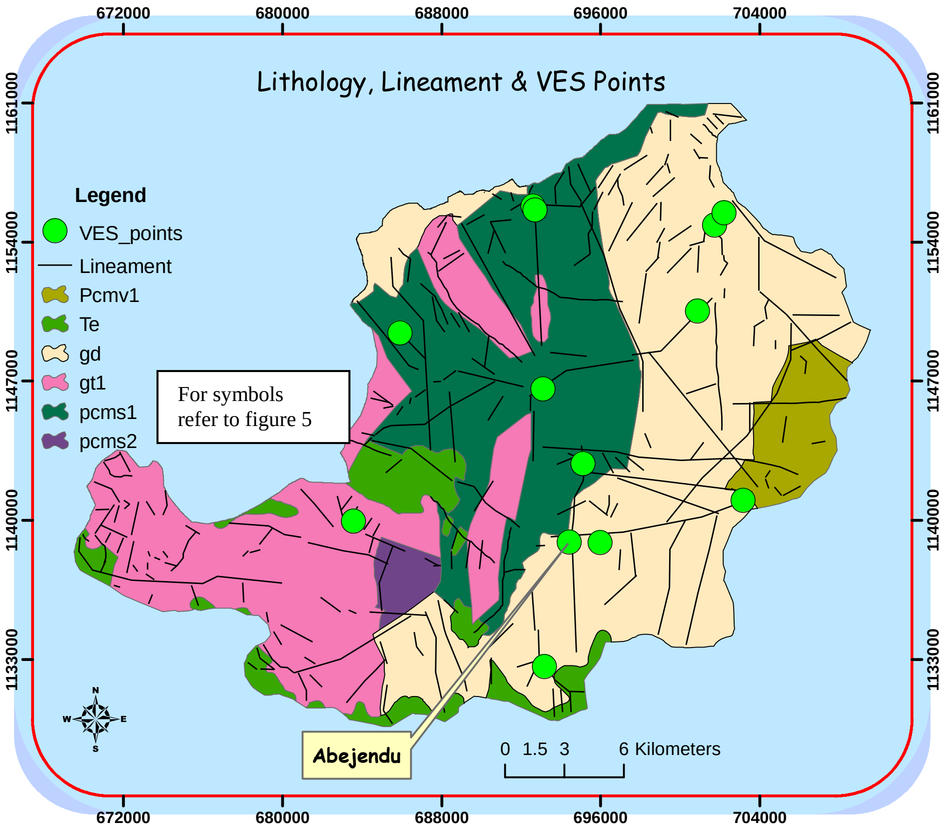
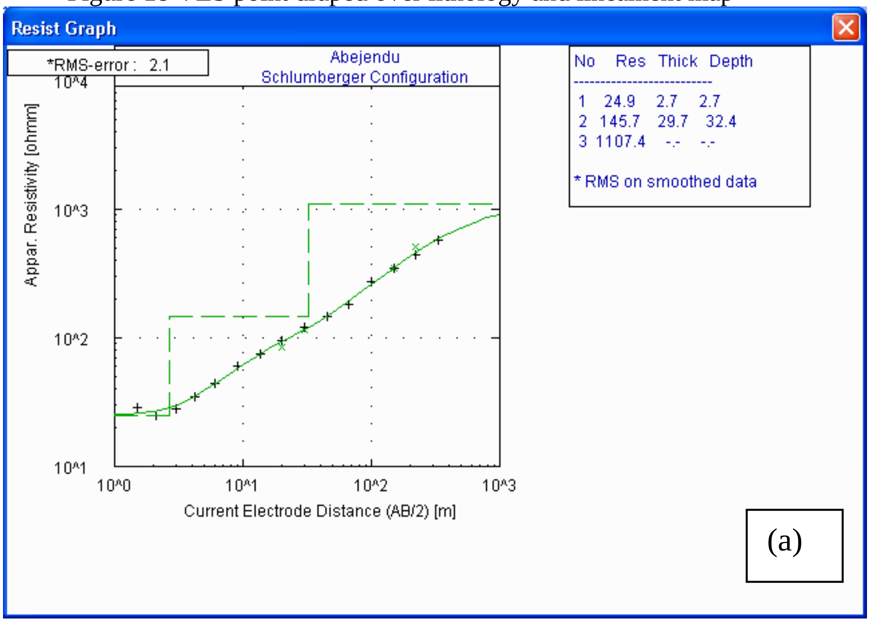


Figure 18 VES point draped over lithology and lineament map



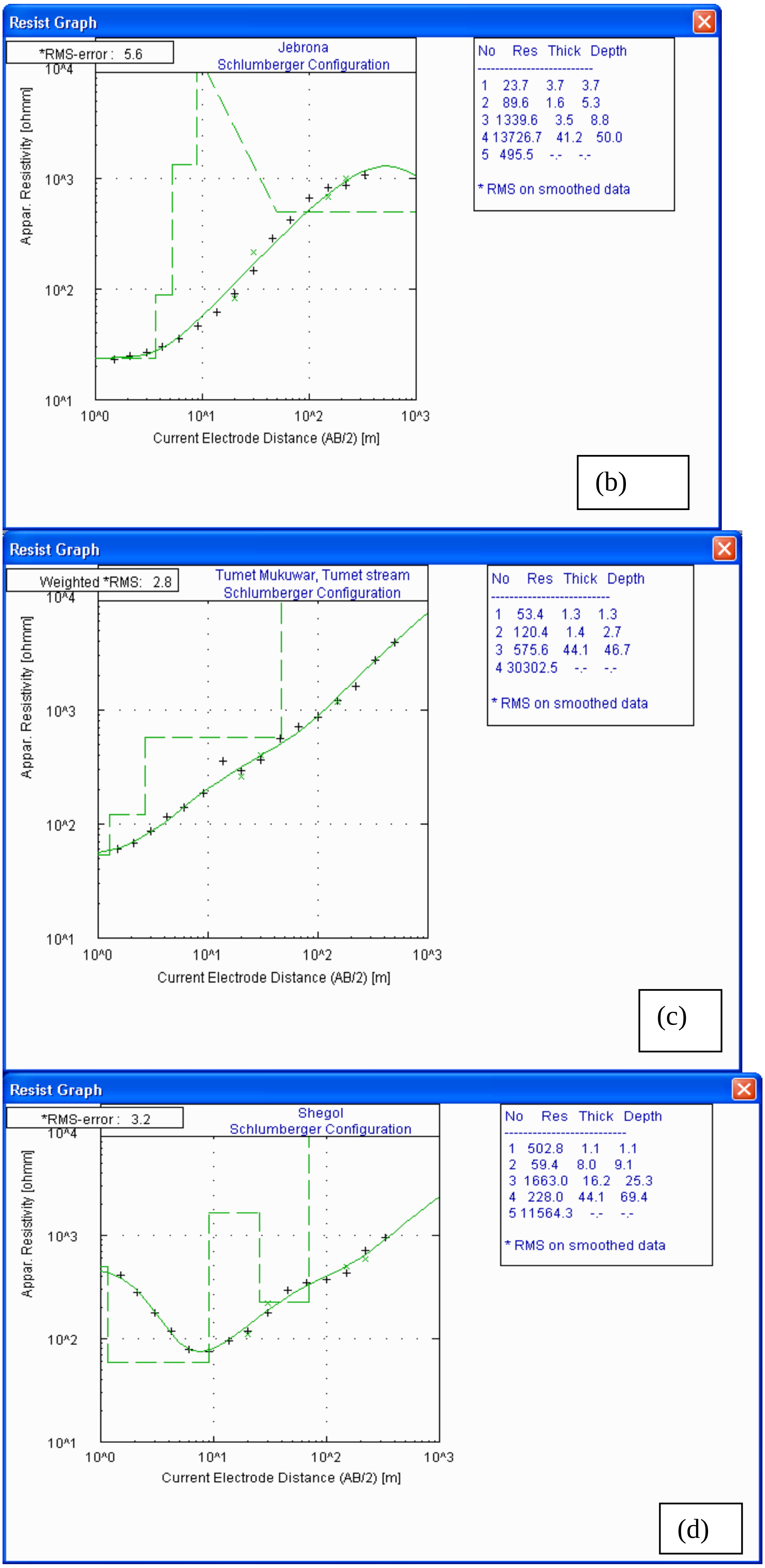


Figure 19 VES interpretation result of (a)Abejendu, (b)Jeberona, (c)Tumet Mukewar, and (d)Shegol sites

The depth of dug wells and zone of weathering point data obtained from the result of the VES survey were used for creating continuous weathering surface. For this Inverse Distance Weight (IDW) interpolation technique in geo-statistical analyst extension of ArcGIS was used. The resulting map was reclassified into 5 classes and assigned class weight based on the pairwise comparison matrix with CR of 0.05 (Figure 20). In the matrix higher weight was assigned to areas having relatively deeper zone of weathering with the assumption that the transmisivity of the aquifer increases with increase in thickness of weathered layer.

The comparison of the resulting depth of weathering map with lithology didn't give clear indication of the relationship between the depth of weathering and type of rock. This is due to partial penetration of the dug wells, lack of uniform spatial distribution of dug wells and unexpected result from the VES survey interpretation.

4.9.2 Water Point Inventory

Understanding the spatial distributions of existing water supply wells helps in developing well sitting strategy. Screening of productive versus dry wells can provide a valuable assessment of groundwater conditions.

The water supply sources for most part of the year in the study area are traditional hand dug wells excavated within the alluvial deposits along intermittent valley bed and dug wells excavated within the weathered zone and equipped with concrete cylinder and hand pump. The depth of the dug wells ranges from 3-18m and their discharge is variable depending on their location and depth. Dug wells located at head water have low discharge and those located at lower elevation along surface water courses have better yield in general.

During field visit 49 water points mostly hand dug wells were inventoried with physical presence and from documents (Annex 3). The water point information was collected for estimating the depth of weathering and validation of the model out put. Accordingly the dug wells were used for estimating depth of weathering while the machine drilled wells were used for validation of the model result.

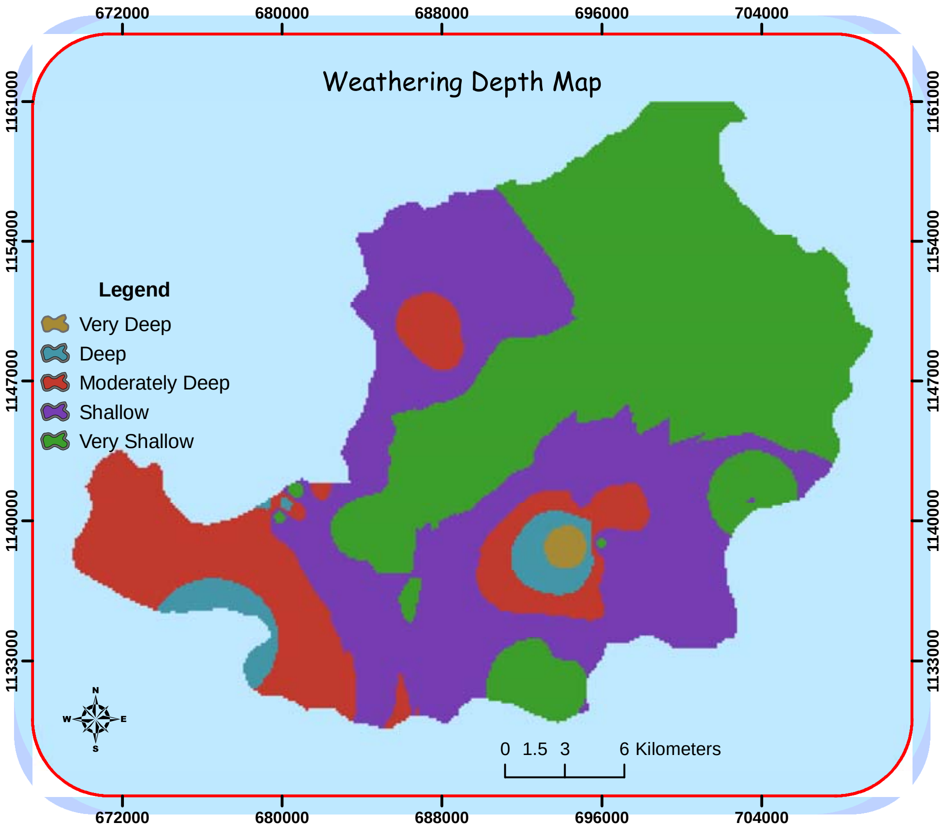


Figure 20 Reclassified depth of weathering map

Table 9 Class weight of depth of weathering

	Depth of weathering (m)	Very deep	Deep	Moderate	Shallow	Very shallow	Weight	Weight %
Very deep	32.31-18.09	1					0.5128	51.3
Deep	18.09-11.40	13	1				0.2615	26.2
Moderate	11.40-8.53	1/5	1/3	1			0.1290	12.9
Shallow	8.53-6.26	1/7	1/5	1/3	1		0.0634	6.3
Very shallow	6.26-1.72	1/9	1/7	1/5	1/3	1	0.0333	3.3

V. Results and Discussion

5.1 Results

The occurrence and movement of groundwater is controlled by multiple factors. Integration of these factors manually requires huge manpower and time. The use of GIS reduces the time required and increases the accuracy. GIS allows map information to be combined, analyzed and presented in many different ways (MacDonald, 2005).

