



ADDIS ABABA UNIVERSITY
COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES
SCHOOL OF EARTH SCIENCES

IDENTIFICATION OF GROUNDWATER POTENTIAL ZONE AREA MAPPING
USING REMOTE SENSING AND GIS TECHNIQUES, THE CASE OF ENDERTA
DISTRICT, TIGRAY ETHIOPIA

By

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GSR/3204/08

Advisor:

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A Thesis submitted to
School of graduate studies of Addis Ababa University in partial fulfillment of the requirements
for the Degree of Masters of Science in Remote Sensing and Geo-informatics

Addis Ababa, Ethiopia
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This is to certify that thesis prepared by KINDEYA KIDANU TADESSE, entitled: Identification of ground water potential zone mapping using Remote Sensing and GIS techniques, incase of Enderta district Ethiopia and submitted in partial fulfillment of the requirements for the degree of Masters of Science in Remote sensing and Geo-informatics complies with the regulations of the University and meets the accepted standards with respect to the originality and quality.

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Acronyms

AHP	Analytical Hierarchical Process
CSA	Central Statistical Agency
DEM	Digital Elevation Model
ERDAS	Earth Resource Data Analyze System
FAO	Food and Agricultural Organization
GIS	Geographic Information System
GPS	Global Positioning System
MCE	Multi Criteria Evaluations
MCDM	Multi Criteria Decision Making
RS	Remote Sensing
SDSS	Spatial Decision System service
WIOA	Weight Index Overlay Analysis
WLC	Weighted Linear Combination
SRTM	Shuttle Radar Topography Mission
SAR	Synthetic Aparture Radar

Abstract

Groundwater is a respected and significant natural resource in the world and it is the most fundamental for the growth and development of one country. However, estimating the potential of groundwater potential zone has still uncertainty due to the natural surroundings of groundwater. Therefore, this study aims to use the timely and cost effective remote sensing and geographical information system (GIS) methods for allocating, classify groundwater prospect zone in the Enderta District. To prepare GWPZAM use eight factors as a thematic map derived from Landsat 8 Operational Land Imager (OLI) Satellite image of the year 2016, SRTM Digital Elevation Models (DEM) with 30 m spatial resolution and secondary sources were utilized in this research. These were rainfall, slope, geomorphology, lithology, lineament density, drainage density, and Land-use/land-cover and soil texture. The methods to assess the identification of groundwater potential zone was using weight overlay analysis and Analytical Hierarchy Process (AHP) algorithm. All thematic layers were reclassified knowledge-based analysis that was reviewed from different kinds of literature. Then the weight for each factor was assigned rendering to their relative significance as per suitable based on Saaty's scale of AHP. The important factors result show that rainfall and slope have a higher weight and lithology has the lowest weight for identifying the possible of groundwater potential zone in the study area, respectively. The GIS method output results were validated by conducting field survey by randomly selecting wells in different places using GPS instruments. Coordinates of each of the well locations were obtained and plotted in the database. The spatial variation of the potential zones indicates that groundwater occurrence is controlled by structures, landforms and slope.

Keywords: Groundwater potential, Groundwater, GIS, Remote Sensing, AHP

CHAPTER ONE

1. INTRODUCTION

Water that collects or flows beneath the Earth's surface, filling the porous spaces in soil, sediment, and rocks. Groundwater initiates from rain and from melting snow and ice and is the source of water for aquifers, springs, and wells (Waikar and Aditya Nilawar, 2014). The upper surface of groundwater is the water table. Groundwater is the water found underground in the cracks and spaces in soil, sand and rock. It is stored in and moves slowly through geologic formations of soil, sand and rocks called aquifers.

In semi-arid and arid areas of Africa, urban growth, irrigation developments, and climate variation, along with inadequate and changeable pattern of the rainfall pose pressure on existing water resources. Surface and ground water resources are insufficient to encounter the crop water requirement and water for domestic use due to a rapid population growth and the demand for more water (Jha *et al.*, 2007 and Singh *et al.*, 2013). The demand for water has increased over the years making the investigation of the quantity and the quality of water resources and its prime utilization and most serious issue for this district. There is a critical need for the evaluation of water resources as water plays a primary role in the sustainability of livelihoods and regional economy. Water management is the primary safeguard against drought and plays a main character in achieving food security at the local, national and global levels. Ever-growing population and urbanization are leading to over-utilization of water resources, thus exerting pressure on the limited civic amenities many of which are on the brink of collapse (Jha *et al.*, 2007 and Singh *et al.*, 2013).

Groundwater is one of the most valuable natural resources, and supports human health, economic development and ecological diversity. Due to its several inherent qualities (e.g. consistent temperature, widespread and continuous availability, excellent natural quality, limited vulnerability, low development cost and drought reliability), it has become an vital and dependable source of water supplies in all climatic regions including both urban and rural areas of developed and developing countries (Hutti and Nijagunappa 2011).

In Ethiopia groundwater is an important source of water and is the leading source for domestic supply in many areas, especially the dry areas where surface waters are scarce and seasonal. Almost 80% of water supply in Ethiopian is from groundwater, 90% for domestic, 95% for industries but only small proportion of irrigation demand <1% (SeifuKebede *et al.*, 2016). Many parts of Ethiopia have limited supplies of groundwater because of the poor permeability of the crystalline rocks and variable water-table depths. Success with obtaining groundwater in these areas depends upon locating water-bearing fractures.

Enderta district have a shortage of water supply for domestic use like for drinking, agriculture and industrial use. The water used for domestic use salty water. Groundwater quality is highly variable across Ethiopia, from fresh waters in many of the springs flowing from basement aquifers, to more saline waters in volcanic aquifers in parts of the Rift Valley and sedimentary aquifers of the plains. Key issues are high fluoride concentrations and/or total dissolved salts in volcanic aquifers in the Rift Valley, linked to the influence of geothermal waters; and increased salinity in many groundwater in sedimentary aquifers in the south, southeast and northeast of the country, linked to the dissolution of evaporate minerals (SeifuKebede *et al.*, 2016).

The present study attempts to delineate suitable locations for groundwater exploration using integrated approach of remote sensing, bore well data and GIS techniques. ArcGIS 10.3 and ERDAS Imagine 2014 software have been used for the generation and analysis of the thematic layers, such as- geomorphology, geology, lineament, slope, soil and land use / land cover, which are assigned using weighted overlay analysis geographic information system techniques. Finally, the layers were classified and prepared with respect to main criteria and parameters.to generate groundwater potential map.

Geographical information system and remote sensing is the optional methods to provide all parameters which influence groundwater potential and zone of an area and it can access, manipulate and analysis the spatial radiometric and temporal data from satellite image (Kamal, 2017). Besides to this, (Gupta and Srivastava, 2010) Explain the several decision analysis approaches such us Multicriteria Decision Making (MCDM), Analytical Hierarchy process

(AHP), weighted linear combination and Fuzzy-AHP fill the gap of water scarcity and decision-making on ground water potential zone mapping. Analytical Hierarchy Process is useful methods for complex decision-making. A serious pairwise comparison matrix used for checking consistency ratio (Saraf and Choudhury, 1998). These decision makers use to reduce the bias in decision making (Saaty,1980). This study was focused on the groundwater potential zone mapping of woredaEnderta by the integrated approach of remote sensing and GIS techniques using AHP modeling approach.

1.1. Statement of the problem

Ethiopia is one of the country known by abundant water resource and they call “water tower of Africa” and there is minimum utilization to groundwater for irrigation, domestic life and industrial use. In Ethiopian arid, semi-arid area and rift valley regions of the country are characterized by shortage rainfall. There are minor rain seasons April and May and the major rain seasons start from half June, July to August sometimes up to half of September. Enderta district urban expansion is higher because of this need for water supply of the town and district.

Enderta highly increase for domestic, industrial and other purpose. The population of Enderta highly increase from time to time. Beside increase the needs of water for industrial, domestic and irrigation purpose. The amount of rainfall trend of dry zone and the increase of population size and demand for water for irrigation and other livelihood requirement’s calls sustainable exploitation of the groundwater resources in the town and district enderta to fulfill the demand of the population of the peoples.

Currently there is a growing interest and need by government and private sectors to invest on groundwater development for agricultural water management for poverty alleviation and economic growth. Due to the fact that the source areas for surface water harvesting are limited district Enderta, to decrease the burden in the future for any demand, consumptive use or productive use, remains on groundwater. To decrease the gap of water scarcity and the number of the population and for further decision making on groundwater potential area identification and mapping in appropriate ground water areas.

The most widely used investigation method for groundwater are geoelectrical and Geophysical techniques are costly and time consuming. By considering the problem and the gap from the other studies in terms of human power, cost and time, increasing number of population density and fluctuation of climate on shortage of water in the city this research is used to analyze, design and map the spatial distribution of drainage, groundwater availability of the study area. there is a limitation of previously working done in the area of the potentials zone in details, the present study fills the gap by applying GIS and remote sensing technique. These techniques are very easy to access, identify groundwater potential zone of large and inaccessible areas.

1.2. Objectives of the study

1.2.1. General objectives

The general objective of the study is to investigate groundwater potential zone of the woredaEnderta by the integrated approach of GIS and remote sensing techniques.

1.2.2. Specific objectives

- a) To prepare thematic mapsofthe study such as rainfall, lineaments, geology, landforms(Geomorphology),drainage,slopes,landuse/landcoveandsoilfromremotelysensed data and otherdata sources.
- b) Toidentifyanddelineategroundwaterpotentialzonesthroughintegrationofvarious thematicmaps usingremote sensingand GIS techniques.
- c) ToshowtheintegrationofremotesensingandGIS techniquesforpredictionofthe groundwaterpotential zone in thestudyarea.

1.3. Significance of the study

The result of this study could provide good information about the ground water potential area in Enderta district. And it can be initial footstep for the coming plans to develop another project for digging of wells.

1.4. Limitation of the Study

The lack of the full groundwater inventory data and unevenly distribution of data point are the major problem of this research.

1.5. Thesis Organization

This research contains five chapters on ground water potential zone mapping by using remote sensing and GIS techniques. Chapter one contains introduction and background of the study, objectives, statement of problems and factors influencing s by these papers, significance of the study and limitation of the study are, finally thesis organization. Chapter two contains reviewing different papers done on the ground water potential and recharge zone mapping and related to the titles and role of remote sensing and GIS on ground water potential and recharge from the other methods. Chapter three contains methodology and material, types of data used in these research and description of study area such as location, physiography, regional geology, local geology, climate, population density, materials and methods, preparation of thematic maps and reclassification according to the standard. Methods to integrate and analyze the various thematic layers using a Geographic Information System (GIS) are given. Moreover, the steps to generate groundwater potential zones using GIS presented in detail. Chapter four contains results and discussion of groundwater potential zone. Chapter five contains conclusion and recommendations.

CHAPTER TWO

2. Review of literature

2.1. Concept of Groundwater

Groundwater is a changeable and renewable natural resource. But in hard rock terrains, availability of groundwater is of limited extent. Amount of groundwater in such rocks is essentially confined-to cracked and weathered horizons. Because of lack of knowledge about this resource, because of its hidden in nature and its occurrence in complex subsurface formations, has been and is still a big obstacle to the efficient management of this important resource (Saraf and Choudhary, 1998).

Groundwater Occurrence in Regions and Basins the upper members of Antalo formation are interrupted nearby by dolerites. The sedimentary outlier is in turn covered by wide basalt flows (Trap series) in the south and south west. Main structural features noted in the sedimentary rocks include bedding with different in thickness, higher in fracturing and tilting of the sedimentary bedding in different directions: south, north, west and east. All the lithologies are known to hold and transmit water at variable rates. The major challenge to groundwater storage is the dissection of the plateau by river incision and regional faults leaving isolated tabular plateau of small lateral extent.

Lithology is the chemical and mineralogical composition, texture, and internal strength of the rock. Texture can be described as unconsolidated, indurated (hard), fractured, or solid. Solid or indurated rock often delivers a control point for bed elevation and slope. The amount of time it acts as a control will be influenced by the lithology. For example, limestone may be eroded faster than basalt in a wet climatic season. Erodibility, porosity, and permeability are characteristics defined by both structure and lithology. Spatial variability of these characteristics should be noted. Textural distribution of unconsolidated sediment can be very significant. Larger-sized sediment, such as cobbles or boulders, may shield the channel at the mouth of a tributary and act as a control point similar to solid rock.

The annual recharge rate is low and its concentration to two months of the year (July and August) limit the generally recharge rate. When suitable structures exist, high yielding aquifers

can be found. The major regional structural element related to tectonics in the area is normal faults with varying trends, lineaments and fractures. Two systems of faulting are noted in many places. The earliest faulting generally trends WNW–ESE.

The utmost vital aquifers in Ethiopia are formed by Tertiary-Quaternary volcanic rocks; unconsolidated Quaternary sediments; and Mesozoic consolidated sedimentary rocks. Basement Precambrian aquifers best. In Northern Ethiopia: the basement rocks of Northern Ethiopia have low groundwater potential. Groundwater occurs generally in fractures in the upper few metres of the unweathered rocks; in very thin regolith layers; and in areas of covering alluvial sediments in river valleys (Kebede *et al.*, 2016). Groundwater plays an important role in the world: it feed springs and streams, supports wetlands, and maintains land surface stability. Groundwater is most valuable global resource, comprising 96% of the Earth’s unfrozen freshwater, as well as being the main water source in many water-scarce areas. The application of satellite remote sensing to groundwater studies presents many challenges.

2.2. Role of remote sensing and Geographic information system and Multi criteria decision making in groundwater

GIS is an application-oriented spatial information system with a variety of influential roles to handle for decision of problems related to spatial dimension. All of the data in a GIS are georeferenced, which is, linked to a precise location on the Earth surface through a system of coordinates. Geographical information assigns a variety of abilities and characteristics to geographical locations. These abilities may be physical factors such as elevation of the surface, soil moistness or groundwater levels, or classifications according to the type of vegetation and land cover, ownership of land, zoning, and so on. Such occurrences as accidents, floods, or landslides may also be included. A general term ‘attributes’ is often used to refer to the qualities or characteristics of places and is considered as one of the two basic elements of terrestrial information, along with positions. GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and benefits of geographic analysis offered by maps. GIS is the best suitable tool for geospatial data input and attribute data handling. It is a computer-based system that provides the following four sets of capabilities to handle georeferenced data (Aronoff, 1989): these are data input, data management, data manipulation and analysis and data output.

Remote sensing and geographic information system plays most important role in studying groundwater evaluation. There are numerous approaches to detect and map the occurrence and supply of groundwater. Nowadays, both Geographical Information System (Tesfaye,2007) and Remote Sensing (RS) are regarded as essential tools for groundwater studies especially for extended and complex systems. Geospatial technology is a rapid and cost-effective tool in producing valuable data on geology, geomorphology, lineaments, drainage slope, etc. using different spatial and non-spatial data. That helps in interpreting groundwater potential zone. A systematic integration of these data with follow-up of hydrogeological exploration and investigation provides rapid and cost-effective delineation of groundwater potential zones (Mayilvaganan et al., 2011).

According to Meijerink (2007) Earth Observation technologies and hydrological cycle observation can help fill these gaps. Different characteristics of current worldwide changes affect the water cycle; satellite remote sensing provides a most important global over-all idea that can monitor variations in rainfall, size of water bodies, vegetation and at local level it helps to identify areas with groundwater potential.

The combination of GIS and MCE has been shown in studies related to site determination in many various subjects including ecological sciences, urban-regional planning, waste management, hydrology and water resource, agriculture, forestry, natural hazards, tourism, housing/real estate, geological sciences, manufacturing and cartography(). GIS-based multi-criteria evaluation is used to govern rates for the classes in each layers and weights for each thematic layer based on Saaty's AHP (Saaty, 1980), whereas combination of the thematic layers is done by the WLC method.

A decision is a choice between different possibilities (Alternatives). The alternatives may represent diverse courses of action, different hypotheses on the character of a feature, different classifications, and so on. Broadly speaking a Decision Support System (DSS) is simply a computer system that helps you make a decision. DSS provide a means for decision-makers to make decisions on the basis of more complete information and analysis. Decision makers historically have indicated that unreachability of required geographic data and difficulties in

synthesizing various recommendations are main obstacles to spatial problem solving. Studies have shown that the quality of decisions (i.e., the capability to produce significant solutions) can be improved if these obstacles are lessened or removed through an integrated systems approach, such as a Spatial Decision Support System (SDSS), particular and important types of DSS.

Spatial decision support system refers to those support systems that combine the use of GIS technology with software packages for selection of alternatives of location for different activities. In addition, multicriteria decision making (MCDM) and a wide range of related methodologies offer a variety of techniques and practices to uncover and integrate decision makers' preferences in order to solve "real-world" GIS-based planning and management problems. However, because of conceptual difficulties (i.e., dynamic preference structures and large decision alternative and evaluation criteria sets) involved in formulating and solving spatial decision problems, researchers have developed multicriteria-spatial decision support systems. Spatial multicriteria decision problems typically involve a set of geographically well-defined alternatives (events) from which select of one or more alternatives is made with respect to a given set of evaluation criteria (Malczewski, 1999). The many types of multicriteria decision making analysis methods. From different methods in this research I used AHP (Analytical Hierarchical Process).

2.3 Analytical Hierarchy Process methods

Many researchers use diverse weight overlay and decision-making analysis methods; from this (Sajikumar and Gigo,2013) Adopt thematic layers of elevation, Land-use/landcover, lineaments, and drainage gave accurate information about groundwater existence and generate the result from Weight Index Overlay Analysis (WIOA) by employing analytical hierarchy process methods. Finally, conclude that analytical hierarchy process is the hopeful methods for groundwater exploration.

2.3. Previous works

Groundwater is fundamentally a subsurface occurrence of water. Remote Sensing technology using aircrafts and satellite platforms has become a progressively valuable technology for understanding groundwater situation (Todd, 1980). The satellite imagery information is often of

substitute nature and has to be combined with geohydrologic data to become significant. Assessing provincial groundwater resources, which begins with conceptualization of the hydrogeology contains three dimensional hydrogeological setting based on shallow and subsurface geology followed by estimation of the regional groundwater surface (Engman, 2000). Availability groundwater in any terrain is basically controlled by the occurrence and orientation of primary and secondary porosity (Semere, 2003).

According to Zeru (2008) has carried out groundwater modelling of the Aynalem wellfield with different themes and he accomplishes the groundwater obtains recharge of 11% the total annual rainfall (Teferi, 2009). The time of simulation in the transient was classified into two stress periods of wet and dry season based on the yearly rainfall distribution in the area. The limited potential of recharge of the Aynalem area from direct precipitation is due to the presence of low permeable layer (shales and dolerite sills) intercalating the more permeable limestone unit, due to the confined nature of the aquifer and to some extent the presence of thick layer of low hydraulic conductivity soil such as clay.

Several researchers have successfully utilized GIS and Remote sensing technologies in identification of groundwater potential zones around the world. (Jaiswal, 2003) used remote sensing and GIS for spatial analysis of groundwater potential in Kanyakumari and Nambiya basins in India. (Krishnamurthy,1996) have used the GIS procedure for generation of groundwater potential zones towards rural development. (Sitender, 2011) have demarcated ground water potential zones through Remote Sensing and Geographical Information system. This paper therefore aims to provide information about groundwater potential zones in woredaEnderta using Remote Sensing and GIS techniques for further groundwater exploration, proper planning, sustainable utilization and management of groundwater resources in the area.

CHAPTER THREE

3. Methods and Material

3.1. Description of the study area

Enderta is one of the districts in the Tigray Region of Ethiopia. It was named for the former Enderta province, which was later merged into Tigray Province. Absolute location of Enderta district bounded by latitudes $13^{\circ}15'25''$ – $13^{\circ}40'30''$ N and $39^{\circ}20'29''$ – $39^{\circ}45'35''$ E longitudes covering a total area of 1864 km^2 (Fig 3.1). Located in the Debub Misraqawi (Southeastern) Zone at the eastern edge of the Ethiopian highlands Enderta is bordered on the south by HintaloWajirat, on the west by Samre, on the northwest by the Mehakelegnaw (Central) Zone, on the north by the Misraqawi (Eastern) Zone, and on the east by the Afar Region; the city and special zone of Mek'ele is an enclave within Enderta. Towns in Enderta include Aynalem and Qwiha; the historic village of Chalacot is also located in this district. The Capital city of tigray regional state mekelle also found in the study area located about 783 km north of Addis Ababa, capital city of Ethiopia. Geographically the town is located at $39^{\circ}28'$ – $39^{\circ}45'$ E longitude and $13^{\circ}32'$ N latitudes, situated in the extension of the central part of the study area. The study area is conduct in Mekelle town and Enderta district. The altitude of northern Enderta district is between 1487–2752 m above sea level.

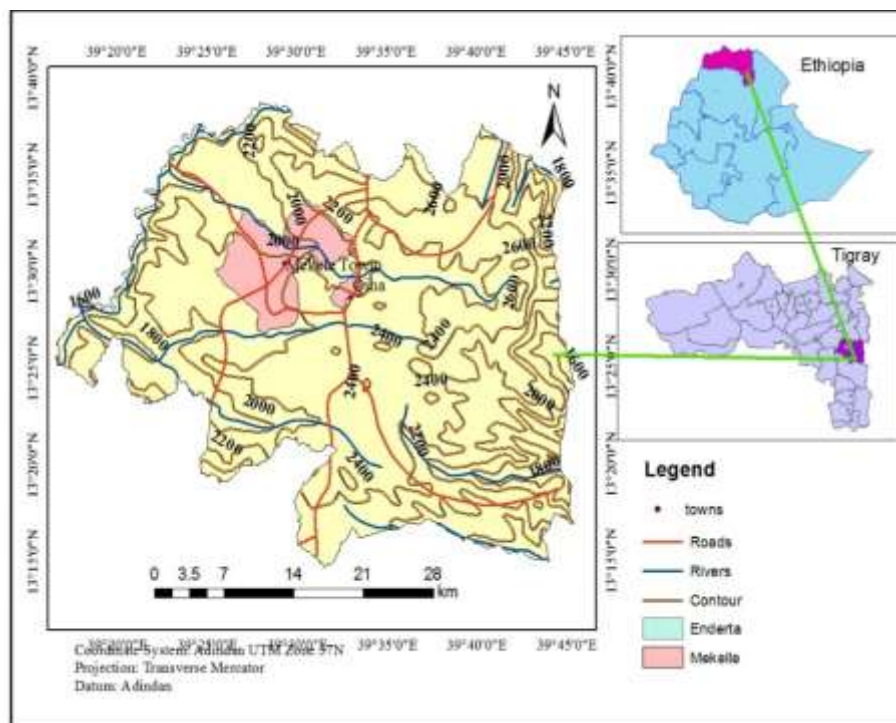


Figure 3.1: Location map of the study area

3.1.1. Population and economic activity

There is only one ethnic group in enderta district Tigrigna speakers. There are two major religions these are Orthodox Christians and Muslim. Their economic activity are dependent on agriculture and some very small population are traders. In the dry season agriculture practice by irrigations along the rivers by diverting them to the riverine areas. According to the statistical central agency of Ethiopia (CSA, 2007) the total number of population Enderta district and Mekelle special zone of the study area 330,211.

3.1.2. Climate and vegetation

Enderta district classified under arid and semi-arid climatic zone. In the summer season receive high rainfall in July and August month in a year. The mean annual rainfall of the area is 550 mm and a minimum rainfall is record in February, March and April. Seasonal. Based on Ethiopian metrological agency (2009–2016), the average annual temperature ranges from 10 to 30°C and the maximum temperature are reaching more than 32°C in May, June and July. The mean average annual rainfall 670 and receives heavy rainfall only from July to August. Sometime the rainfall can rain rarely in the other seasons.

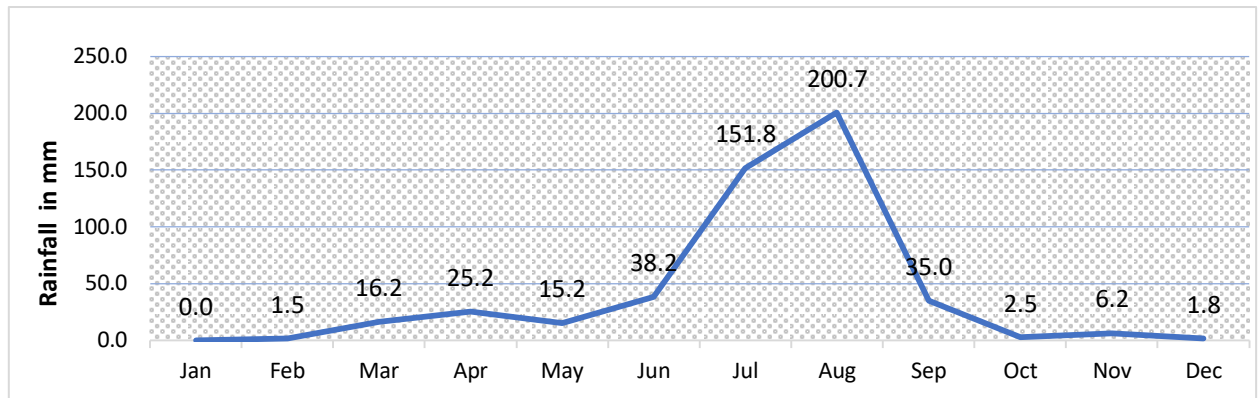


Figure 3.2: Mean monthly average rainfall

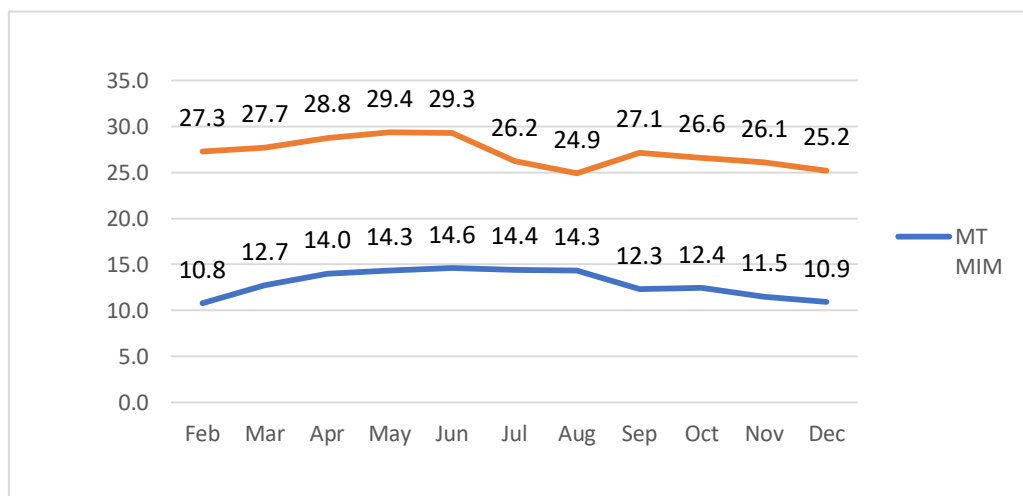


Figure3.3. Mean monthly temperature minimum and maximum

3.1.3. Land use, Vegetation and Soil

Land use is a major controlling factor in groundwater potential (Pappas et al., 2008). For example, precipitation that rains on roof tops and pavement results in quick runoff instead of infiltrating into soil as it would generally do in a natural or farmed landscape. The main land use in the study area is rain-fed agricultural area and mainly crop land area. Grazing land and settlements inhabit a considerable part of the area. Enderta district is sparsely vegetated as a result of unnecessary deforestation primarily for agricultural land. The sparse vegetation cover results in extreme soil degradation and resulting in silt deposition difficulties in water harvesting structures made within the study area.

According to WWDSE (2006) conducted soil type classification in the district based on the grain size distribution categorized to four classes such as sandy loam, silty loam, clay loam and clay soils and some other types (Fig 4). The dominant soil types recognized are the soil types in the area are strongly related to geology and geomorphology. The steep area dominated by sandy and silty loam soils, while the clay loam and clay soils cover the physio graphically flat area and following the river banks.