In order to delineate the study area into different groundwater prospect zones the factor maps produced from satellite images, existing maps and field survey result were combined in GIS environment.

For this the vector thematic layers generated from topographic maps, geologic map and satellite images were converted to raster layer. All factor maps were reclassified and class weight determined through multi-criteria evaluation technique using pairwise comparison matrix. The weight of each factor map was determined through similar procedure (Table 9). CR for the matrix is 0.10. Accordingly thermal lineaments which were assumed to be tectonic lineaments and having groundwater manifestation were given a higher degree of influence as compared to the remaining seven factors.

Aggregation of the class and factor map weight was done using WLC whereby the class weights were multiplied with the factor weight and the products were summed over all attributes.

The resulting groundwater prospect map was categorized as Excellent, Very good, Good, Moderate and Poor (Figure 21). The model result indicated that large part of the study area is classified under poor groundwater potential.

5.2 Evaluation of Model Result and Discussion

The validity of the model result was checked against borehole data which reflects the actual groundwater potential of the area. Accordingly the result showed that the groundwater potential zones prepared through this model are generally in agreement with borehole data (Figure 22 & Table 11).

The northeastern extensive plain underlain by metagranodiorite is found to have poor groundwater potential except along intermittent stream courses whereas areas underlain by basalt is the most prospective with few isolated pockets within the intrusive and metavolcano-sedimentary assemblage.

The northeastern part of the study area has relatively lower elevation. The rainfall amount is expected to decrease with altitude which in turn reduces the degree of weathering and hence the groundwater potential. The two dry wells at Alfashir and Jebrona villages are located in this part of the study area. This shows that the model output has good match with the actual groundwater condition of the study area.

The borehole at Tumet Mukewar is located on an area classified as poor groundwater potential but the well has low yield. This is probably due to the local variation of the geology which might have resulted in the development of localized aquifer system.

The borehole at Menge is the only well that has been tested for yield in the study area. This well is located on an area classified as good with respect to groundwater potential but has a yield of 4l/s which is high in basement terrain. In order to explain the major controlling factor of this high yielding well the boreholes point data was overlaid on all the factor maps turn by turn. The result indicated that this well is located along major lineament but on an area classified as low lineament density (Figure 23). Hence it was concluded that lineaments play a significant role for locating a high yield well in the study area.

The boreholes at Keshaf (Belfru) and Keshaf (Kartoum) were described to have good sustainable yield through hand pump by beneficiary community. These boreholes are located in an area where the underlying geology is basalt and land use is mixed agricultural and residential. Many hand dug wells that give year round water supply are also found in this area which indicates that the area has good recharge possibility and relatively thick weathered mantle. All these show the classification of the area under excellent groundwater potential is acceptable.

In general the result of the model is found to be in good agreement with the information on the ground. Hence the finding of this work demonstrated that the methodology has merits to be replicated in groundwater exploration in other areas with appropriate modification of factors.

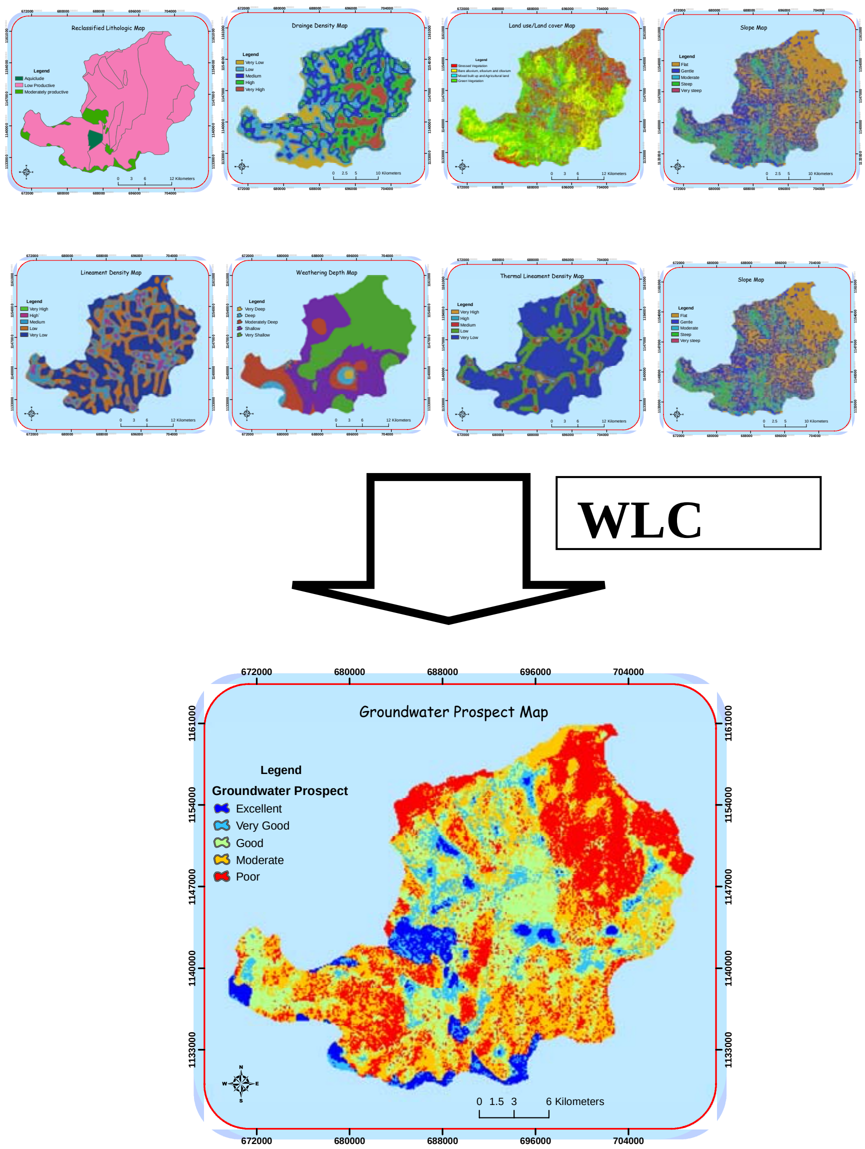


Figure 21 Groundwater Prospect map

Table 10 Pairwise comparison matrix and weight of factor maps

	TLD	LD	Lithology	D.D	Slope	DW	SVA	Lu/lc	Weight	Weight %
TLD	1								0.3780	37.80
LD	1/3	1							0.2141	21.41
Lithology	1/5	1/3	1						0.1500	15.00
D.D	1/9	1/7	1/3	1					0.0339	3.39
Slope	1/5	1/3	1/5	5	1				0.0967	9.67
DW	1/5	1/3	1/3	3	1/3	1			0.0595	5.95
SVA	1/7	1/5	1/3	3	1/3	1	1		0.0498	4.98
Lu/lc	1/9	1/9	1/7	1/5	1/5	1/5	1/3	1	0.0179	1.79

TD-Thermal Lineament Density, LD-Lineament Density, D.D-Drainage Density, DW-Depth of Weathering, SVA-Soil & Vegetation anomaly, Lu/lc-Land use/land/cover

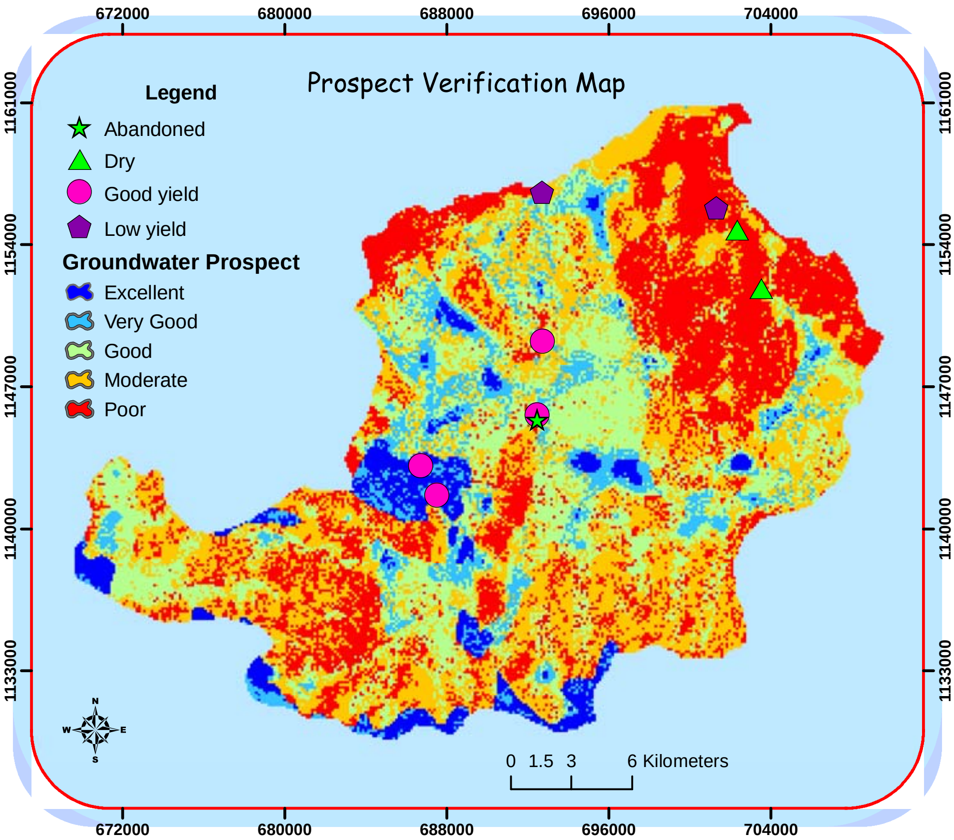


Figure 22 Model verification map

Table 11 Comparison of well yield and model result

No	Name of water point	Yield	Depth (m)	Location of water point in the model
1	Menge town	4l/s	51	Good
2	Menge town	Productive (abandoned)	-	Good
3	Keshaf (Kartoum)	Good yield through hand pump	-	Excellent
4	Keshaf (Belfru)	Good yield through hand pump	-	Excellent
5	Tumet Mukwar	Low yield	46	Poor
6	Tumet Mukwar	Dry	31	Poor
7	Alfashir	Dry	26	Poor
8	Shegol	Productive (low yield)	46.5	Moderate
9	Bane	Productive (good yield)	40	Good