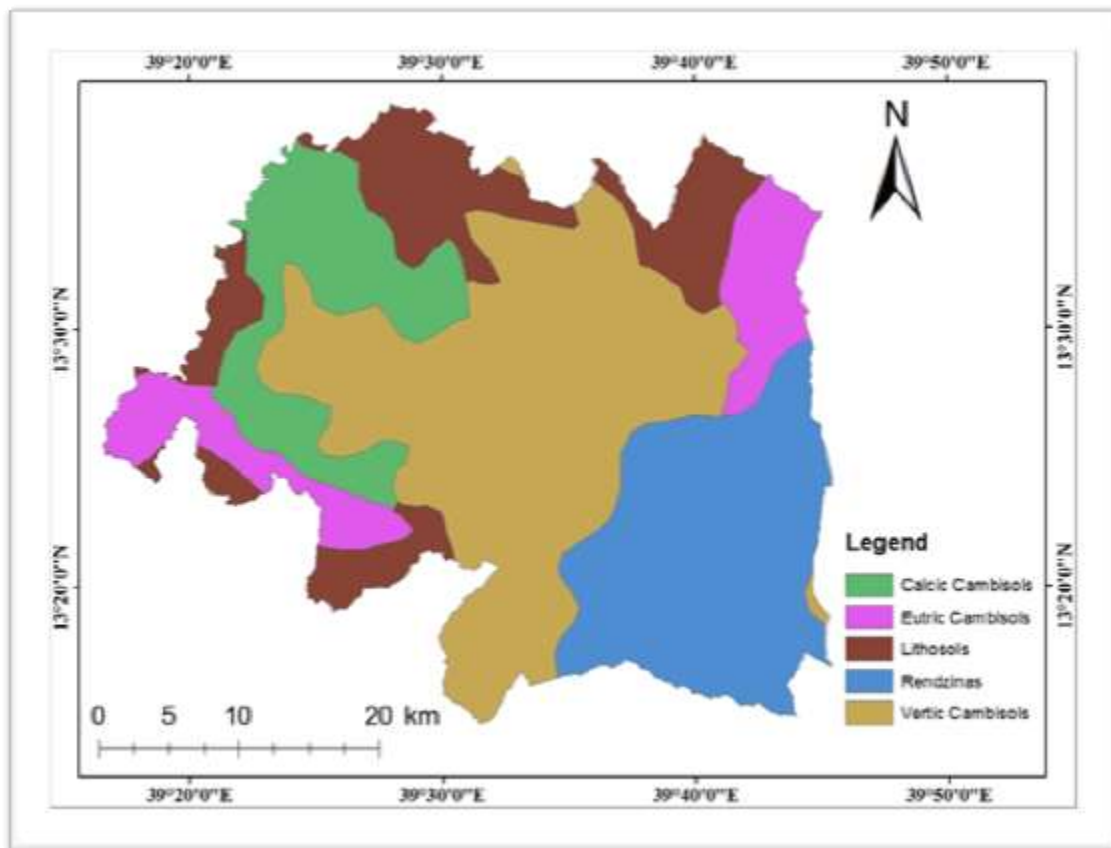


Figure3.4. Soil map of the study area

3.1.4. Physiography and Drainage

The study area covers about 1864 kms the altitude ranges from 1487–2752 m above sea level. The altitude of the Enderta varies from 1487 m above mean sea level at the eastern part of the study area 2752 m above mean sea level at the extreme south of the study area boundary. The northern and southern ends of the district are bounded by a chain of dolerite

ridges mainly oriented N–W and the central part is categorized by relatively flat topography of Mesozoic sedimentary terrain loamy clay soils. The Eastern limit of the district is physically separated by the dolerite ridge from Afar depression lowlands.

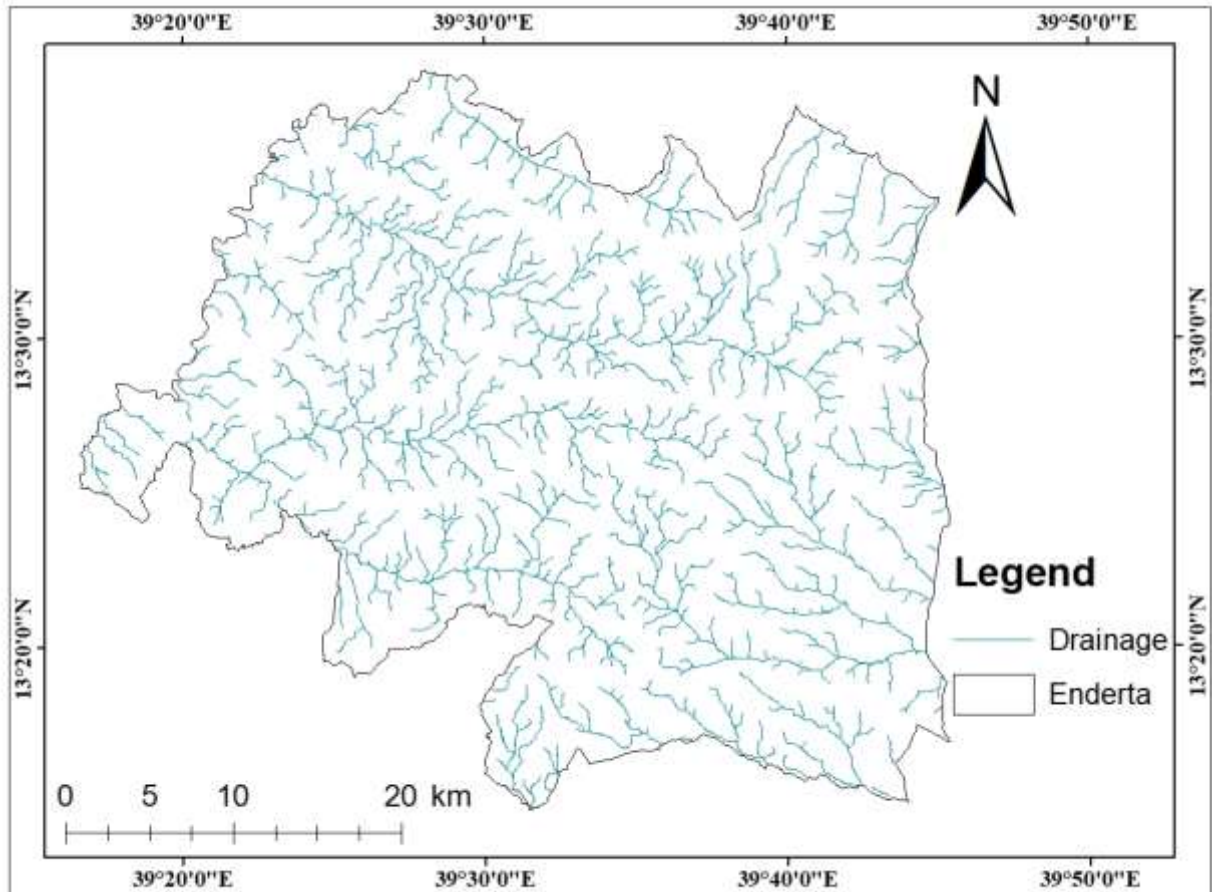


Figure 3.5. Drainage map

3.1.5. Geology

3.1.5.1. Regional Geology

The geological units in Ethiopia fall into three main categories (Mengeasha et al., 1996). These are Precambrian basement, late Palaeozoic to early tertiary sediments and Cenozoic volcanic and associated sediments. During late Palaeozoic to early Mesozoic the northern and eastern parts of East Africa acted as depositional basins for sediments coming from the higher cratons. According to Kazmin, (1975) this period is mainly represented by the deposition of the Enticho sandstone and Edaga-arbi glacial in Tigray. According to the author two major transgression-

regression se took place during Mesozoic era. It was considered that cycles are related to major regional tectonic events that have influence the entire East African region area. The Mesozoic sedimentary sequence of the Mekele outlier is the product of transgression-regression cycles and rocks representing a range of sedimentary environments have been recognized (Bossellini et al., 1997). The first cycle began during early Jurassic or late Triassic and resulted in the deposition of the Adigrat sandstone consisting mainly of sandstone and minor lenses of siltstone and Antalo formation consisting mainly fossiliferous limestone in Tigray Region (Mengesha et al., 1996). The reversion of the first phase caused the deposition of the Agula formation that is constituted of black shale, marl and clay stone with some beds of black limestone in the Mekele area. Regression of the second phase during late Cretaceous resulted in the deposition of Amba Aradam formation that is formed of siltstone, sandstone and conglomerates. The works of Beyth (1972) and Kazmin (1975), state that these Mesozoic sedimentary series unconformably superimposed on the Precambrian basement, that shaped a nearly circular outlier 800 km², called Mekele outlier. As described by Bosellini et al. (1995), Mekele outlier consists of Adigrat sandstone, Jurassic carbonate-marl-shale succession Antalo limestone and Amba Aradam formation. Tertiary flood basalts unconformably covered the sedimentary rocks of the area. The basaltic rock around Mekele area is called dolerite. According to Levitte (1970), the dolerite mostly occurs as sills with a thickness of ranging from one meter to 30 meters and dykes that intruded the sedimentary rocks.

3.1.5.2. Local Geology

Enderta district is located in the central part of Mekele outlier. The geology of the study area is more complex. The main rock formations which outcropped in the larger part of the study area are shale-limestone intercalation and igneous rocks of Mekele dolerite, Agula shale, Adigrat sandstone and intruded Mesozoic sedimentary rocks. Stratigraphically, the shale-lime stone intercalation is the upper most part of the Antalo limestone group. It is mixed of shale, marl and limestone intercalation which infrequently contain thin layers of gypsum (Yehdego, 2003). Almost half of the study covered by finely crystalline limestone, marl and shale (Mengeasha *et al.*, 1996). In the areas where there is dolerite intrusion it grows highly upset and the intercalation beds tilted from horizontal. The main sedimentary rock unit outcropping in the study area underlying the shale and limestone intercalation is limestone. The limestone unit

outcrops mainly in the low land areas of the Aynalem,. Ridge forming dolerite dykes and sill are commonly outcropped in around mekellecity, in the small town Aynalem, Chellekot, Dagiya villages and some other villages. The rocks are black, fine to medium grained and mostly contains phenocrysts of plagioclase crystals in the dolerite (Hussien, 2000). The existence of dolerite sill is evidenced by the penetration of the dolerite unit in almost all wells. The trap volcanics also found around the Mehibere Genet and Mariam dahinekebeles (Geological Survey Ethiopia, 1971). TsalietMetavocanics green schist orginally agglomerate and Tuffaceous sediments and sheet flood terraces silt, sand and gravel (Geological survey ethiopia, 1971). EdagaArbiGlaciarstillite, containing granite boulders with the diameter of up 6 meters found in the eastern part of the study area boundary with the afar depression drainage system. Antalo limestone marl was found interbedded with coquina and marl. Enticho sandstone commonly calcareous, with lenses of polymict conglomerate with Edagaarbi glaciers tillite the palaeozoic Ordovician period. According to map of Geological survey prepared map the study area is dominantly cover by the following three lithology, finely crystalline Limestone Marl and Shale, Agula Shale and Limestone and Sandstone.

A) Dolerite

Thesills intrude mainly the upper part of the Jurassic limestone-shale succession (Agulae Shale) anddisplay a generally concordant to sub-concordant relationship with the flat laying sedimentaryrocks, as shown on the photograph depicted in Figure 3.6. The thickness of the sills may reach 80to130 m with a large areal extent of up to 20 km and more along the strike. Depending on localerosional morphology, the sills either form steep cliffs or flat mountain tops. Although it is notwell identified, the major conduits for the nearby doleritic sills seem to be the WNW-ESE aligned faults and the NNE-SSW aligned fractures. These exposures are mainly concentrated inthe Mekelle Outlier particularly in the areas bounded by the Mekelle Fault in the north and theChelekot Fault in the south.

B) Adigrat Sandstone

The Adigrat Sandstone is the bottom most and the oldest of the Mesozoic sedimentary succession of the Mekelle Outlier. It locally overlies the horizontal Paleozoic sedimentary rocks of the Enticho Sandstone and the EdagaArbiTillites (Dow et al., 1971; Saxena and Assefa,1973). The Adigrat Sandstone is also significantly thinning westward and completely disappears north

of the Adigrat Axum road. It is estimated to have a maximum thickness of 700 m in the Mekelle Outlier, around northeast of the study area.

C) Enticho Sandstone and EdagaArbiTillites

According to Dow et al.(1971) describe two Paleozoic formations Enticho Sandstone and EdagaArbiTillites, both connected with a glacial environment and discordantly covered by the Adigrat Sandstone with a none identifiable chronological gap. Garland (1980) favored a “close lithological relation” of the three units and thus lumped them into a major “Adigrat Group”. Dow et al.(1971) describe a unit made only of sandstone and conglomerate (Enticho Sandstone, thickness less than 160 m) and one unit rich in tillites (EdagaArbiTillite, thickness 150 to 180 m) with boulders up to 6 m in diameter. The tillite bearing unit generally overlies the other one, though the two are often described as interfingering. The Paleozoic sequence as a whole overlies the basement with a clear unconformity, whereas a slight angular unconformity is described at the top. These geological units found in the eastern part of the study.

D)AntaloLimestone,fine crystalline limestone, Marl and shale

The AntaloSupersequence is a major sedimentary succession of the Mekelle Outlier, composed of several layers of limestone, shale, marl, and minor amounts of gypsum and sandstone intercalations. Several investigations of different scales have been carried out on these sediments. However, there is no common understanding on the naming of these successions and the subsequent subgroups. Therefore, in this study, the classification of the whole succession into several units has been made based on the dominant lithology. The overlying unit is composed of marl and marl limestone, rich in brachiopods and ammonites, with scattered coquinas (storm layers).

The top of the Marl-Limestone unit occurs as a laterally continuous cliff in the Messebo section near Mekelle. The thickness exceeds 200 m around Mekelle and decreases westward. It consists of shale and Geba bridge and at the Mekelle fault scarp, the limestone is characterized by black color, microcrystalline texture, hardness, and varying thickness. The top most unit, mapped as “Shale-Marl-Limestone” is well exposed along the main road from Mai-Mekden to Agulae.

Reclassified Lithology map of the study area

3.2. Data description, software and methods

3.2.1. Methods

The method employed is summarized in the flow chart below. It involves digital image processing for the extraction of lithological and linear features, evaluation of digital elevation model (DEM) as well as field studies. The field studies are comprised of hydrogeological and structural investigations. The SRTM DEM was used to extract drainage systems and landforms. Moreover, comparisons of digital elevation models derived from contours and radar interferometry in the Shuttle Radar Topographic Mission (SRTM) were made in relation to location, extraction of drainage networks. All data were integrated in a Geographic Information System (GIS) and analyzed to assess the Groundwater controlling parameters. The schematic representation of the methodology has been showed in figure 7.

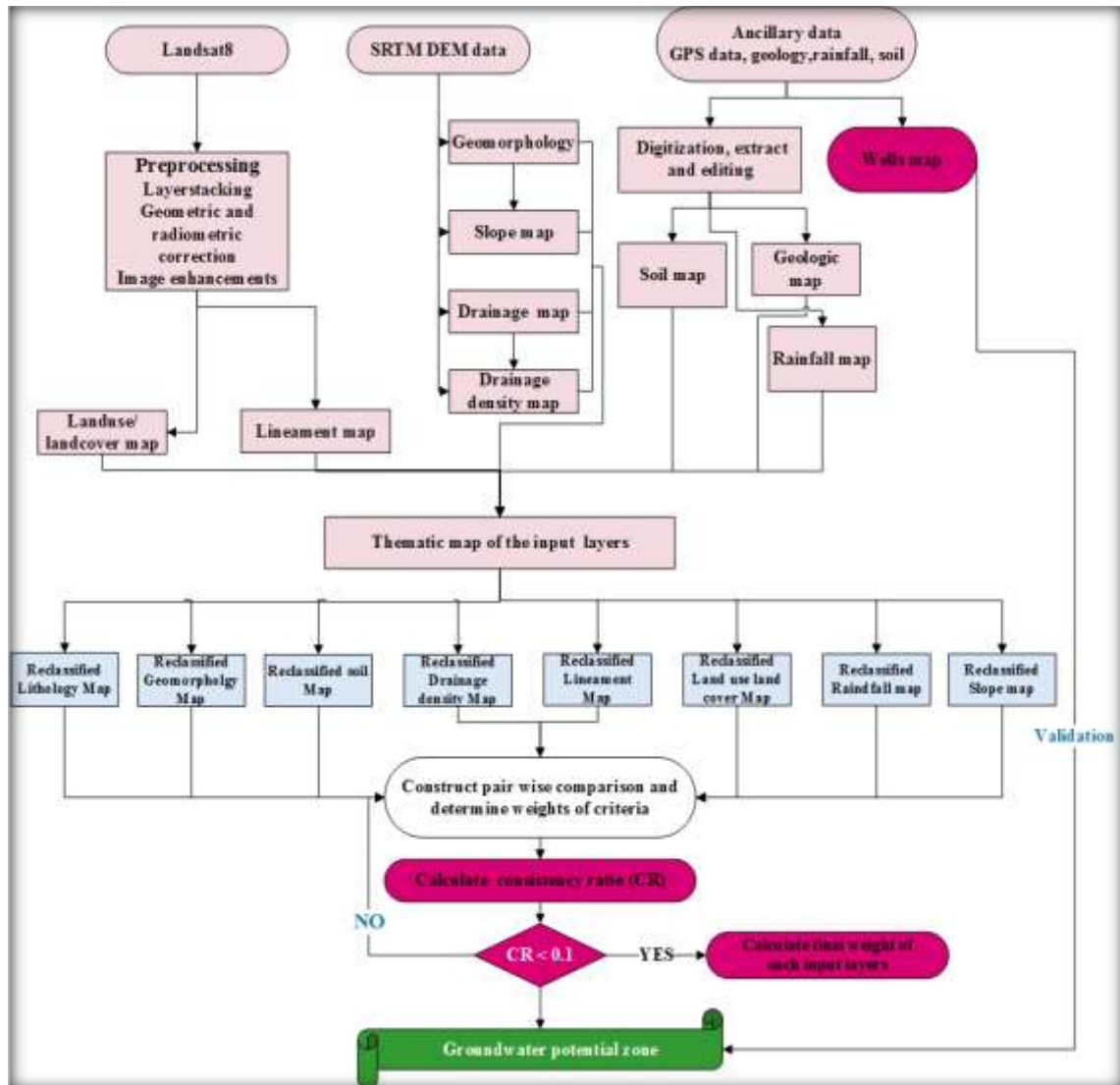


Figure 3.6. Flowchart of the study

3.2.2. Software's used

There are many types of software can be used for the analysis of Groundwater potential zone mapping. From these software ArcGIS 10.3, ERDAS 2015, Geomatica 2016 trial, Arc Hydro extension, IDRISI Selva 17.0. ArcGIS used for GIS analysis. ERDAS for the purpose preprocessing and processing remote sensing analysis. IDRISI best software for give weighted for each thematic layer based on the importance to the final output groundwater potential zone map. Show in table 2.1

Table 3.1. Types of software used

No	Software used	Version	Description
1	ArcGIS	10.3	clipping image, merging polygon, Generating different Thematic map
2	ERDAS imagine	15	Layer stacking and mosaicking in preprocessing image.
3	IDIRISI Selva	17	Weight calculation and pairwise comparison
4	PCI Geomatica 2015	15	Layer stacking and mosaicking in preprocessing image.
5	ArcHydro10.5	10.5	Drainage network extraction
5	Global Mapper	11	Geomorphology mapping

Arc Hydro used for the drainage system of the landscape defines the direction of surface water flow according to land surface topography. Drainage divides defined by ridge lines separate the area draining to one stream from the adjacent areas draining to neighboring streams.

Drainage Area is a generic term used within the Arc Hydro data model to describe any feature class describing such drainage areas, and it is sub classed into Catchment, Watershed and Basin, to describe specific types of drainage areas. Accurate drainage boundaries are essential for hydrologic modeling studies. Drainage boundaries may be delineated manually from a topographic map, digitized from digital raster graphic map, or determined through the use of raster data from Digital Elevations Models.

3.2.3. Data description

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

Satellite image of Landsat 8 sensor operational land imagery (OLI), path 168 and row 051, which was acquired on January 1, 2017 and path 169 and row 51 date acquired January 17, 2017 with a map projection of UTM zone 37N, spheroid and datum WGS 84 has been used for most of the processing and mapping activities after re-projection into Adindan datum. From this image, 7 bands were used. Bands 2, 3, 4, 5,6,7 and 8 in visible, near infrared and short wave infrared electromagnetic spectrum having spatial resolution of 30 meters and band 8 is panchromatic having 15 meter spatial resolution.

These images were imported to ERDAS Imagine 15 software and stack the bands. the study area was subset from the scene of path 168 and row 51 and 169 path and 51 row. The finally image mosaic to one after the subset image of band 8, directional filter was done in order to digitize the existing geological structures and the result was compared with the previous structural map of the area. Printouts of different band combinations were used to identify features during field survey.

The Shuttle Radar Topography Mission (SRTM) was a joint project approved out by the US National Geospatial Intelligence Agency (NGA), the US National Aeronautics and Space Administration (NASA), the German Aerospace Center (DLR) and the Italian Space Agency (ASI) (Mukul et al., 2015). The principal objective of the SRTM project was to collect near-global topographic data with entire horizontal and vertical accuracies better than 20 and 16 m, respectively, with 90% confidence (Rabus et al. 2004) this 16 m linear error at 90% confidence (LE90) corresponded to a root mean square error (RMSE) of ~10 m, assuming a normal.

The Shuttle Radar Topography Mission (SRTM) data were collected with a sophisticated synthetic aperture radar (SAR) system with a pair of C- and X-band antennas having carrier frequency 5.3 and 9.6 GHz, respectively, and acquired topographic elevation data at 30 m resolution (Farr and Kobrick, 2000) during an 11-day mission (Werner, 2001; Rabuset al., 2004). Data were only collected between 60 N and 57S latitude (Rabusset al., 2004) as high-latitude regions above 60 latitudes in both the hemispheres were not within the scope of the mission and resulted in the exclusion of about 20% of the Earth's surface. The SRTM DEM is most important used in different research's.

3.3. The integration of Remote Sensing and GIS in Hydrogeology

Image preprocessing operation is done to correct inaccurate image data to create a more faithful representation of the original image data values. It involves initial processing of the image data to correct for geometric falsification, to calibrate the data radiometrically and to reduce noise present in the data (Lillesand, 2000).

Remote sensing imageries are fundamentally exposed to geometric biases. These inaccurate value may be due to the viewpoint of the sensor optics, the signal of the scanning system, the motion of the platform (the platform altitude and velocity), the terrain relief, or the degree of the curvature and rotation of the earth (Lillesand, 2000). Geometric corrections are done in order to reduce ad color balance or bad pixel value balance for these falsifications so that the geometric improvement of the imagery will be as close as possible to the real world. The Landsat satellite data, used in this study, were all ortho-rectified by Global Land Cover System (GLSF).

Image Enhancement

Image enhancement is applied to image data in order to improve effectiveness to display or record the data for subsequent visual interpretation. These methods are best useful because numerous satellite images, when test on a color display give insufficient information for image clarification. Contrast stretching, density slicing, edge segmentation, and spatial filtering are the more commonly used techniques.

Spatial filtering and edge segmentation is done on the panchromatic image to get good visual interpretation and generate lineament form the 15meter resolution. spatial resolutions in order to get improved linear features and subdue other features. This was used to perform for the mapping of lithological structures of the area.

Image Transformation

Image transformation is done in order to distinguish the difference between the various brightness values, which are get from identical surfaces due to physiographic slope, shadows, or seasonal changes in sunlight brightness angle, and intensity. This condition might be hinder the ability of an interpreter to distinguish correctly surface materials in remotely sensed image. Ratio transformation of the image can reduce the effect of such environmental conditions and

may also additionally gives sole information not available in any single band that is useful for discriminating between soils and vegetation.

Vegetation discrimination in land use/cover mapping band ratio of 5 to 4 band and False color combinations for geological analysis order of bands 5,6,2 for Landsat 8 of OLI image was done. In the ration image vegetation cover has shown true color light color where as in false color composite open forest has brown to red color. Image classification includes the analysis of multispectral image data and the application of statistically based decision rules for determining the land use or land cover identification of every pixel in an image. Decision based on spectral radiance classification procedure is spectral pattern recognition whereas decision based on geometric shapes, size, and patterns the procedure falls into spatial pattern recognition (Lillesand, 2000).

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

3.4. Analytical Hierarchy Process (AHP)

The analytical hierarchy process (AHP) is a system of measurement using pairwise comparison and subject on the decision of professionals to descend priority scales from the give criteria. The comparison was made on a scale of numbers 1–9 which shows how many times a layer is important than the other (Saaty, 1980). Table 2.2 represents the scaling used in AHP. If the matrix formed is equal

$$A_{ij}, B_{ij} = W_i/W_j, \quad \text{Eq. (1)}$$

where w is the weight of each parameters, $i, j=1\dots n$ of every positive numbers entry to everywhere and satisfy the reciprocal properties, A_{ij} which is called reciprocal matrices.

Table 3.2. Saatty’s, scale of intensity relative importance

Intensity of relative important	Definition
1	Equal importance
2	Weak or slight
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong
8	Very, Very strong
9	Extremely importance

Source: (Saatty’s, 1980)

3.5. Weight Assignment and Normalization

The pairwise comparison matrix was carried out by using AHP procedures. To calculate the cumulative weight of the main criteria, the relative weight of their corresponding classes was considered. Map Category and weight Assignment for groundwater potential zone mapping eight parameters (land use land cover, lineament, slope, Geomorphology, geology, soil, Drainage and rainfall) are selected for groundwater potential zone mapping. Categorization and weight Assignment for Groundwater potential zones. Normalization of Assign Weight using AHP, on the basis of Saaty’s scale, considering two themes and classes at a time on the basis of their relative importance to determine the Groundwater Potentials zone. Thereafter, pairwise comparison matrices of assigned weights to different thematic layers and their individual classes are constructed using (Saaty’s, 1980) AHP and weights normalized by eigenvector approach. Consistency Ratio (CR) calculated to examine the normalized weights of various thematic layers and their individual classes according to Saaty (1980).

$$A_1 \begin{bmatrix} a_{11} & a_{12} \dots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{21} & a_{22} \dots & a_{2n} \\ \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} \dots & a_{nn} \end{bmatrix}, a_{ij} = \frac{a_{ij}}{\sum a_{ij}} \text{ for } i, j = 1, 2, \dots, n \quad \text{Eq.(2)}$$

The eigenvalue and the eigenvector calculated as:

$$W = \begin{bmatrix} W1 \\ W2 \\ \vdots \\ Wn \end{bmatrix} \text{ and } W_i = \frac{\sum_1^n a_{ij}}{n} \text{ for all } n=1, 2 \dots n \text{ and } W' = \begin{bmatrix} W1' \\ W2' \\ \vdots \\ Wn' \end{bmatrix} \quad \text{Eq. (3)}$$

$$\lambda_{\max} = \frac{1}{n} \left(\frac{W'}{W1} + \frac{W'}{W2} + \dots + \frac{W'}{Wn} \right) \quad \text{Eq. (4)}$$

W: Eigenvector,

w_i: Eigenvalue of criterion i, and.

λ_{max}: Average eigenvalue of the pair wise comparison matrix.

CR is a measurement of consistency, of pairwise comparison matrix and it is calculated using equation. Consistency ratio is the indication of acceptability of reciprocal matrix, which calculated as the following

$$CR = \frac{CI}{RI} \quad \text{Eq. (5)}$$

Where CI is consistency index and RI is random consistency index

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad \text{Eq. (6)}$$

These matrixes have the property of consistency known as consistency ratio (CR). if the consistency ratio of the matrix is greater than 0.1 the matrix should be re-evaluated. Show the table 3.3.

Table 3.3: Random consistency index

Matrix size	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

3.6. Identification and Evaluation Criteria for Groundwater Potential Zone Mapping

Parameters influencing groundwater potential zone and their relative importance a taken from earlier works. The exactly the same factors were combined and only characteristic parameters were selected. They use lithology, geomorphology, land use land cover, lineaments, slope, soil, drainage density and rainfall which affects groundwater potential and recharge as the key parameters (Sajikumar and Gigo, 2013; Mahswaran et al., 2016).

Geology

The types geology that exposed to the surface are highly affect groundwater recharge by governing the percolation and movement of water to the ground Shabanet *al.* (2005) and geology plays a excessive role in the existence and distribution of groundwater potentials zone. Each lithological unit and their aquifer characteristics described in Table 3.4.

Table 3.4 : Geology and its aquifer characteristics

Factors	Geological unit	Aquifer characteristics
Lithology	Biotite-granite gneiss	Poor
	Charnockite	Poor
	Quartzite	Poor
	Sandstone/conglomerate	Good
	Granite gneiss	Poor

Source: (Kamal *et al.*, 2017)

Geomorphology

Geomorphology describes the landform and structural geographies including; plateau, Valley, Denudational hill, Hill, Floodplain good for groundwater. Geomorphology helps to recognize the characteristics of the hydrological formations of an area. The value of geomorphology varies in terms of their characteristics and spatial distribution for groundwater potential and recharge processes. show table 3.5.

Table 3.5: Reviewed Geomorphology effect on groundwater potentials

Factors	Class	Rank	Groundwater potential
Geomorphology	hill	1	Very Poor
	Denudational hill	2	Poor
	Valley	3	Moderate
	Floodplain /flat	4	Good

Source: (Nagaraju, 2016)

Lineament density

Lineaments are the structural disjointedness of the earth surface such as faults, foliations, joints, and bedding planes. also, a mappable lined feature present on the surfaces indicates the zone of weakness and structural disjointedness it may be curve, linear and slightly curve which is the most essential for the infiltration and movement of water to the ground (Mogajiet *al.*, 2011). Show table 3.6.