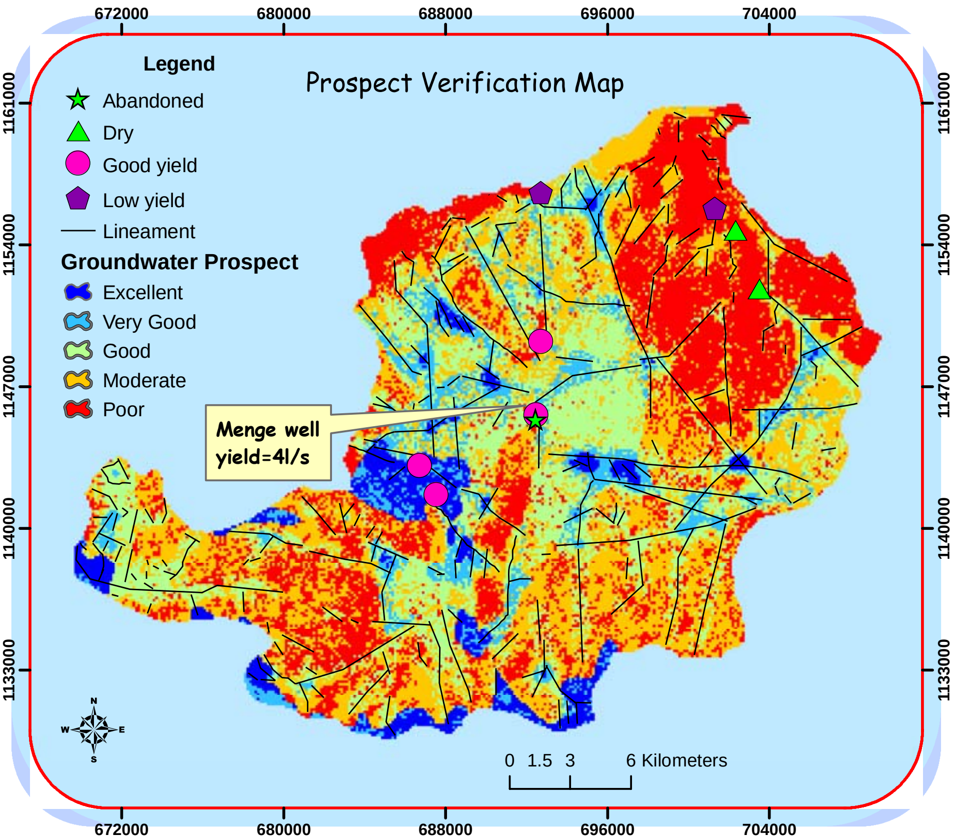


Figure 23 Comparison of lineament vs. yield of wells

VI. Summary, Conclusion and Recommendations

6.1 Summary and Conclusion

Water is one of the basic requirements for sustainable socio-economic development. Ethiopia has abundant surface and groundwater resources but the resources are not uniformly distributed through out its geographic boundary. Availability of surface water resource in peripheral lowland areas is limited in spatial distribution. Groundwater is the dependable source to be explored and developed to improve the socio-economic and cultural well being of the society living in this part of the country.

Remote sensing offers great potential in groundwater resource evaluation as it provides medium to high spatial, temporal and spectral resolution synoptic coverage digital data that can be interpreted by integrating with the available ground information in GIS environment.

In this study remote sensing and GIS was used for delineation of groundwater potential zones in upper Tumet catchment, Menge area. Factor maps like lineament, thermal lineament, soil moisture and vegetation anomaly and land use/land cover were generated from Landsat ETM+ and TM5 sensors. The satellite images used for this study were acquired in November and January which are cloud free dry month images for extracting maximum information. In order to get the information from the images, image pre-processing, spatial, radiometric and spectral enhancements were performed. Different false color composite images were generated and classified.

Additional information was generated from existing maps. Accordingly drainage, contour and lithology were digitized from topographic and geologic maps. The digitized lithologic units were reclassified based on their relative hydrogeological significance. Field survey was conducted to collect primary point data like ground control point for geometric rectification of maps and images, ground truth for image classification, water point inventory and Vertical Electrical Sounding (VES) surveys for mapping the zone of weathering and model validation.

GIS analysis was conducted on the input dataset to get new derived information. Accordingly Lineament, thermal lineament and drainage network were analyzed to generate lineament, thermal lineament and drainage density maps; contour was used for generating slope map. Weathering surface was generated using point data from depth of dug wells and VES interpretation results. The resulting maps were reclassified to common scale and class weight was assigned using pairwise comparison matrix. Other thematic layers like soil and vegetation anomaly, land use/land cover and lithology were also given class weight using similar technique.

In order to combine the eight thematic factor maps generated from different sources multi-criteria evaluation was performed using Saaty's 9 point continuous scale to assigning factor weight. Then Weighted Linear Combination method was used to combine the thematic layers and model the groundwater potential of the study area.

The resulting map was classified into 5 groundwater prospect zones; Excellent, Very good, Good, Moderate and Poor. The model result showed that large part of the study area has poor groundwater potential.

The groundwater potential map generated through this model was verified using drilled shallow wells to ascertain the validity of the model. The result showed the developed model is in agreement with the information from the drilled shallow wells. This illustrated the methodology has merits and can be successfully used.

6.2 Recommendations

Based on the present study the following recommendations are made

- Satellite image processing provides important groundwater indicator parameters in shorter time and lesser cost. Therefore integration of these data with ground based information in GIS environment is recommended for groundwater development projects.
- In basement terrain especially where rainfall amount is high and duration is long, the zone of weathering is an important source of groundwater that can be exploited economically. Therefore proper mapping of this zone needs to be done using VES data calibrated with electrical well logging and lithologic log results.
- For more realistic result detailed ground verification of thematic layers generated from satellite images and GIS model output needs to be done.

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Annexes

Annex I VES Raw Data

SCHLUMBERGER ARRAY DATA COLLECTION SHEET

Instrument:-ABM Terrameter SAS 300C

Site Name Abejendu, Menge, Benishanguel Gumuz

Research Title: Delineation of Groundwater Potential zones in upper Tumet Catchment, Menge area, Western Ethiopia Using Remote Sensing and GIS

UTM Grid 0694426mE, 1138937mN, Elevation 1083m DATE of Data collection:- May 18, 2007

	AB/2 (M)	MN/2 (M)	K	R (ohm)	p (ohm-m)=E*D	REMARK
1	1.5	0.5	6.28	4.59	28.8252	
2	2.1	5	13.1	1.879	24.6149	
3	3	0.5	27.5	1.011	27.8025	
4	4.2	0.5	54.7	0.636	34.7892	
5	6	0.5	113	0.396	44.748	
6	9	0.5	254	0.236	59.944	
7	13.5	0.5	572	0.1308	74.8176	
8	20	0.5	1250	0.0765	95.625	
9	20	6	95.3	0.889	84.7217	
10	30	0.5	2830	0.0408	115.464	
11	30	6	226	0.537	121.362	
12	45	6	520	0.28	145.6	
13	66	6	1130	0.1617	182.721	
14	100	6	2620	0.1034	270.908	
15	150	6	5880	0.0592	348.096	
16	150	45	715	0.491	351.065	
17	220	6	12600	0.0409	515.34	
18	220	45	1620	0.271	439.02	
19	330	45	3750	0.1524	571.5	

SCHLUMBERGER ARRAY DATA COLLECTION SHEET

Instrument:-ABM Terrameter SAS 300C

Site Name Bela Gali, Menge, Benishanguel Gumuz

Research Title: Delineation of Groundwater Potential zones in upper Tumet Catchment, Menge area, Western Ethiopia Using Remote Sensing and GIS

UTM Grid 0700863mE, 1150548mN, Elevation 919m DATE:- May 17, 2007

	AB/2 (M)	MN/2 (M)	K	R (ohm)	p (ohm-m)=E*D	REMARK
1	1.5	0.5	6.28	42.3	265.644	
2	2.1	5	13.1	21.4	280.34	
3	3	0.5	27.5	9.37	257.675	
4	4.2	0.5	54.7	5.29	289.363	
5	6	0.5	113	3.06	345.78	
6	9	0.5	254	2.01	510.54	
7	13.5	0.5	572	1.313	751.036	
8	20	0.5	1250	1.038	1297.5	
9	20	6	95.3	5.46	520.338	
10	30	0.5	2830	0.29	820.7	
11	30	6	226	3.37	761.62	
12	45	6	520	0.94	488.8	
13	66	6	1130	0.666	752.58	
14	100	6	2620	0.391	1024.42	
15	150	6	5880	0.28	1646.4	
16	150	45	715	3.12	2230.8	
17	220	6	12600	0.188	2368.8	
18	220	45	1620	1.94	3142.8	
19	330	45	3750	0.874	3277.5	

SCHLUMBERGER ARRAY DATA COLLECTION SHEET

Instrument:-ABM Terrameter SAS 300C

Site Name Belmagoha, Menge, Benishanguel Gumuz

Research Title: Delineation of Groundwater Potential zones in upper Tumet Catchment, Menge area, Western Ethiopia Using Remote Sensing and GIS

UTM Grid 0695109mE, 1142875mN, Elevation 1127m DATE:- May 19, 2007

	AB/2 (M)	MN/2 (M)	K	R (ohm)	p (ohm-m)=E*D	REMARK
1	1.5	0.5	6.28	4	25.12	
2	2.1	5	13.1	1.617	21.1827	
3	3	0.5	27.5	0.852	23.43	
4	4.2	0.5	54.7	0.458	25.0526	
5	6	0.5	113	0.243	27.459	
6	9	0.5	254	0.1096	27.8384	
7	13.5	0.5	572	0.0781	44.6732	
8	20	0.5	1250	0.0474	59.25	
9	20	6	95.3	0.597	56.8941	
10	30	0.5	2830	0.0276	78.108	
11	30	6	226	0.346	78.196	
12	45	6	520	0.252	131.04	
13	66	6	1130	0.1534	173.342	
14	100	6	2620	0.0849	222.438	
15	150	6	5880	0.0488	286.944	
16	150	45	715	0.319	228.085	
17	220	6	12600	0.0267	336.42	
18	220	45	1620	0.1765	285.93	
19	330	45	3750	0.1079	404.625	

SCHLUMBERGER ARRAY DATA COLLECTION SHEET

Instrument:-ABM Terrameter SAS 300C

Site Name Keshaf, Menge, Benishanguel Gumuz

Research Title: Delineation of Groundwater Potential zones in upper Tumet Catchment, Menge area, Western Ethiopia Using Remote Sensing and GIS

UTM Grid 0683562mE, 1139994mN, Elevation 1259m DATE:- May 21, 2007

	AB/2 (M)	MN/2 (M)	K	R (ohm)	p (ohm-m)=E*D	REMARK
1	1.5	0.5	6.28	22.1	138.788	
2	2.1	5	13.1	7.94	104.014	
3	3	0.5	27.5	3.26	89.65	
4	4.2	0.5	54.7	1.516	82.9252	
5	6	0.5	113	0.684	77.292	
6	9	0.5	254	0.573	145.542	
7	13.5	0.5	572	0.464	265.408	
8	20	0.5	1250	0.312	390	
9	20	6	95.3	1.135	108.1655	
10	30	0.5	2830	0.1829	517.607	
11	30	6	226	0.719	162.494	
12	45	6	520	0.487	253.24	
13	66	6	1130	0.296	334.48	
14	100	6	2620	0.1947	510.114	
15	150	6	5880	0.1528	898.464	
16	150	45	715	0.772	551.98	
17	220	6	12600	0.1254	1580.04	
18	220	45	1620	0.357	578.34	
19	330	45	3750	0.1978	741.75	

SCHLUMBERGER ARRAY DATA COLLECTION SHEET

Instrument:-ABM Terrameter SAS 300C

Site Name Kudiya, Menge, Benishanguel Gumuz

Research Title: Delineation of Groundwater Potential zones in upper Tumet Catchment, Menge area, Western Ethiopia Using Remote Sensing and GIS

UTM Grid 0693103mE, 1146643mN, Elevation 1113m DATE:- May 15, 2007

	AB/2 (M)	MN/2 (M)	K	R (ohm)	p (ohm-m)=E*D	REMARK
1	1.5	0.5	6.28	18.66	117.1848	
2	2.1	5	13.1	6.86	89.866	
3	3	0.5	27.5	2.7	74.25	
4	4.2	0.5	54.7	1.427	78.0569	
5	6	0.5	113	0.722	81.586	
6	9	0.5	254	0.415	105.41	
7	13.5	0.5	572	0.272	155.584	
8	20	0.5	1250	0.1805	225.625	
9	20	6	95.3	1.99	189.647	
10	30	0.5	2830	0.1287	364.221	
11	30	6	226	1.72	388.72	
12	45	6	520	1.115	579.8	
13	66	6	1130	0.693	783.09	
14	100	6	2620	0.396	1037.52	
15	150	6	5880	0.22	1293.6	
16	150	45	715	1.533	1096.095	
17	220	6	12600	0.1366	1721.16	
18	220	45	1620	0.902	1461.24	
19	330	45	3750	0.904	3390	