Table 3.6: Lineament Density

Factors	Criteria Value in km/km ²	Classification
Lineament density	0 – 0.34	Very low
	0.34 – 0.99	low
	0.99 – 1.57	Moderate
	1.57 – 2.11	High
	2.11–2.69	Very high

Source: (Waikar and Aditya, 2014)

Slope

Slope is one of the factors governing infiltration of water to the ground and the pointer of groundwater potential appropriateness. A high sloping region causes more runoff and less infiltration and have poor groundwater prospects related to the low slope region. Low sloping regions causes less runoff and high infiltration rate and have good ground water prospect as shown in Table (HsinFuYeh, 2016). Representation of slope show in table 3.7.

Table 3.7: Role of Slope for groundwater potential

Factors	Value (Degree)	Classification	Infiltration rate
Slope	0 – 1	Flat	very high infiltration
	1– 3	Gentle slope	High infiltration
	3 – 15	High slope	Low infiltration
	15 – 45	Hill	Very low infiltration

Source: (Maheswaranet *al.*, 1999)

Drainage density

Drainage basin is the natural draining of water runoff to lowland surface. Drainage density and type of drainage direct to the information of rock and soil permeability, penetration of water and surface runoff (Horton, 1945). There are several types of drainage network, dendritic drainage, rectangular, parallel drainage and coarse drainage. show table 3.8.

Table 3.8: role of drainage density for groundwater

Drainage density (km/km ²)	Description	Suitability
0 – 0.5	Low density	Good
0.5 – 1.0	Moderate density	Moderate
1.0 – 1.5	High density	Poor
1.5	Very high density	Poor

Source: (Salwa, 2014).

3.6.1. Factors controlling groundwater occurrence in the study area

Factors that have significant influence in groundwater dissemination and occurrence that are used for integration to delineate potential groundwater zones are discussed below.

3.6.1.9 Rainfall

Rainfall is the most important factors for the formation of ground water potential. The rainfall map of the study area is shown in Figure (Fig3.7). The southern and western part of the study area receives very high rainfall of around 541.3–612 mm/year. The northwestern and southeastern highland foot receives moderate rainfall 510–521.6 mm/year. Some part of the study area receives 521.6847– 541.3 from southern to the center. The central rift floor receives low rainfall 500.15–510.01 mm/year. The northern part of the study area part receives very low rainfalls (484.3–500.1 mm/year as presented in table 3.9. The high rainfall distribution along high slope gradient in the southern and southwest highland parts directly affects the infiltration rate groundwater potential zones in the downstream central of the study area.

Table 3.9: Rainfall and its rank as per suitable for groundwater potential

Factors	Value in mm	Suitability classes	Rank in number
Rainfall	484.3–500.1	Very low	1
	500.15–510.01	Low	2
	510–521.6	Moderate	3
	521.6847–541.3	High	4
	541.3–612	Very high	5

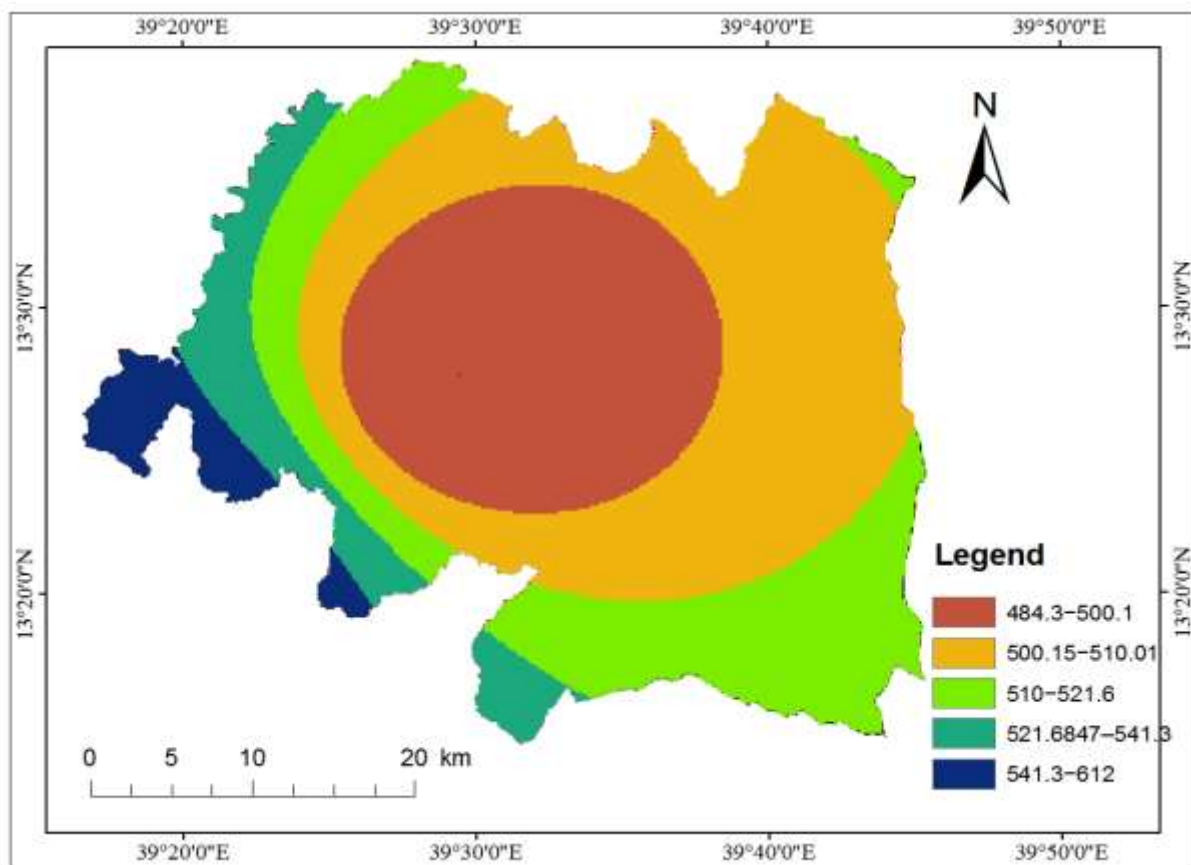


Figure3.7. Rainfall map

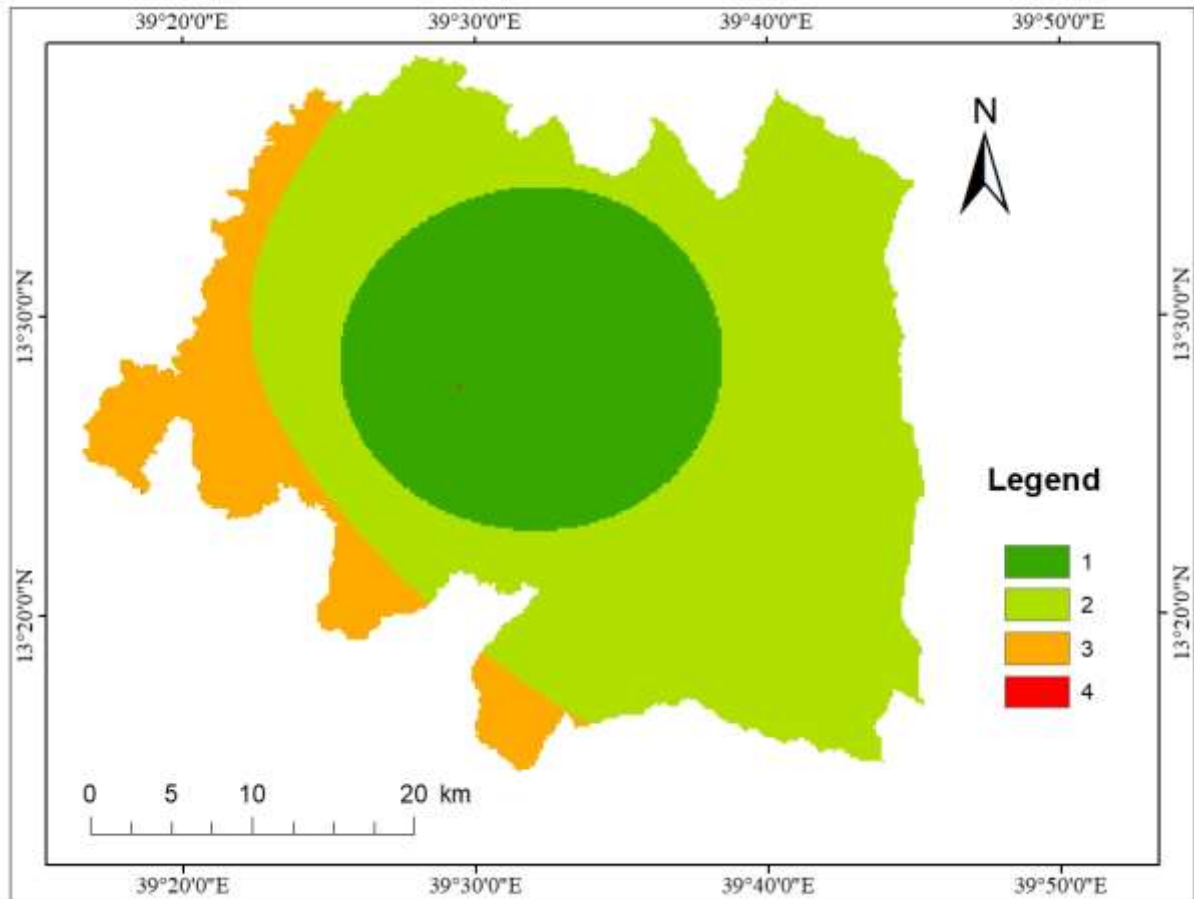


Figure 3.8. Reclassified Rainfall map

3.6.1.10 Drainage Density

The drainage system of any area always plays an important role in various ways. They reflect the lithology and structure of a given area. The drainage network of the study area was generated from The Shuttle Radar Topography Mission (SRTM) DEM using ArcHydro ArcGIS extension software. During digitization magnifying glass was used for magnification of blurred and closely spaced contours. each drainage line order was assigned in the attribute table. The major rivers present in the study area figure(fig3.9). chellekot, Illala and Aynalem all the other rivers are tributaries Giba river. But main river Giba is found in the western part of the study not fully included in the study.

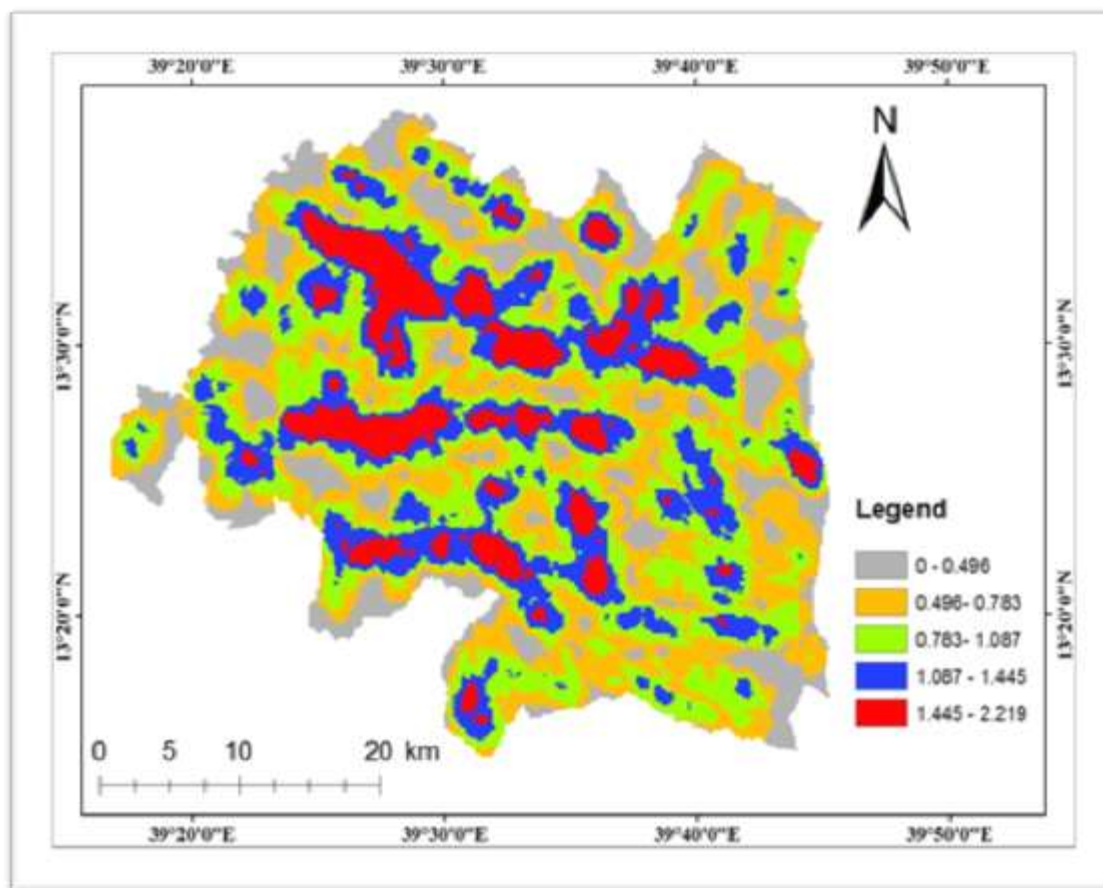


Figure3.9. Drainage density map of the study area

Almost the small river and large rivers, which are found in the study area drain from east to west but some small river drain to the afar depression drainage system.

Relationship of the drainage system of the area and lineaments has shown that the drainage system of the area is structurally controlled following lineaments directions (Fig.3.10). In the study area dendritic and parallel drainage pattern are recognized, which are indicative of the presence of structures that act as conduits or storage for sub-surface water. Structurally controlled drainage patterns are observed in NE part of the study area.

The pattern of tributaries within a drainage basin depends largely on the type of rock beneath, and on structures within that rock (folds, fractures, faults, etc.). Dendritic patterns, which are by far the most common, develop in areas where the rock (or unconsolidated material) beneath the stream has no particular fabric or structure and can be eroded equally easily in all directions.