SCHLUMBERGER ARRAY DATA COLLECTION SHEET

Instrument:-ABM Terrameter SAS 300C

Site Name Malo, Menge, Benishanguel Gumuz

Research Title: Delineation of Groundwater Potential zones in upper Tumet Catchment, Menge area, Western Ethiopia Using Remote Sensing and GIS

UTM Grid 0685913mE, 1149450mN, Elevation 1144m DATE:- May 17, 2007

	AB/2 (M)	MN/2 (M)	K	R (ohm)	p (ohm-m)=E*D	REMARK
1	1.5	0.5	6.28	1.5	9.42	
2	2.1	5	13.1	0.9	11.79	
3	3	0.5	27.5	0.643	17.6825	
4	4.2	0.5	54.7	0.432	23.6304	
5	6	0.5	113	0.313	35.369	
6	9	0.5	254	0.215	54.61	
7	13.5	0.5	572	0.149	85.228	
8	20	0.5	1250	0.1117	139.625	
9	20	6	95.3	1.945	185.3585	
10	30	0.5	2830	0.0507	143.481	
11	30	6	226	0.856	193.456	
12	45	6	520	0.524	272.48	
13	66	6	1130	0.387	437.31	
14	100	6	2620	0.1396	365.752	
15	150	6	5880	0.0827	486.276	
16	150	45	715	1.426	1019.59	
17	220	6	12600	0.0516	650.16	
18	220	45	1620	0.821	1330.02	
19	330	45	3750	0.446	1672.5	

SCHLUMBERGER ARRAY DATA COLLECTION SHEET

Instrument:-ABM Terrameter SAS 300C

Site Name Rob Megele, Menge, Benishanguel Gumuz

Research Title: Delineation of Groundwater Potential zones in upper Tumet Catchment, Menge area, Western Ethiopia Using Remote Sensing and GIS

UTM Grid 0693175mE, 1132673mN, Elevation 1245m DATE:- May 21, 2007

	AB/2 (M)	MN/2 (M)	K	R (ohm)	p (ohm-m)=E*D	REMARK
1	1.5	0.5	6.28	17.15	107.702	
2	2.1	5	13.1	4.03	52.793	
3	3	0.5	27.5	1.265	34.7875	
4	4.2	0.5	54.7	0.673	36.8131	
5	6	0.5	113	0.451	50.963	
6	9	0.5	254	0.309	78.486	
7	13.5	0.5	572	0.211	120.692	
8	20	0.5	1250	0.1301	162.625	
9	20	6	95.3	1.585	151.0505	
10	30	0.5	2830	0.0889	251.587	
11	30	6	226	1.055	238.43	
12	45	6	520	0.687	357.24	
13	66	6	1130	0.466	526.58	
14	100	6	2620	0.266	696.92	
15	150	6	5880	0.1741	1023.708	
16	150	45	715	1.07	765.05	
17	220	6	12600	0.1058	1333.08	
18	220	45	1620	0.607	983.34	
19	330	45	3750	0.299	1121.25	

SCHLUMBERGER ARRAY DATA COLLECTION SHEET

Instrument:-ABM Terrameter SAS 300C

Site Name Shegol 1, Menge, Benishanguel Gumuz

Research Title: Delineation of Groundwater Potential zones in upper Tumet Catchment, Menge area, Western Ethiopia Using Remote Sensing and GIS

UTM Grid 0692689mE, 1155633mN, Elevation 946m DATE:- May 15, 2007

	AB/2 (M)	MN/2 (M)	K	R (ohm)	p (ohm-m)=E*D	REMARK
1	1.5	0.5	6.28	149.7	940.116	
2	2.1	5	13.1	145.5	1906.05	
3	3	0.5	27.5	143.2	3938	
4	4.2	0.5	54.7	118.8	6498.36	
5	6	0.5	113	142.8	16136.4	
6	9	0.5	254	137.4	34899.6	
7	13.5	0.5	572	178.2	101930.4	
8	20	0.5	1250	183.6	229500	
9	20	6	95.3	172.2	16410.66	
10	30	0.5	2830	138.5	391955	
11	30	6	226	157.4	35572.4	
12	45	6	520	166.3	86476	
13	66	6	1130	255	288150	
14	100	6	2620	294	770280	
15	150	6	5880	184.9	1087212	
16	150	45	715	120.6	86229	
17	220	6	12600	260	3276000	
18	220	45	1620	152.1	246402	
19	330	45	3750	166.4	624000	

SCHLUMBERGER ARRAY DATA COLLECTION SHEET

Instrument:-ABM Terrameter SAS 300C

Site Name Shegol 2, Menge, Benishanguel Gumuz

Research Title: Delineation of Groundwater Potential zones in upper Tumet Catchment, Menge area, Western Ethiopia Using Remote Sensing and GIS

UTM Grid 0692598mE, 1155838mN, Elevation 945m DATE:- May 22, 2007

	AB/2 (M)	MN/2 (M)	K	R (ohm)	p (ohm-m)=E*D	REMARK
1	1.5	0.5	6.28	65.1	408.828	
2	2.1	5	13.1	21.3	279.03	
3	3	0.5	27.5	6.49	178.475	
4	4.2	0.5	54.7	2.15	117.605	
5	6	0.5	113	0.702	79.326	
6	9	0.5	254	0.294	74.676	
7	13.5	0.5	572	0.1667	95.3524	
8	20	0.5	1250	0.0947	118.375	
9	20	6	95.3	1.155	110.0715	
10	30	0.5	2830	0.0775	219.325	
11	30	6	226	0.784	177.184	
12	45	6	520	0.565	293.8	
13	66	6	1130	0.309	349.17	
14	100	6	2620	0.1437	376.494	
15	150	6	5880	0.0736	432.768	
16	150	45	715	0.69	493.35	
17	220	6	12600	0.0469	590.94	
18	220	45	1620	0.443	717.66	
19	330	45	3750	0.256	960	

SCHLUMBERGER ARRAY DATA COLLECTION SHEET

Instrument:-ABM Terrameter SAS 300C

Site Name Tumet Bariya, Menge, Benishanguel Gumuz

Research Title: Delineation of Groundwater Potential zones in upper Tumet Catchment, Menge area, Western Ethiopia Using Remote Sensing and GIS

UTM Grid 0695958mE, 1138919mN, Elevation 1072m DATE:- May 18, 2007

	AB/2 (M)	MN/2 (M)	K	R (ohm)	p (ohm-m)=E*D	REMARK
1	1.5	0.5	6.28	11.81	74.1668	
2	2.1	5	13.1	4.35	56.985	
3	3	0.5	27.5	1.98	54.45	
4	4.2	0.5	54.7	1.04	56.888	
5	6	0.5	113	0.574	64.862	
6	9	0.5	254	0.313	79.502	
7	13.5	0.5	572	0.1959	112.0548	
8	20	0.5	1250	0.124	155	
9	20	6	95.3	1.493	142.2829	
10	30	0.5	2830	0.0814	230.362	
11	30	6	226	0.974	220.124	
12	45	6	520	0.627	326.04	
13	66	6	1130	0.37	418.1	
14	100	6	2620	0.142	372.04	
15	150	6	5880	0.063	370.44	
16	150	45	715	0.507	362.505	
17	220	6	12600	0.0356	448.56	
18	220	45	1620	0.274	443.88	
19	330	45	3750	0.1424	534	

SCHLUMBERGER ARRAY DATA COLLECTION SHEET

Instrument:-ABM Terrameter SAS 300C

Site Name Tumet Mukwar , Menge, Benishanguel Gumuz

Research Title: Delineation of Groundwater Potential zones in upper Tumet Catchment, Menge area, Western Ethiopia Using Remote Sensing and GIS

UTM Grid 0701719mE, 1154884mN, Elevation 890m DATE:- May 16, 2007

	AB/2 (M)	MN/2 (M)	K	R (ohm)	p (ohm-m)=E*D	REMARK
1	1.5	0.5	6.28	59.9	376.172	
2	2.1	5	13.1	25.1	328.81	
3	3	0.5	27.5	11.26	309.65	
4	4.2	0.5	54.7	6.61	361.567	
5	6	0.5	113	4.19	473.47	
6	9	0.5	254	2.64	670.56	
7	13.5	0.5	572	1.547	884.884	
8	20	0.5	1250	0.883	1103.75	
9	20	6	95.3	10.11	963.483	
10	30	0.5	2830	0.395	1117.85	
11	30	6	226	4.36	985.36	
12	45	6	520	2.07	1076.4	
13	66	6	1130	1.134	1281.42	
14	100	6	2620	0.672	1760.64	
15	150	6	5880	0.379	2228.52	
16	150	45	715	2.4	1716	
17	220	6	12600	0.1855	2337.3	
18	220	45	1620	1.126	1824.12	
19	330	45	3750	0.431	1616.25	

SCHLUMBERGER ARRAY DATA COLLECTION SHEET

Instrument:-ABM Terrameter SAS 300C

Site Name Tumet Mukwar 2, Menge, Benishanguel Gumuz

Research Title: Delineation of Groundwater Potential zones in upper Tumet Catchment, Menge area, Western Ethiopia Using Remote Sensing and GIS

UTM Grid 0702216mE, 1155512mN, Elevation 893m DATE:- May 16, 2007

	AB/2 (M)	MN/2 (M)	K	R (ohm)	p (ohm-m)=E*D	REMARK
1	1.5	0.5	6.28	9.68	60.7904	
2	2.1	5	13.1	5.18	67.858	
3	3	0.5	27.5	3.15	86.625	
4	4.2	0.5	54.7	2.09	114.323	
5	6	0.5	113	1.25	141.25	
6	9	0.5	254	0.728	184.912	
7	13.5	0.5	572	0.629	359.788	
8	20	0.5	1250	0.233	291.25	
9	20	6	95.3	2.72	259.216	
10	30	0.5	2830	0.1414	400.162	
11	30	6	226	1.608	363.408	
12	45	6	520	1.07	556.4	
13	66	6	1130	0.627	708.51	
14	100	6	2620	0.33	864.6	
15	150	6	5880	0.208	1223.04	
16	150	45	715	1.655	1183.325	
17	220	6	12600	8.12	102312	
18	220	45	1620	1.005	1628.1	
19	330	45	3750	0.726	2722.5	
20	500	45	8650	0.455	3935.75	

SCHLUMBERGER ARRAY DATA COLLECTION SHEET

Instrument:-ABM Terrameter SAS 300C

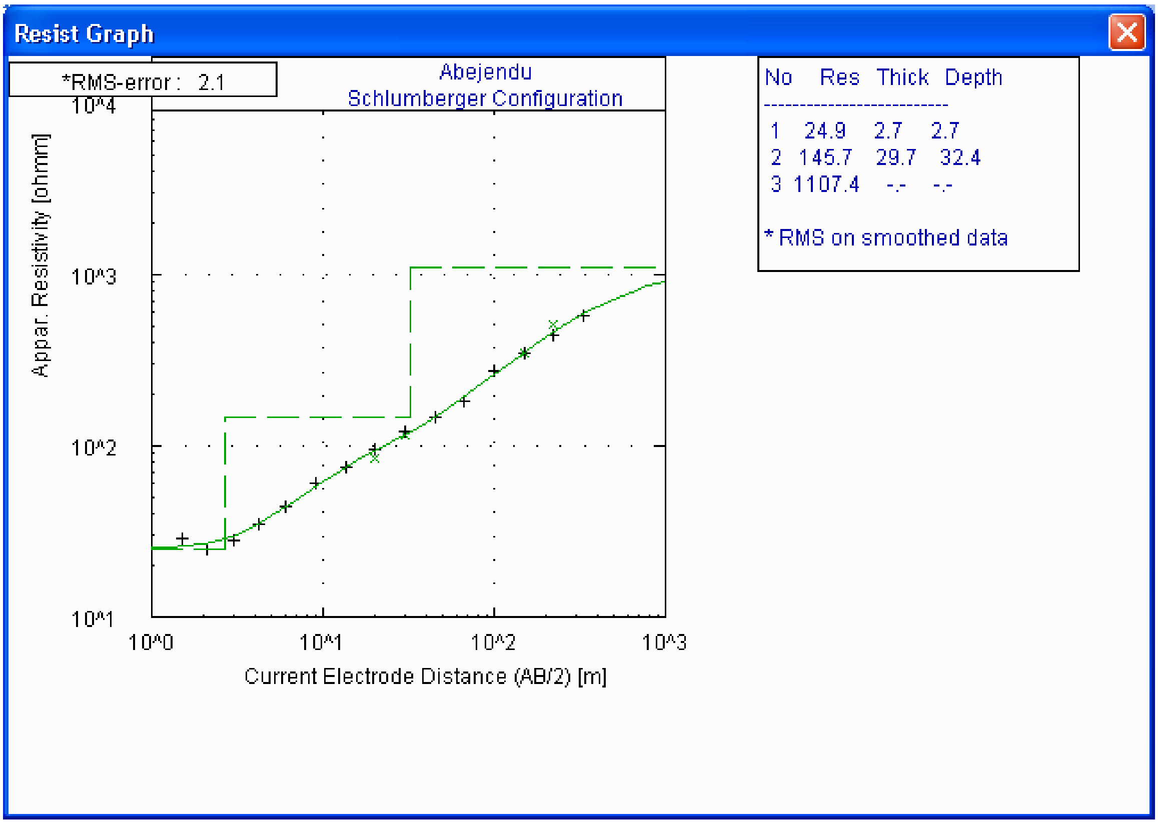
Site Name Jebrona, Menge, Benishanguel Gumuz

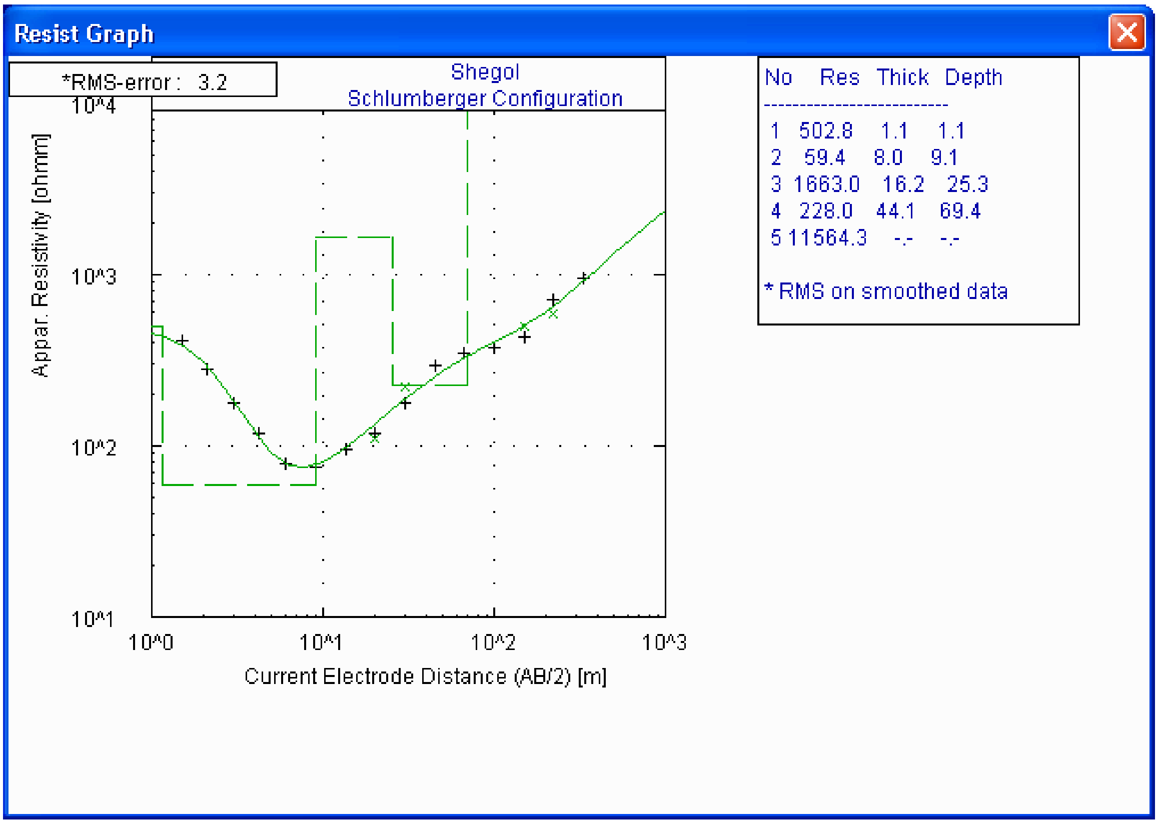
Research Title: Delineation of Groundwater Potential zones in upper Tumet Catchment, Menge area, Western Ethiopia Using Remote Sensing and GIS

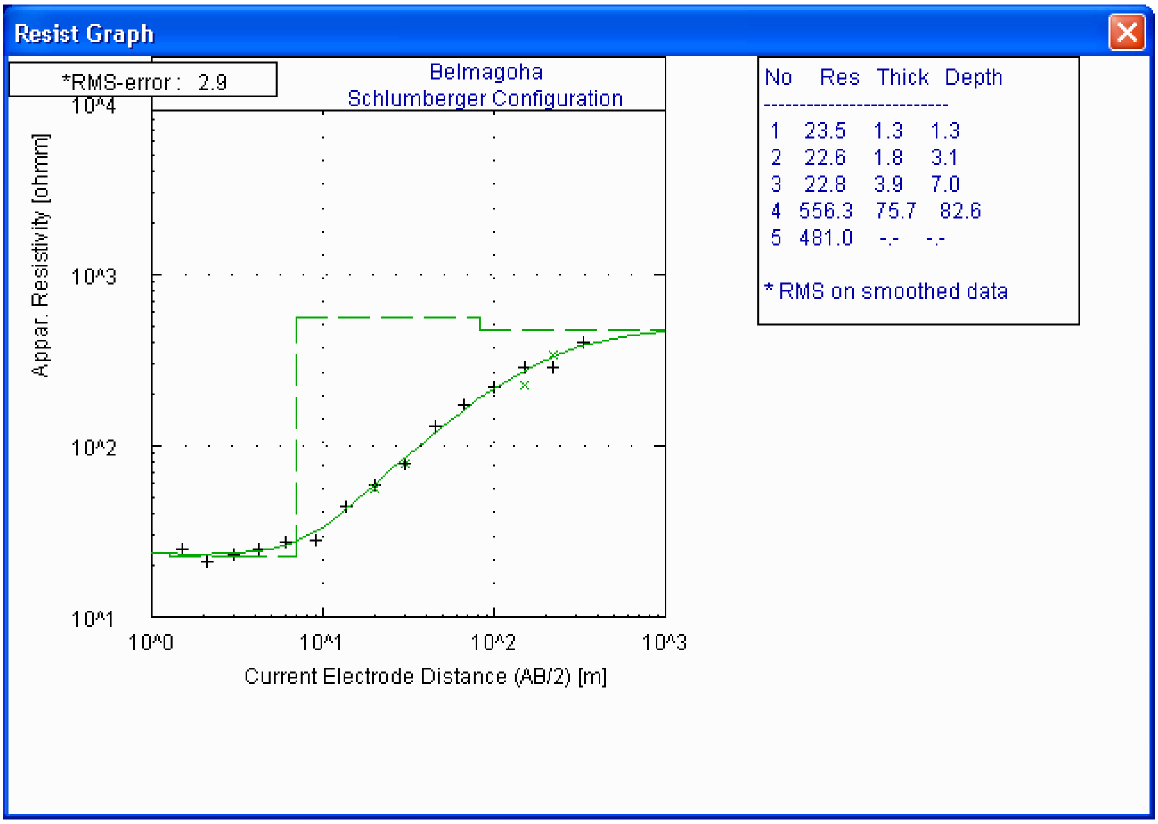
UTM Grid 0703155mE, 1141038mN, Elevation 1026m DATE:- May 16, 2007

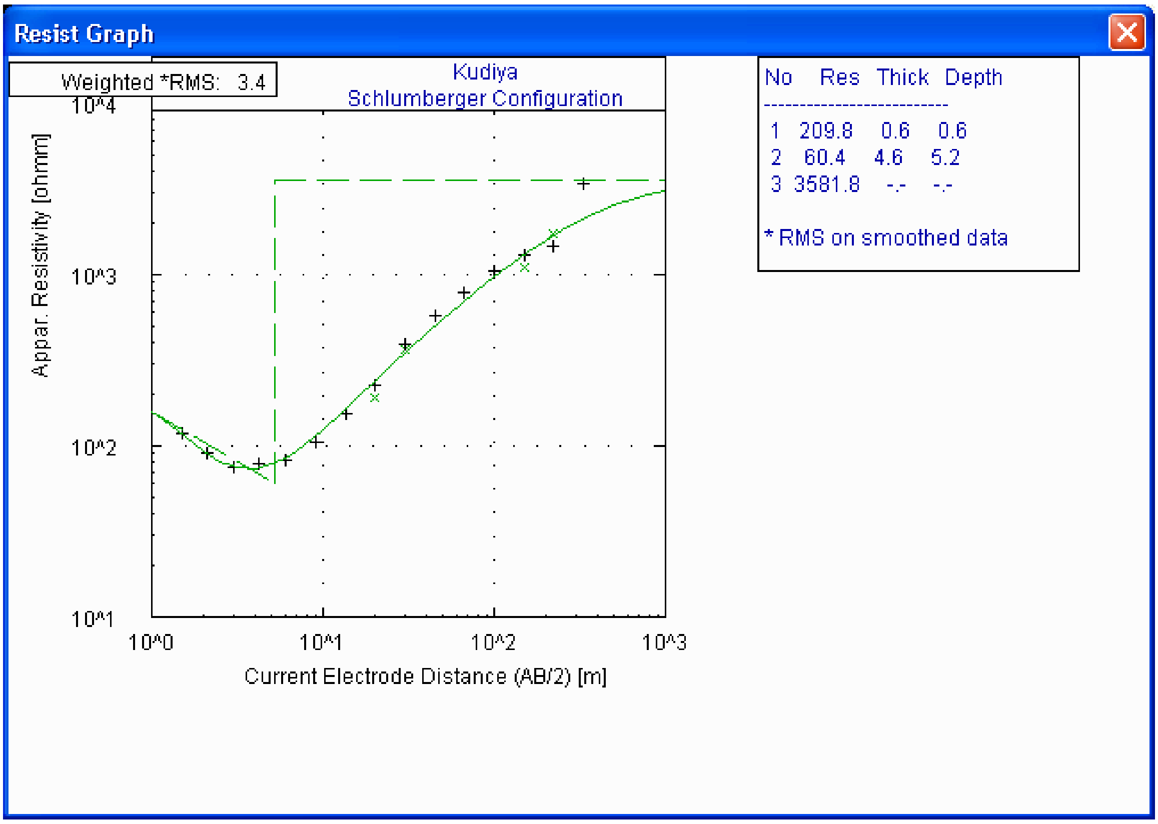
	AB/2 (M)	MN/2 (M)	K	R (ohm)	p (ohm-m)=E*D	REMARK
1	1.5	0.5	6.28	3.73	23.4244	
2	2.1	5	13.1	1.912	25.0472	
3	3	0.5	27.5	0.964	26.51	
4	4.2	0.5	54.7	0.545	29.8115	
5	6	0.5	113	0.312	35.256	
6	9	0.5	254	0.1808	45.9232	
7	13.5	0.5	572	0.109	62.348	
8	20	0.5	1250	0.073	91.25	
9	20	6	95.3	0.862	82.1486	
10	30	0.5	2830	0.077	217.91	
11	30	6	226	0.655	148.03	
12	45	6	520	0.546	283.92	
13	66	6	1130	0.373	421.49	
14	100	6	2620	0.255	668.1	
15	150	6	5880	0.1419	834.372	
16	150	45	715	0.949	678.535	
17	220	6	12600	0.079	995.4	
18	220	45	1620	0.53	858.6	
19	330	45	3750	0.288	1080	