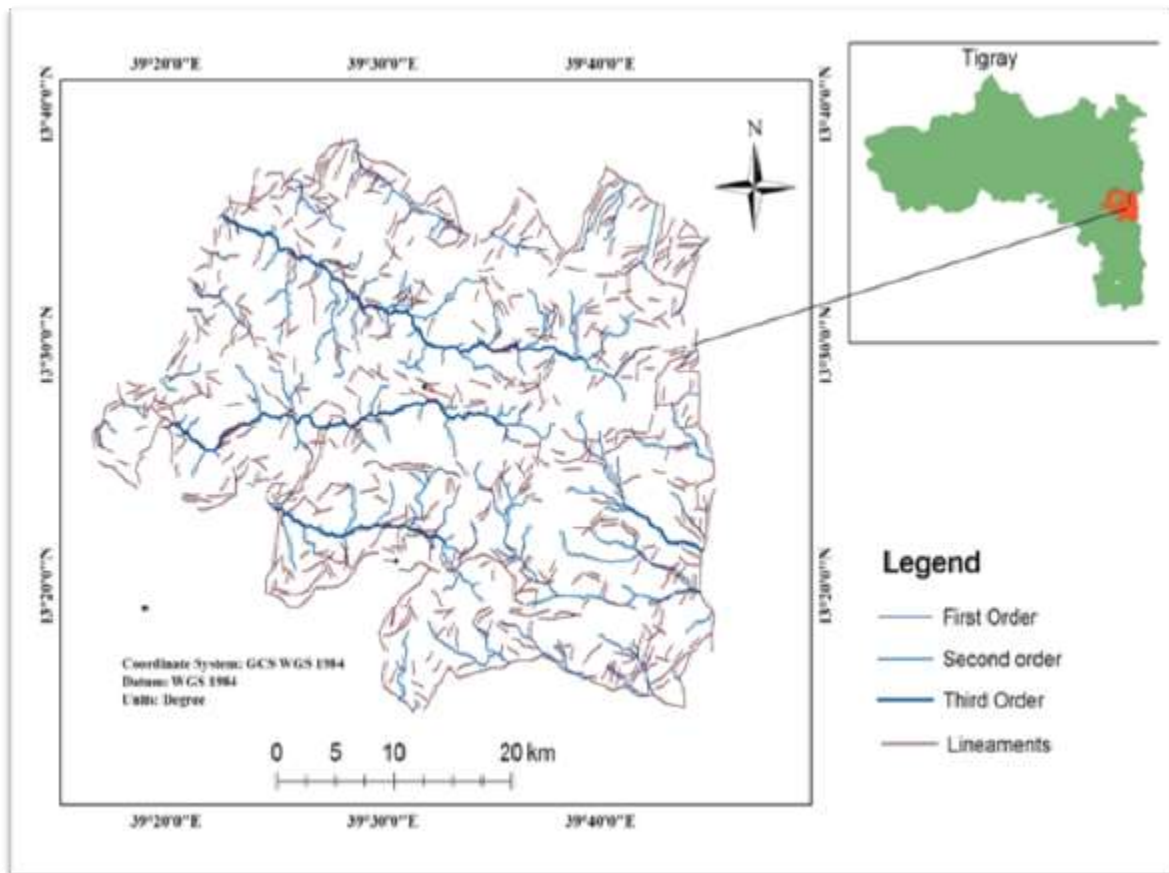


Figure3.10. Comparison of drainage and lineaments

The drainage density was calculated directly in ArcMap using spatial analyst extension using line density tool. In the study area, mainly four drainage density categories have been identified and mapped as shown in (Fig 3.11). Very high drainage density is found in the Eastern part of the study area whereas high drainage density is found in Central, southern more dense parts. Moderate and low drainage density concentrate in the extremely north and west part of the study area. Structurally controlled drainage is normally seen in northern part of the study area. Drainage texture and patterns are controlled by different litho-units, structure and morphology. In the northern part of the area drainage pattern is dendritic.

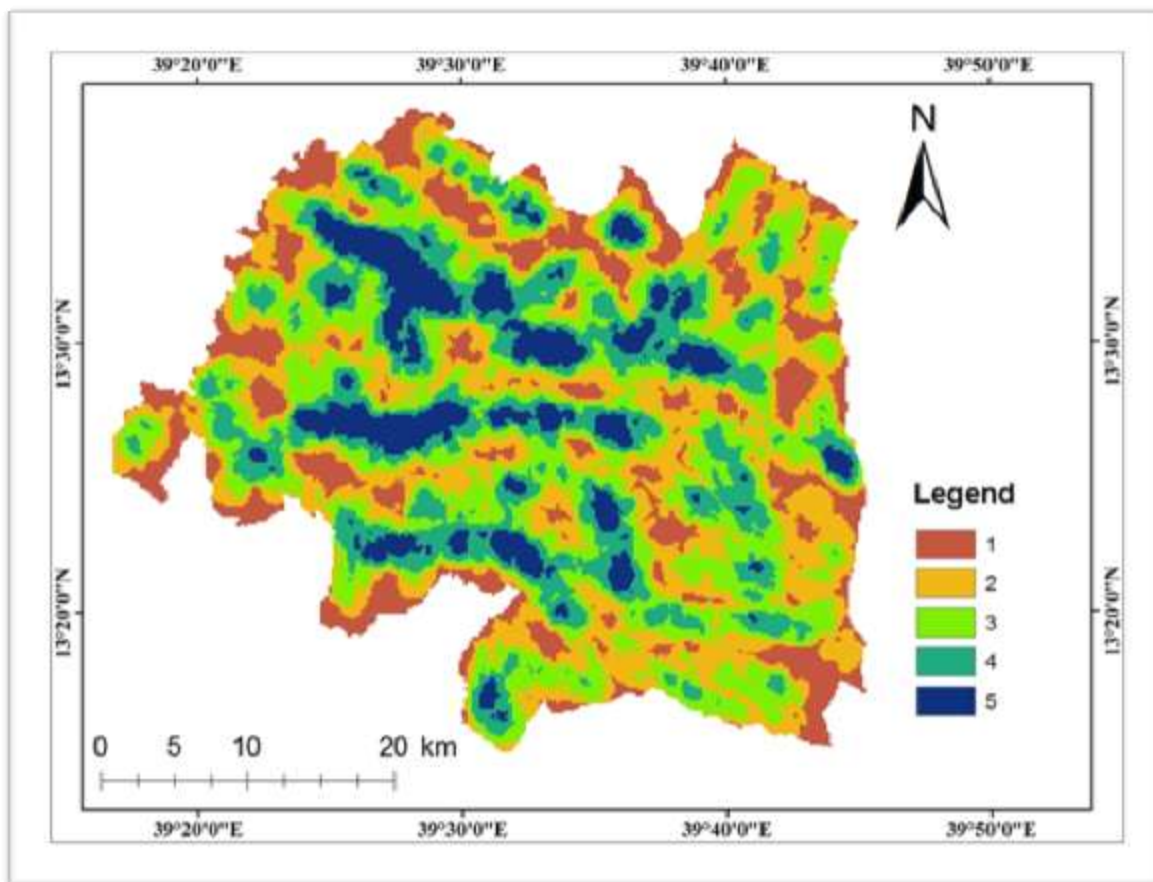


Figure3.11. Reclassified drainage density map of the study area.

With respect to groundwater existence the higher drainage density is related to less infiltration of water to the ground because of higher runoff water, and vice versa. The pair-wise comparison done based on this fact has shown that for areas with low drainage density higher weight was calculated and vice versa and the reclassified map of drainage density was produced based on these weights.

3.6.1.11 Slope

Slope is one of the factors controlling infiltration of water to the underground of the earth and the indicator of groundwater potential suitability. A very high step slope region causes more runoff and less infiltration and have poor groundwater prospects compared to the low slope region presented in (fig3.12). Low slopping regions causes less runoff and high infiltration rate and have good ground water prospect (HsinFuYeh, 2016). shown in Table3.10.

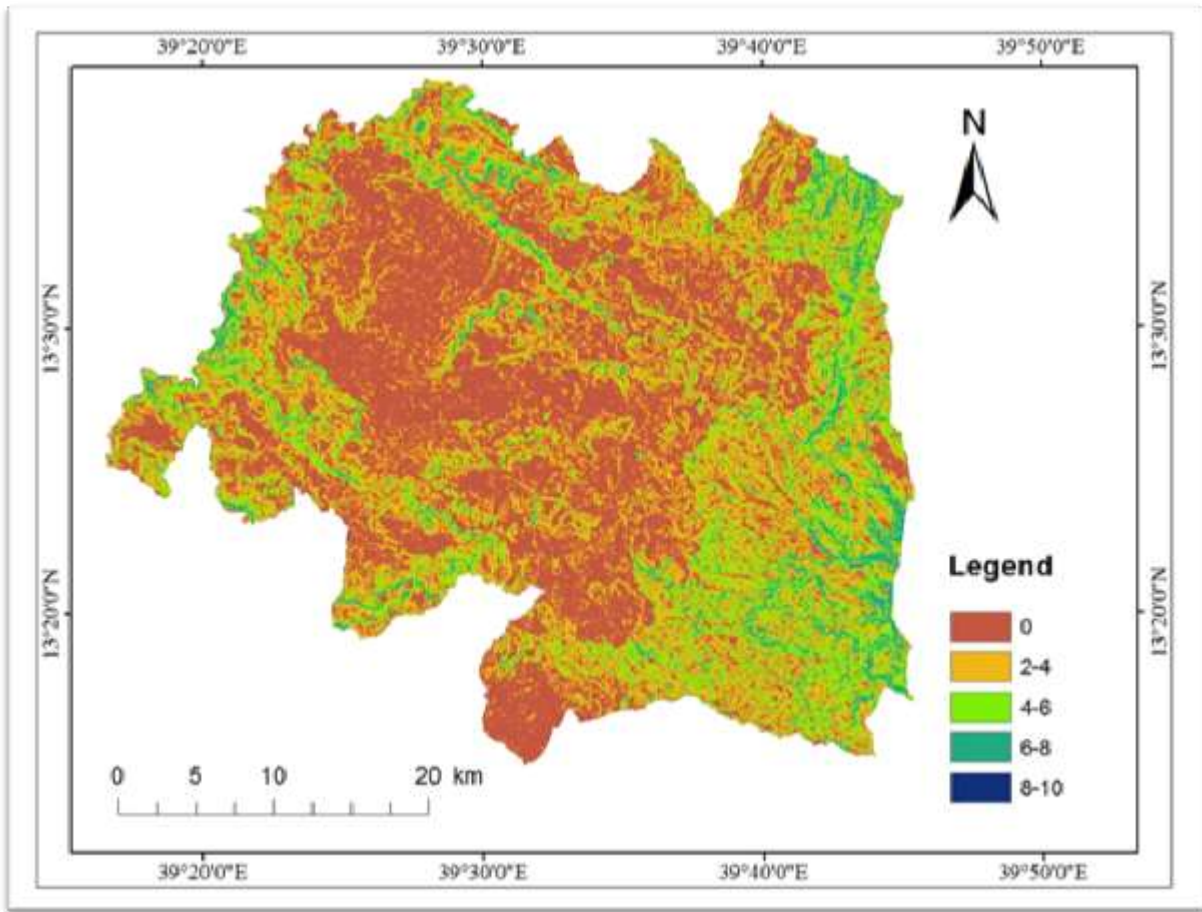


Figure3.13. Slope map of the study Area

Table 3.10: Role of slope and classification

Factors	Value (Degree)	Classification	Suitability
Slope	0 – 1	Flat	very high infiltration
	2– 3	Gentle slope	High infiltration
	3 – 15	High slope	Low infiltration
	15 – 45 and above	Hill	Very low infiltration

Source: (Maheswaranet *al.*, 1999)

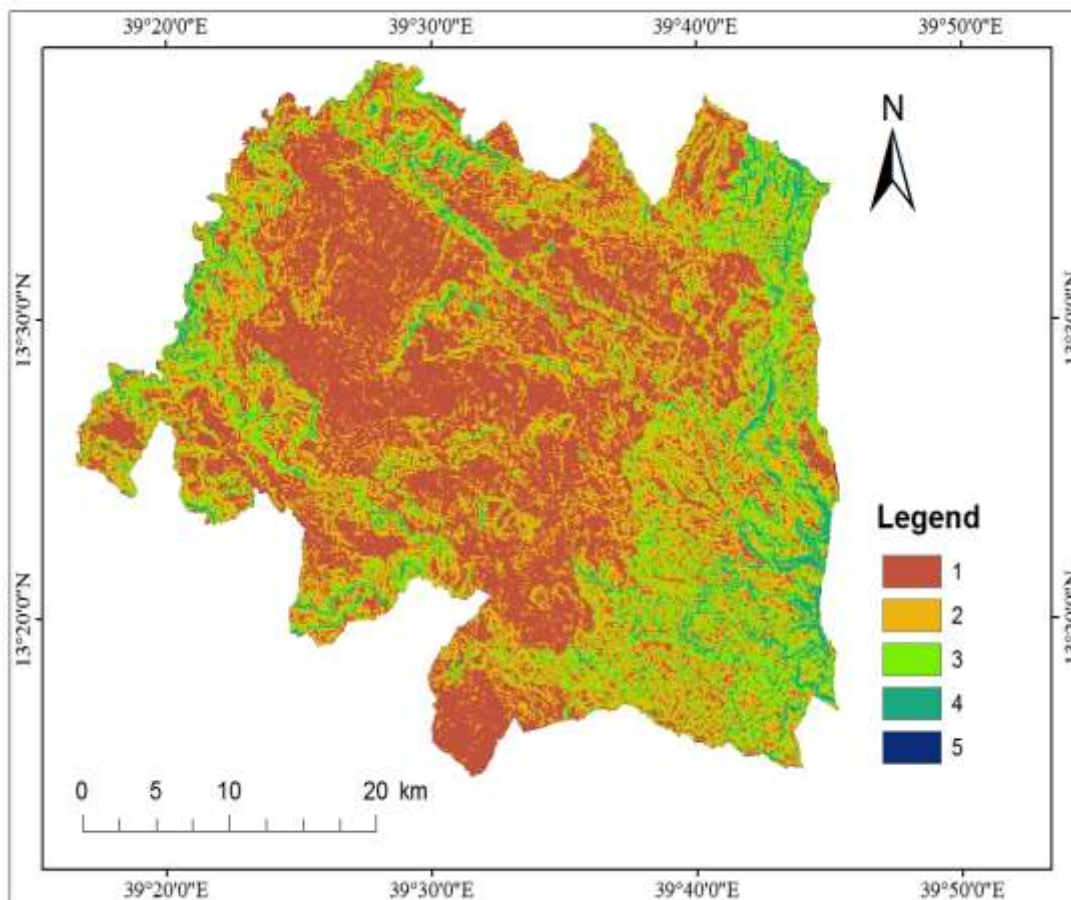


Figure 3.14. Reclassified slope map

Table 10: Slope value and its rank as per suitable for ground water potential

Factors	Slope(Degree)	Classification	Groundwater suitability	Rank
Slope	0	Flat	Very high	5
	0 – 2	Gentle slope	High	4
	2–4	Moderate slope	Moderate	3
	4 – 6	High slope	Low	2
	6 – 10	Steep slope	Very Low	1

3.6.1.12 Lineaments

Lineaments are linear features caused by the linear arrangement of regional morphological features such as streams, escarpments, and mountain ranges, and tonal features that in many areas are the surface expressions of breaks or fault zones (Lillesand, T.M., and Kiefer, R.W.,

1994). Lineament analysis of remote sensing data constitutes an important part of studies related to tectonics, engineering, geomorphology and in the investigation of natural resources such as groundwater, petroleum and minerals (Koopmans 1986; Kar 1994; Philip 1996).