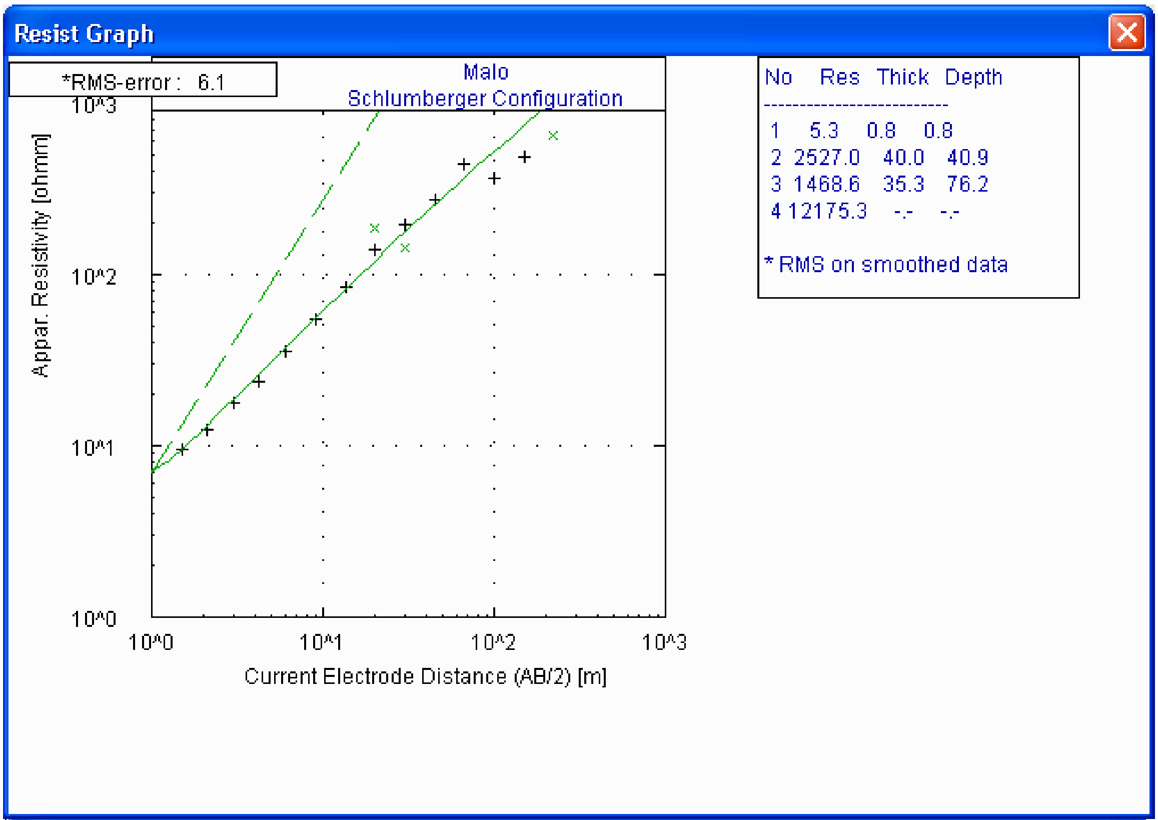
Annex 2 VES graphs

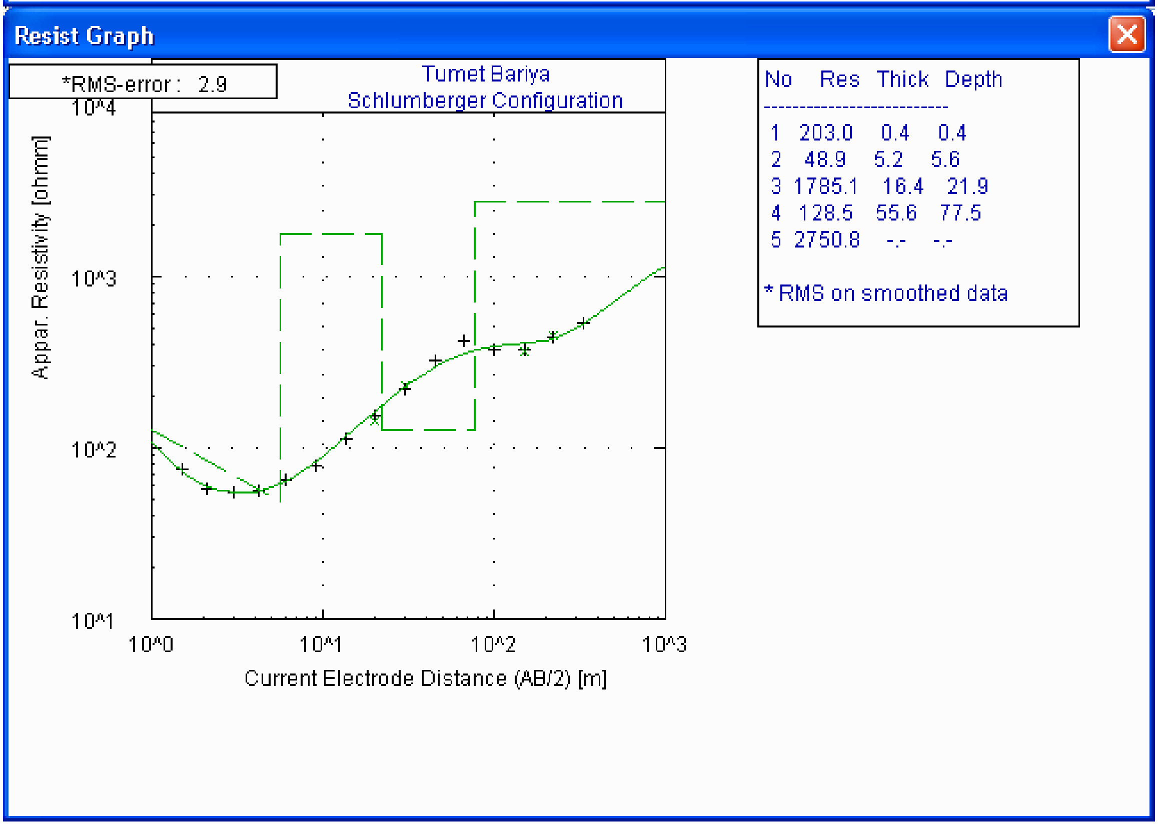


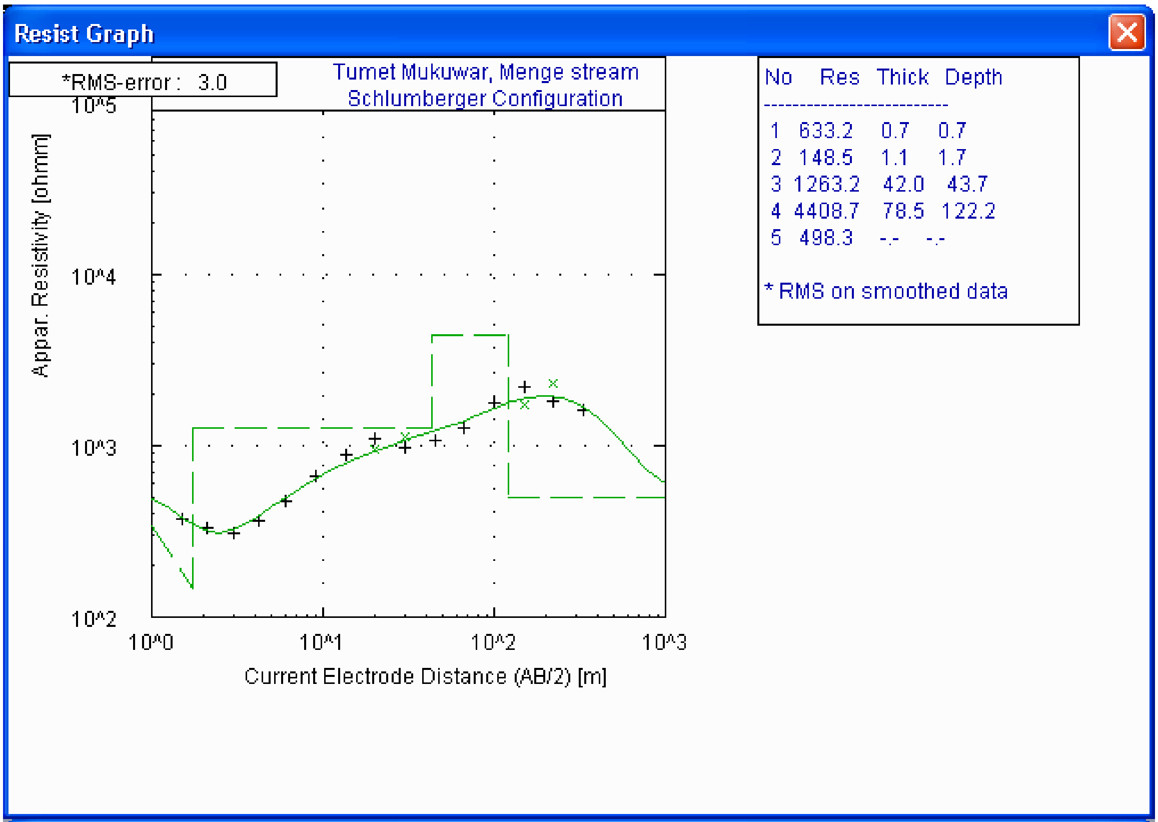


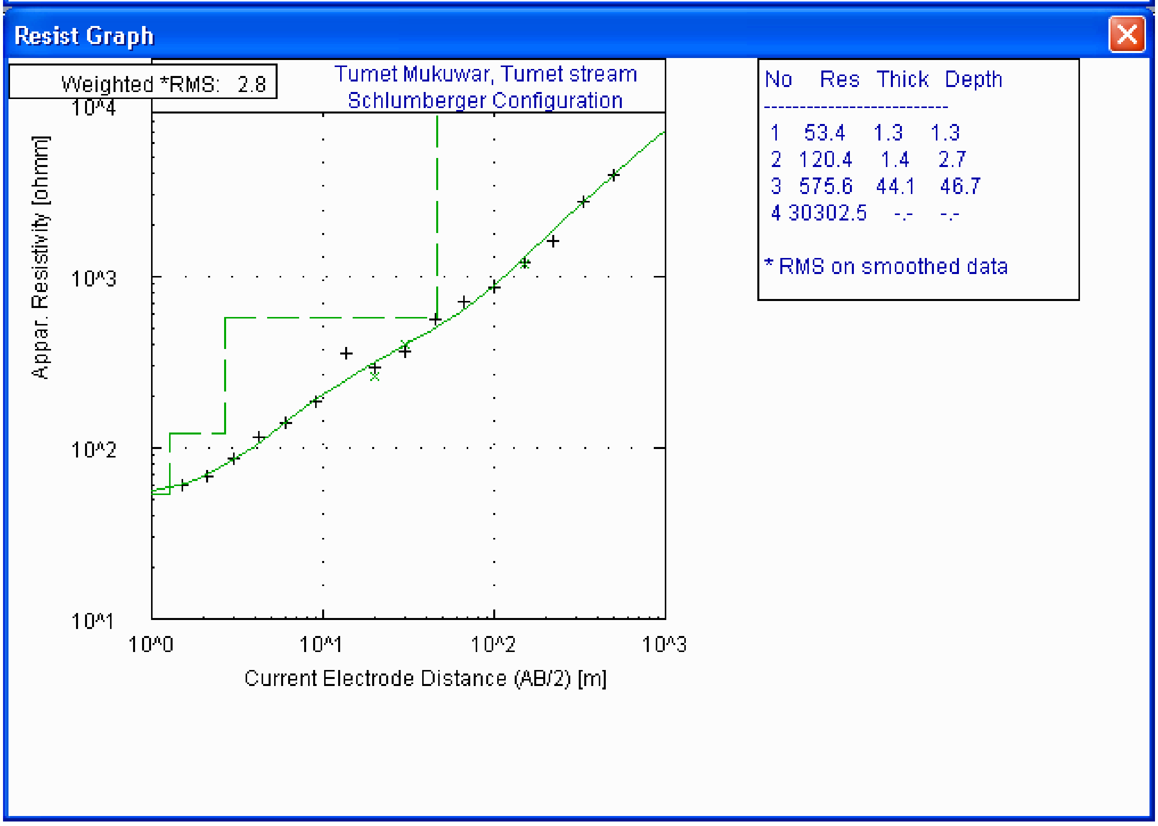

Resist Graph
*RMS-error : 2.9
Belmagoha
Schlumberger Configuration
Appar. Resistivity [ohmm]
10^4
10^3
10^2
10^1
10^0
10^1
10^2
10^3
Current Electrode Distance (AB/2) [m]
No Res Thick Depth
1 23.5 1.3 1.3
2 22.6 1.8 3.1
3 22.8 3.9 7.0
4 556.3 75.7 82.6
5 481.0 -.- -.-
* RMS on smoothed data

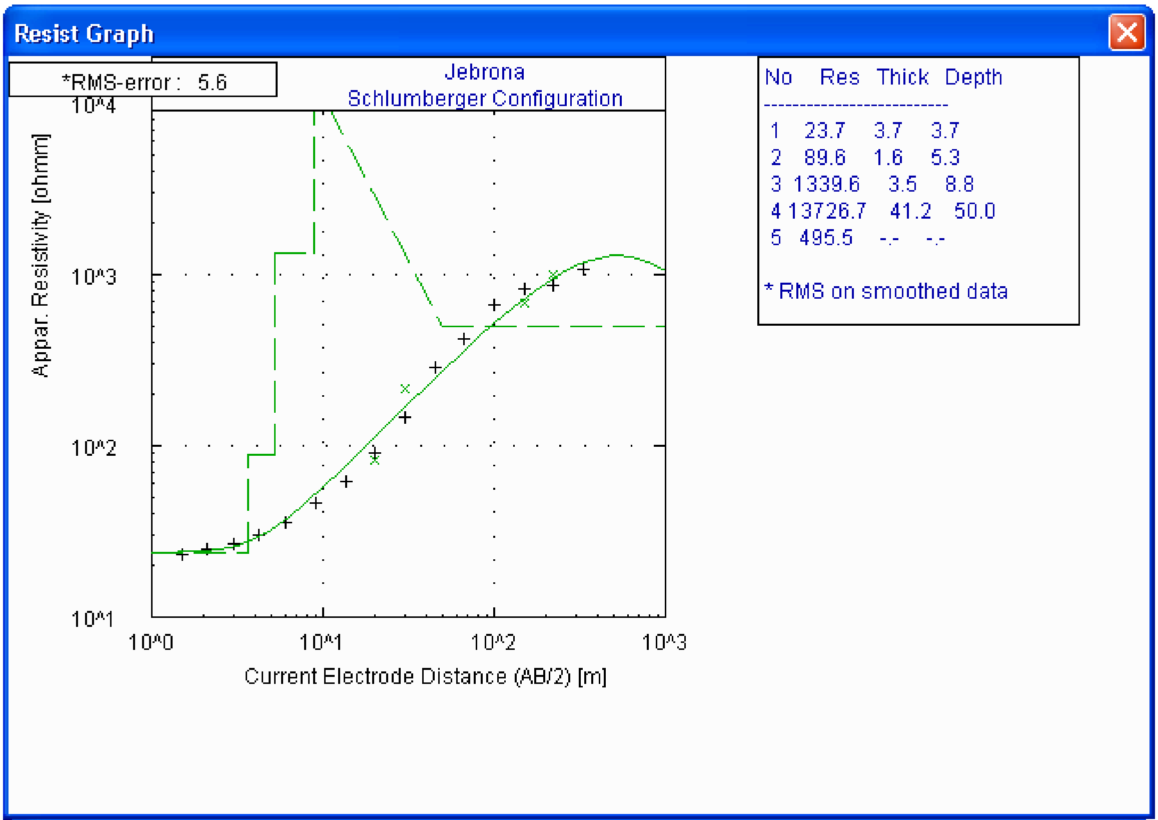

Resist Graph
Weighted *RMS: 3.4
Kudiya
Schlumberger Configuration
Appar. Resistivity [ohmm]
10^4
10^3
10^2
10^1
10^0
10^1
10^2
10^3
Current Electrode Distance (AB/2) [m]
No Res Thick Depth
1 209.8 0.6 0.6
2 60.4 4.6 5.2
3 3581.8 -.- -.-
* RMS on smoothed data

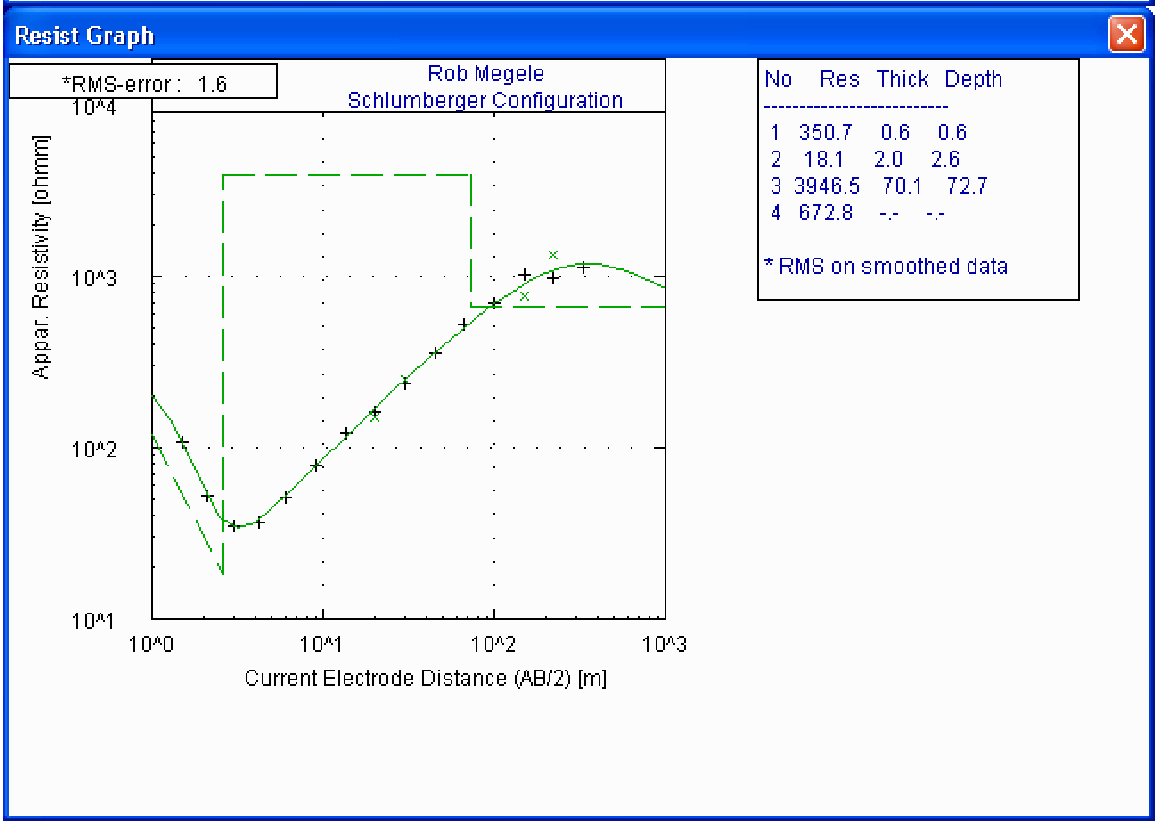

Resist Graph
*RMS-error : 6.1
Malo
Schlumberger Configuration
Appar. Resistivity [ohmm]
10^3
10^2
10^1
10^0
10^0
10^1
10^2
10^3
Current Electrode Distance (AB/2) [m]
No Res Thick Depth
1 5.3 0.8 0.8
2 2527.0 40.0 40.9
3 1468.6 35.3 76.2
4 12175.3 -.- -.-
* RMS on smoothed data

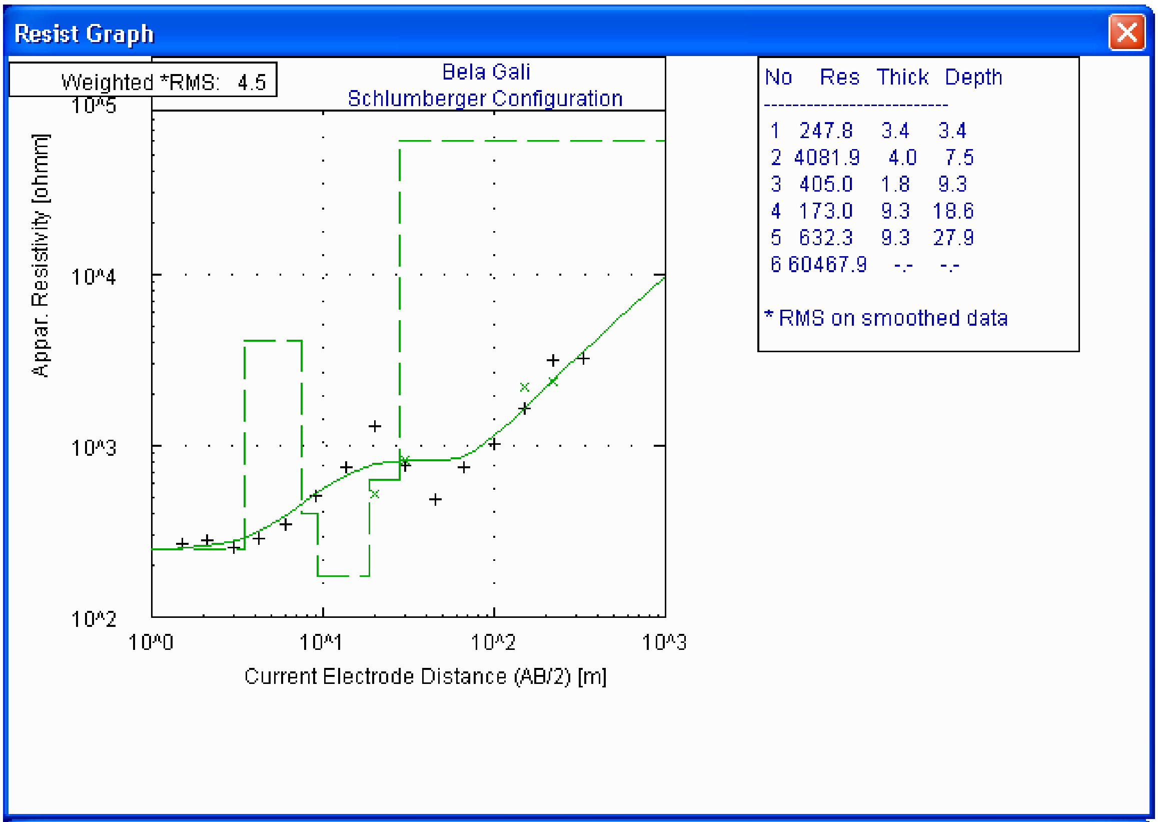

Resist Graph
*RMS-error : 2.9
Tumet Bariya
Schlumberger Configuration
Appar. Resistivity [ohmm]
10^4
10^3
10^2
10^1
10^0
10^1
10^2
10^3
Current Electrode Distance (AB/2) [m]
No Res Thick Depth
1 203.0 0.4 0.4
2 48.9 5.2 5.6
3 1785.1 16.4 21.9
4 128.5 55.6 77.5
5 2750.8 -.- -.-
* RMS on smoothed data


Resist Graph
*RMS-error : 3.0
Tumet Mukuwar, Menge stream
Schlumberger Configuration
Appar. Resistivity [ohmm]
10^5
10^4
10^3
10^2
10^0
10^1
10^2
10^3
Current Electrode Distance (AB/2) [m]
No Res Thick Depth
1 633.2 0.7 0.7
2 148.5 1.1 1.7
3 1263.2 42.0 43.7
4 4408.7 78.5 122.2
5 498.3 -.- -.-
* RMS on smoothed data