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

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

Mapping of lineaments in the study was done by visual interpretation of various digitally enhanced single band (Fig.3.15) and multi band images that involves standard band combinations, principal component analysis and directional filtering.

The lineaments were identified by visual interpretation and automatic extraction from landsat image using PCI Geomatica from the images. A final lineaments map was constructed from the digital enhancement of individual single band and multiband images together with ground truth and previous work.

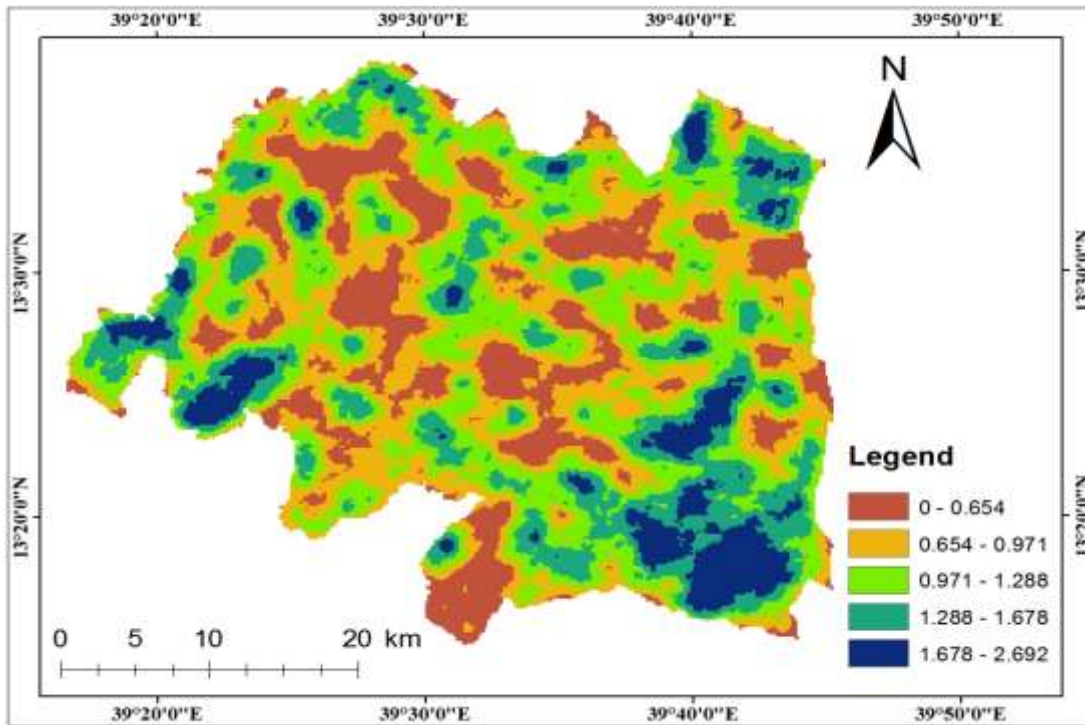


Figure 3.15. Lineament density map of the study area

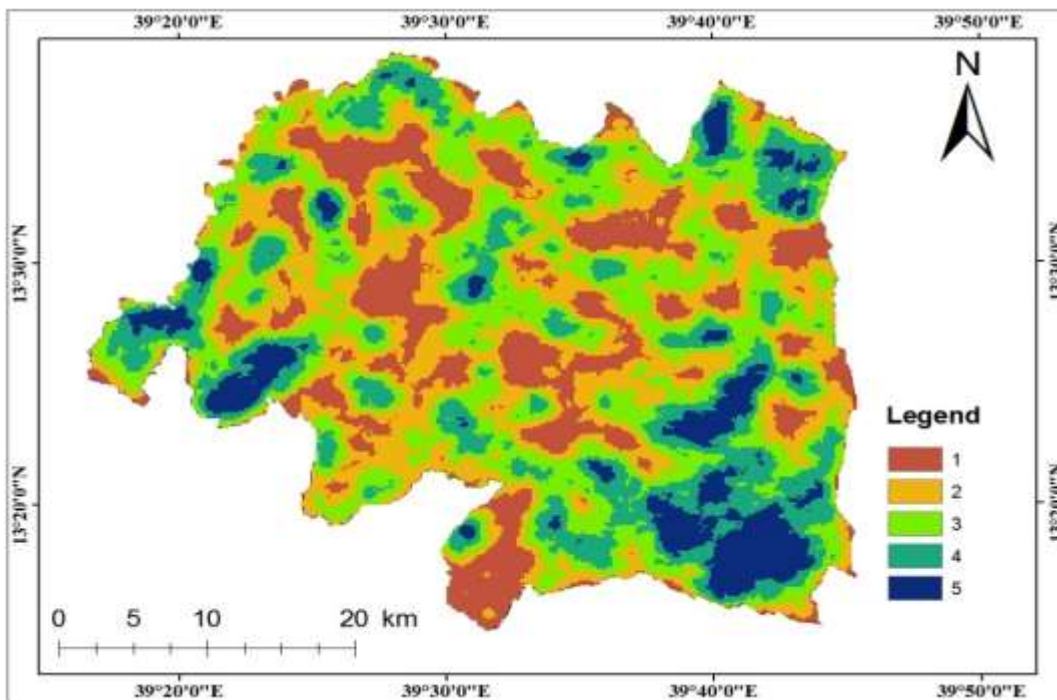


Figure 3.16. Reclassified lineament density map of the study area

3.6.1.13 Soil

Soil is an important factor for defining the groundwater potential zones. The analysis of the soil type reveals that the study area is predominantly covered by clay, silt loamy and sandy silt soils, sandy soils generally happen on hilly to undulating land slope on granite and gneissic terrain show map soil texture (fig3.17).

Soil characteristics always regulate penetration of surface water into an aquifer system and they are directly related to rates of infiltration, filtration and permeability. Extensive variety of geological, climatic, vegetation and physiographic features, which have influenced soil development and thus given rise to various types of soils.

Source FAO, 1998

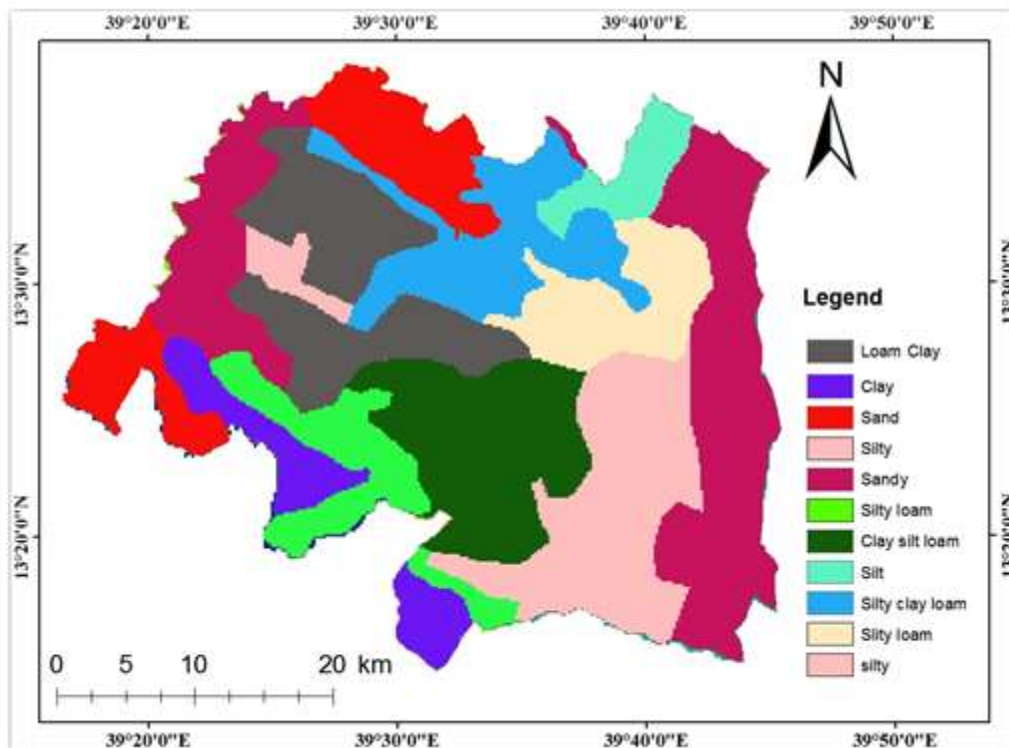


Figure3.17. Soil texture map

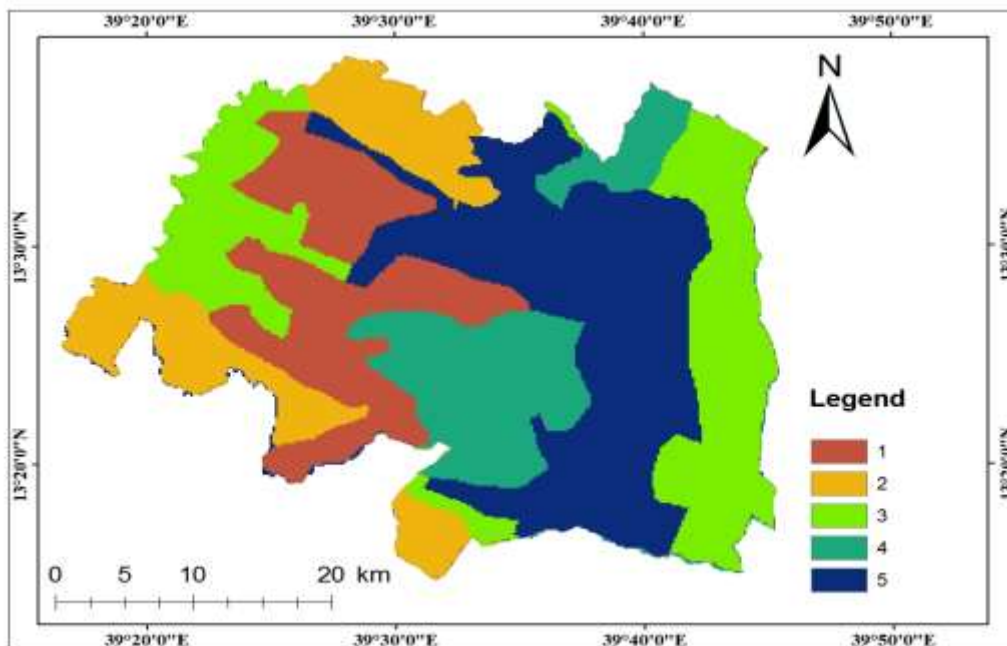


Figure 3.18. Reclassified soil texture map of the study area

3.6.1.14 Geology

The way of Geologic formation and genetic type is essential condition for ground water flow, transport and mineral composition. Types of rocks determine peculiarities of hydrological cross-section structure, type of porosity values, the nature of permeability, geological structure geomorphology and character of spatial heterogeneity of flow and transport parameters. Lithological stratigraphy of the Enderta district investigated by the Ethiopian Geological survey in different times as presented in Figure 3.19. Based the importance for groundwater potential geological units are classified in table 3.11.

Table 3. 11: Geology and its rank as per suitable for groundwater potential zone

Factors	Classification	Rank in word	Rank in numbers
Geology	Tlm, Tlt, Jq	Very low	1
	Jq, Pz	Low	2
	Jte, Lms	Moderate	3
	Jt, Plt, Jg	High	4
	Qpa, Ja, Pt, Od On	Very high	5

Entichosandstone (On) this is a white fine to medium grained sandstone with calcareous (locally siliceous) cement which is percolated at the surface. This sandstone shows variations in grain size, sorting and degree of cementation. This good for groundwater.

Antalo limestone (Jte) high outcrop exposure of 80%, with much travertine, beds one metre thick, highly jointed with joint spacing of 50 to 80 centimetres.

Adigrat Sandstone (Ja) The Adigrat Sandstone is a medium to coarse grained cliff forming sandstone with some shale. most product geological units etc.