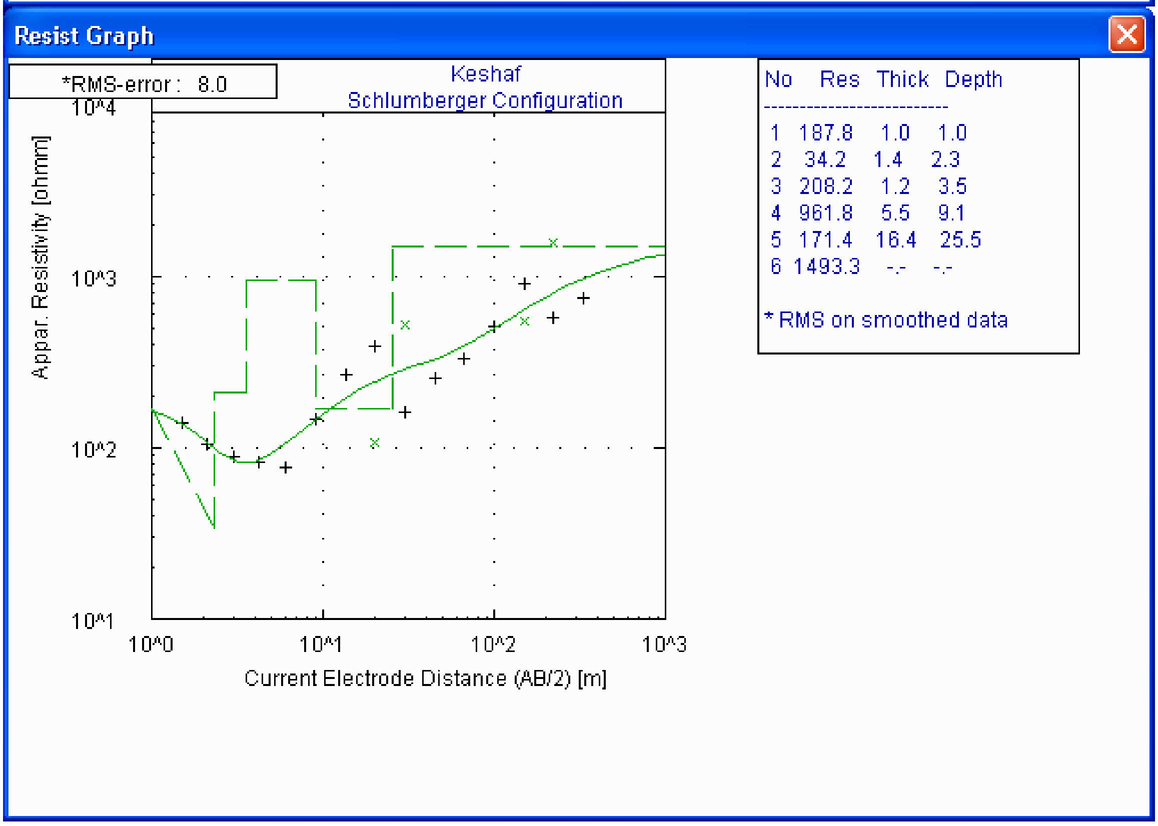

Resist Graph
Weighted *RMS: 2.8
Tumet Mukuwar, Tumet stream
Schlumberger Configuration
Appar. Resistivity [ohmm]
10^4
10^3
10^2
10^1
10^0
10^1
10^2
10^3
Current Electrode Distance (AB/2) [m]
No Res Thick Depth
1 53.4 1.3 1.3
2 120.4 1.4 2.7
3 575.6 44.1 46.7
4 30302.5 -.- -.-
* RMS on smoothed data


Resist Graph
*RMS-error : 5.6
Jebrona
Schlumberger Configuration
Appar. Resistivity [ohmm]
10^4
10^3
10^2
10^1
10^0
10^1
10^2
10^3
Current Electrode Distance (AB/2) [m]
No Res Thick Depth
1 23.7 3.7 3.7
2 89.6 1.6 5.3
3 1339.6 3.5 8.8
4 13726.7 41.2 50.0
5 495.5 -.- -.-
* RMS on smoothed data


Resist Graph
*RMS-error : 1.6
Rob Megele
Schlumberger Configuration
Appar. Resistivity [ohmm]
10^4
10^3
10^2
10^1
10^0
10^1
10^2
10^3
Current Electrode Distance (AB/2) [m]
No Res Thick Depth
1 350.7 0.6 0.6
2 18.1 2.0 2.6
3 3946.5 70.1 72.7
4 672.8 -.- -.-
* RMS on smoothed data



Resist Graph
Weighted *RMS: 4.5
Bela Gali
Schlumberger Configuration
Appar. Resistivity [ohmm]
10^5
10^4
10^3
10^2
10^0
10^1
10^2
10^3
Current Electrode Distance (AB/2) [m]
No Res Thick Depth
1 247.8 3.4 3.4
2 4081.9 4.0 7.5
3 405.0 1.8 9.3
4 173.0 9.3 18.6
5 632.3 9.3 27.9
6 60467.9 -.- -.-
* RMS on smoothed data



Resist Graph
*RMS-error : 8.0
Keshaf
Schlumberger Configuration
Appar. Resistivity [ohmm]
10^4
10^3
10^2
10^1
10^0
10^1
10^2
10^3
Current Electrode Distance (AB/2) [m]
No Res Thick Depth
1 187.8 1.0 1.0
2 34.2 1.4 2.3
3 208.2 1.2 3.5
4 961.8 5.5 9.1
5 171.4 16.4 25.5
6 1493.3 -.- -.-
* RMS on smoothed data

Annex 3 Water Point Inventory Data

OBJECTID	WEREDA	WATER POINT	LATITUDE	LONGITUDE	TYPE OF WELL	DEPTH (M)	STATUS	Pump	Comment of users about yield
1	Menge	Tumet Mukewar	701306	1155823	SW*	46	Productive		Good
2	Menge	Tumet Mukewar	702335	1154735	SW	26	Dry		
3	Menge	Tumet Mukewar	702266	1155491	HDW**	7	Productive		Dries in May
4	Menge	Alfashir	703522	1151857	SW	31	Dry		
5	Menge	Tumet Aziz	703382	1141033	HDW	7	Productive		Shortage
6	Menge	Menge	692469	1145654	SW	_	Productive	Indian Mark Ii	Abandoned
7	Menge	Menge	692448	1145379	SW	51	Productive	Submersible	Good
8	Menge	Malo	688210	1148400	HDW	9.5	Productive	Afridev	Good
9	Menge	Malo	687576	1149689	HDW	10	Productive	Afridev	Good
10	Menge	Kudiya	691973	1146457	HDW	5.8	Productive	Afridev	
11	Menge	Kudiya	692058	1146660	HDW	3	Productive	Indian Mark II	
12	Menge	Keshaf (Metema)	686132	1141820	HDW	3.36	Productive	Afridev	Shortage
13	Menge	Keshaf (Tinyndu)	687980	1142951	HDW	3.4	Productive	Afridev	enough
14	Menge	Keshaf	688092	1142437	HDW	5.5	Productive		
15	Menge	Keshaf (Belfru)	686718	1143134	SW	_	Productive	Afridev	Good
16	Menge	Keshaf	694968	1141078	HDW	8	Productive		
17	Menge	Keshaf (Akofiya)	686770	1142389	HDW	4.25	Productive	Afridev	Shortage
18	Menge	Keshaf (Clinic)	687346	1142296	HDW	-	Productive	Indian Mark II	
19	Menge	Keshaf (Kartum)	687523	1141689	SW	-	Productive	Afridev	Good
19	Mene	Bane 1	692707	1149274	SW	40	Productive	Afridev	Good
20	Menge	Bane3	692458	1150548	HDW	_	Productive	Afridev	Shortage
21	Menge	Bane2	692673	1149382	HDW	_	Productive		Good
22	Menge	Shegol	692705	1156592	SW	46.5	productive	Afridev	Shortage
23	Menge	Malo	687576	1149689	HDW	10	Productive	Afridev	
24	Menge	Malo	688210	1148400	HDW	0	Productive	Afridev	
25	Menge	Belamegua	693573	1143650	HDW	6.7	Productive		
26	Menge	Belamegua	693637	1143646	HDW	6.85	Productive	Indian Mark II	
27	Menge	Beldozi	703030	1141179	HDW	5.2	Productive		
28	Menge	Menge	692458	1145031	HDW	6.6	Productive		
29	Menge	Abejendu	694505	1138796	HDW	9	Productive		
30	Menge	Fatseko	689581	1130818	HDW	4.8	Productive		
31	Menge	Malo	687576	1149689	HDW	10	Productive	Afridev	

OBJECTID	WEREDA	WATER POINT	LATITUDE	LONGITUDE	TYPE OF WELL	DEPTH (M)	STATUS	Pump	Comment of users about yield
32	Menge	Bariya	696706	1136947	HDW	7	Productive	Afridev	Shortage
33	Menge	Tumet Bariya	696870	1138163	HDW	7	Productive	Afridev	Good
34	Menge	Tselenger	694247	1141442	HDW	_	Productive	Afridev	
35	Menge	Megele	693807	1133477	HDW	7	Productive	Afridev	Shortage
36	Menge	Megele	694025	1133020	HDW	7	Productive	Afridev	Shortage
37	Menge	Abora	690219	1143080	HDW	_	Productive	Damaged	
38	Menge	Abora	690182	1143074	HDW	_	Productive	Afridev	Shortage
39	Menge	Abora	690657	1142313	HDW	7	Productive	Afridev	Shortage
40	Komosha	Dareselam	682617	1141619	HDW	18	Productive	Afridev	Good
41	Komosha	Dareselam	682732	1141874	HDW	8	Productive	Afridev	
42	Komosha	Dareselam	682072	1141940	HDW	11	Productive	Afridev	
43	Komosha	Algela	680668	1141756	HDW	14	Productive	Afridev	Shortage
44	Komosha	Algela	680653	1141511	HDW	8	Productive	Afridev	Shortage
45	Komosha	Algela	680179	1140825	HDW	-	Productive	Afridev	Shortage
46	Komosha	Algela	679860	1140272	HDW	6	Productive	Afridev	Shortage
47	Komosha	Tumet	679494	1140768	HDW	12.65	Productive	Afridev	Good
48	Komosha	Tumet	679376	1140213	HDW	7	Productive	Afridev	Shortage
49	Menge	Malo	687642	1149803	Spring	-	Perennial	Unprotected	Good

*SW Shallow machine drilled well

**HDW Hand dug well

Annex 4 Rainfall and Temperature Data

Long year monthly average rainfall of Menge (1974-2004) station					Maximum .of 30 years	
NO.	Month	Rainfall amount (mm)	Standard deviation	Coefficient of Variability (%)	year	amount (mm)
1	January	5.01	18.1	360	2003	87.1
2	February	4.5	9.8	208	1999	41
3	March	26.4	49.2	190	1997	226
4	April	79.3	29.2	74	2003	113.4
5	May	192.5	92.5	48	2002	421.6
6	June	208.5	70.6	33	1987	365.9
7	July	242.2	140.44	57	1976	775.6
8	August	254.4	109.7	43	1980	562.4
9	September	177.1	80.4	45	1980	347
10	October	89.8	53.9	60	1985	226.5
11	November	44.8	59.1	131	1988	129.2
12	December	14.5	53.1	365	1988	26.7

Long year mean daily average (1972-1999) temperature (^{0}c) of Menge station			
No.	Month	Mean temperature	Maximum temperature
1	January	20.7	21.2
2	February	20.2	24.7
3	March	24.8	24.3
4	April	24.8	26.7
5	May	26.3	28
6	June	25.2	27.4
7	July	24.8	27.3
8	August	23.6	25.6
9	September	23.7	25.6
10	October	26.7	27.7
11	November	26.2	28
12	December	22.4	24.8

Declaration

I the undersigned, declare that this thesis entitled "**DELINEATION OF GROUNDWATER POTENTIAL ZONES OF UPPER TUMET CATCHMENT, MENGE AREA, WESTERN ETHIOPIA USING REMOTE SENSING AND GIS**" is my work and that all sources of the materials used for the thesis have been duly acknowledged. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

Name: - Gezahegn Lemecha

Place: - Addis Ababa University, Addis Ababa

Signature________________

Date____________________

This thesis entitled "**DELINEATION OF GROUNDWATER POTENTIAL ZONES OF UPPER TUMET CATCHMENT, MENGE AREA, WESTERN ETHIOPIA USING REMOTE SENSING AND GIS**" is an original work by Gezahegn Lemecha under my supervision.

Name:-DR. Dagnachew Legesse

Signature__________________

Date______________________