Source Geological survey of Ethiopia 1982

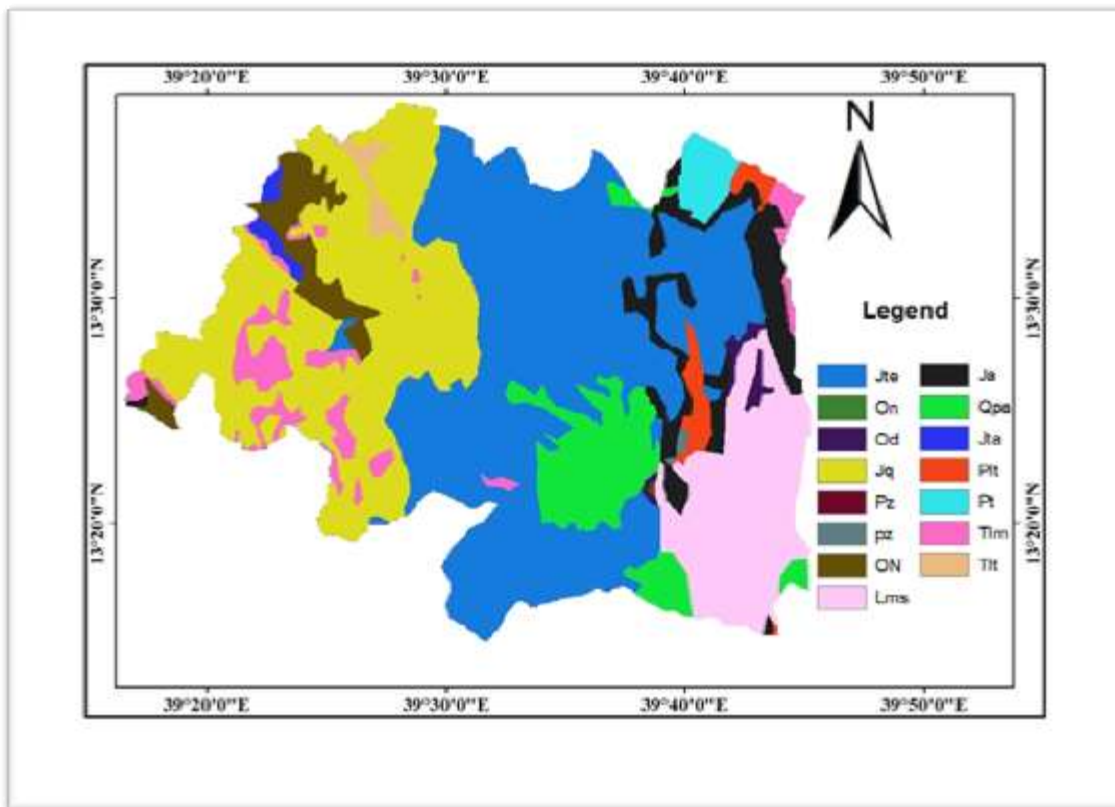


Figure 3.19: Geological map of the study area

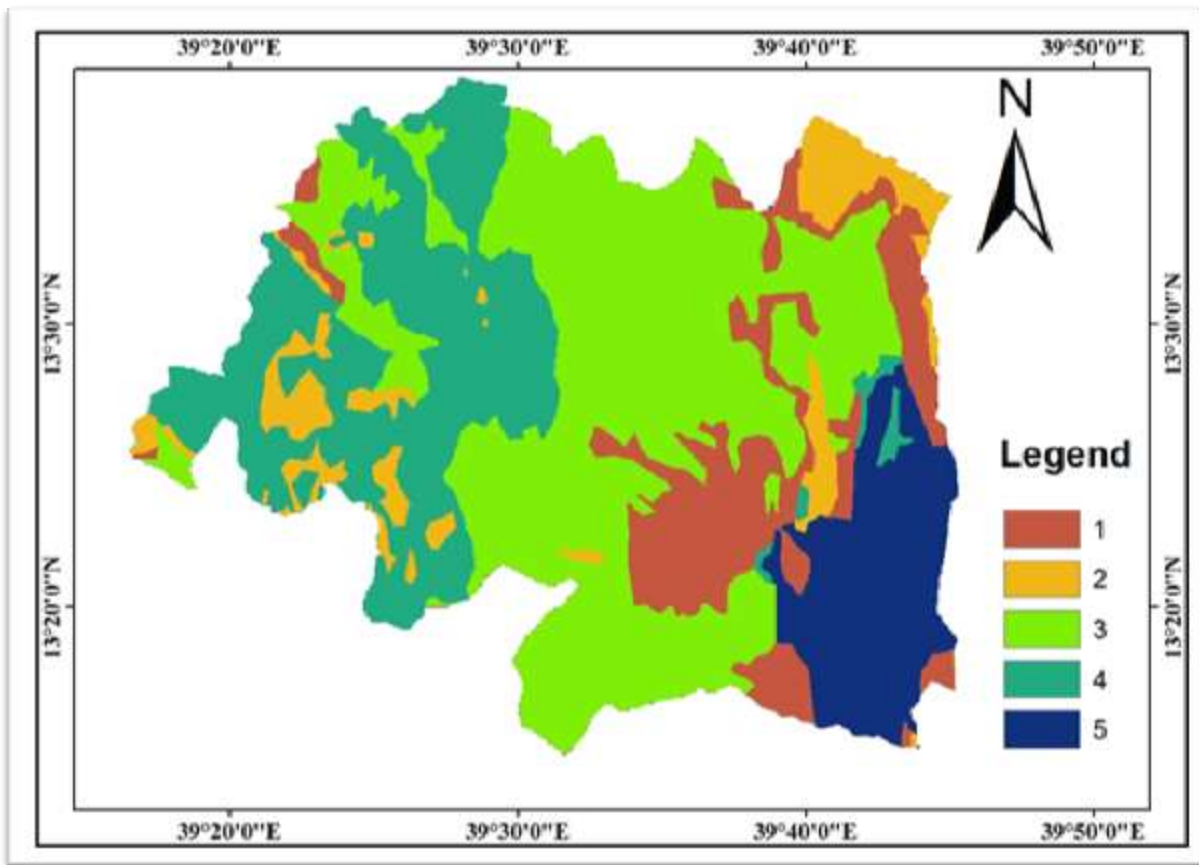


Figure 3.20: Reclassified geological map of the study area

3.6.1.15 Geomorphology

Geomorphology important erosional and depositional geomorphic units such as Hill, denudational hills, plateau, flood plain and valley mapped. Show geomorphological map of the study area (Fig 3.21).

A floodplain or flood plain is an area of land adjacent to a stream or river which stretches from the banks of its channel to the base of the enclosing valley walls, and which experiences flooding during periods of high discharge

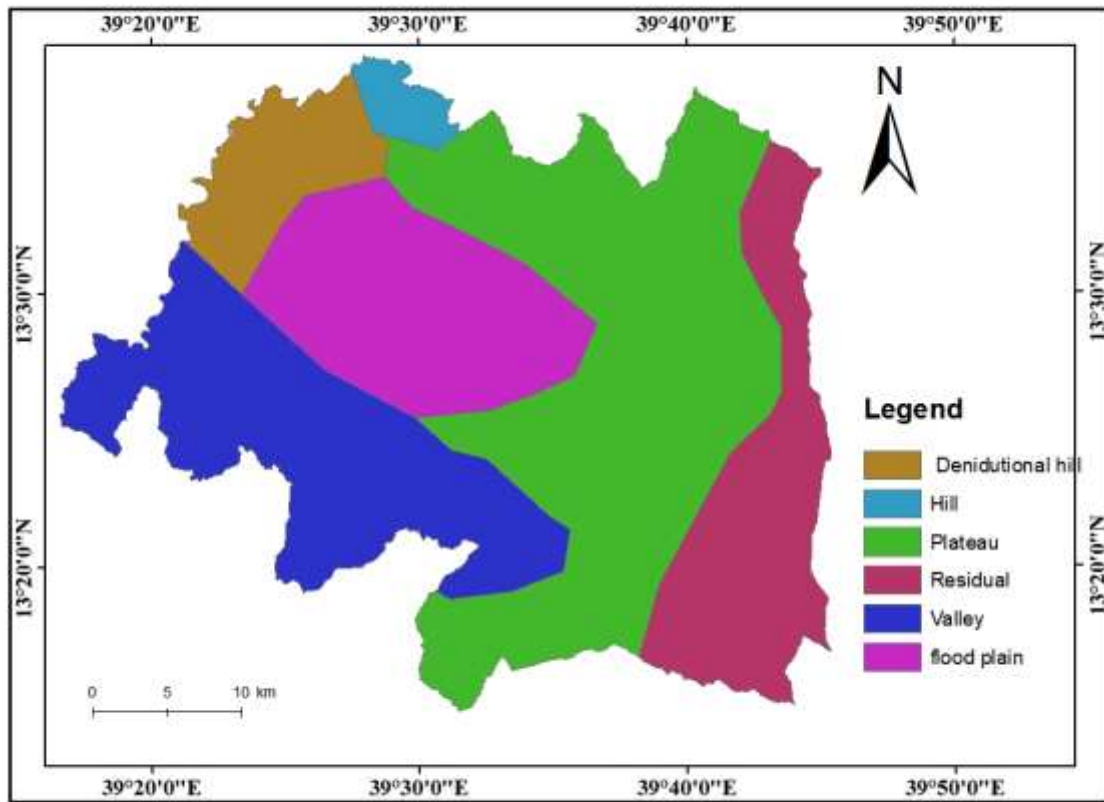


Figure3.21: Geomorphological map of the study area

Residual landform, also called **Relict Landform**, landform that was produced as the remains of an ancient landscape, escaping burial or destruction to remain as part of the present landscape. Residual landforms are often the result of changed climatic conditions, but they may be due to volcanism or to crustal uplift and downwarping.

What does mean residual Geomorphology?

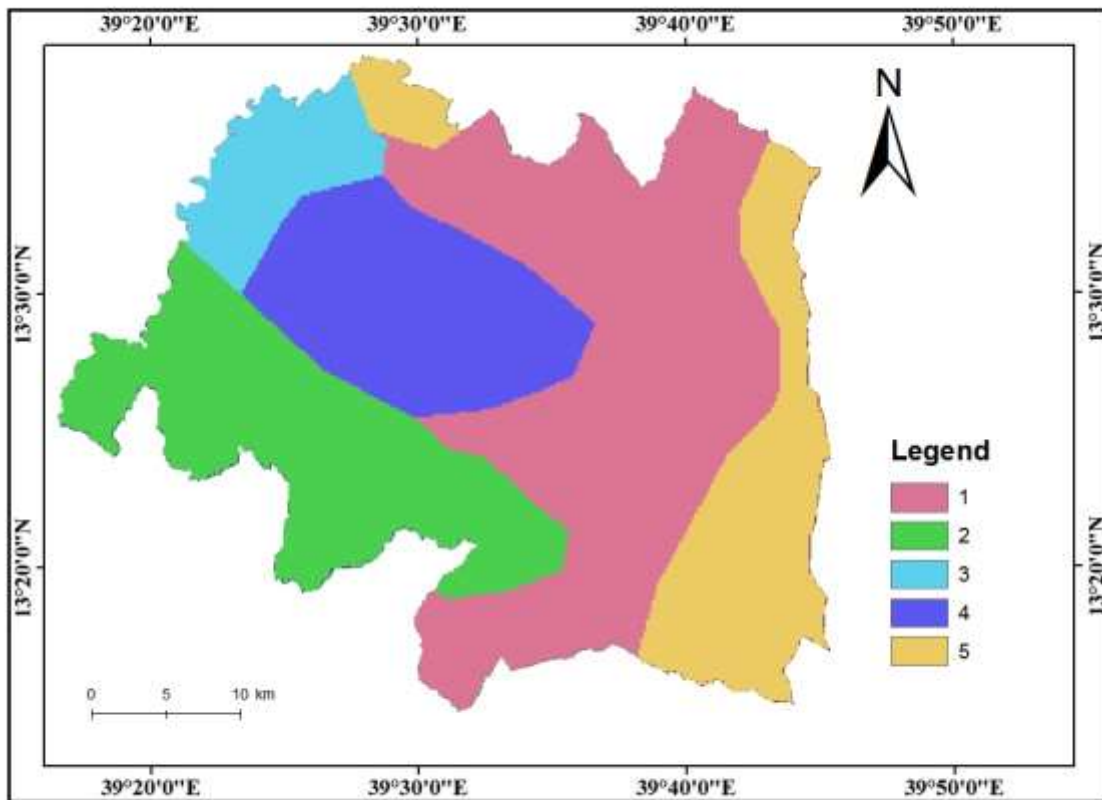


Figure3.22: Reclassified geomorphological map of the study area

Denudational hills are the remnants of the natural dynamic process of denudation and weathering. The geomorphic forms of denudational hills occur as exfoliation domes, linear ridges, mesas, low mounds and tors with partial scree or debris covered at the foot slopes. Hill landforms also not good for groundwater. The geomorphic expression and shape of the denudational hills are monitored by lithology, and spacing of structural features like joints and fractures occurring in them. Flood plan and valleys are good for groundwater

3.6.1.16 Land use

Land use map was developed by USGS using landsat 8 satellite data was classified into different land use layers. The major land use of the areas were grouped into different categories or classes like water bodies, irrigated agriculture, mixed agriculture/settlement, dry International Journal of

Applied Research Arable land, forest, bare land, grassland, urban and water body. Arable land had more ground water potential zones because of regular irrigation and infiltration accordingly so they have given fifth and sixth ranks. Water bodies showed high groundwater potentiality due to highest infiltration rate so they ranked highest i.e. seventh among others classes. Hence high weightage and rank was given to water bodies. Barren land and highly urbanized area was given smallest rank as there was no water accessible so infiltration capacity was not there. In the same way other land use classes were ranked like dry vegetation and thorn forest were ranked third and fourth based on infiltration rate and its impact on groundwater potential. Weightage given and ranks assigned are shown the map is shown in fig 3.23.

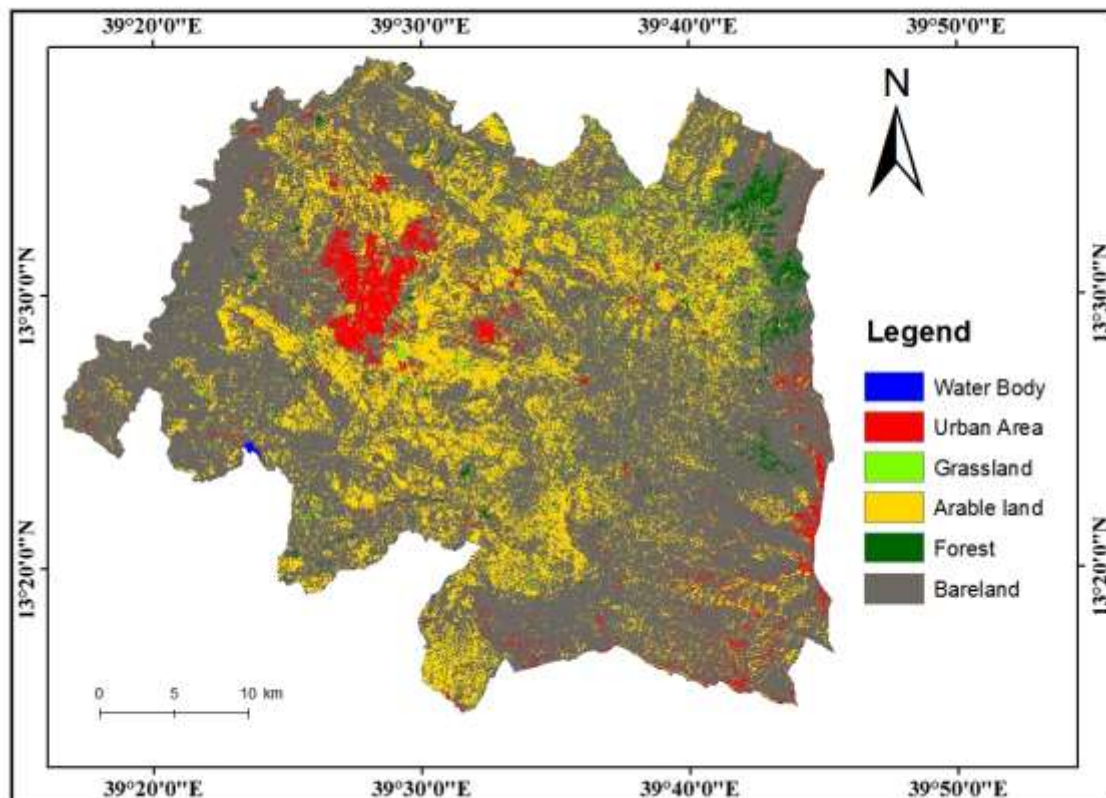


Figure3.23: Land use land cover map of the study area

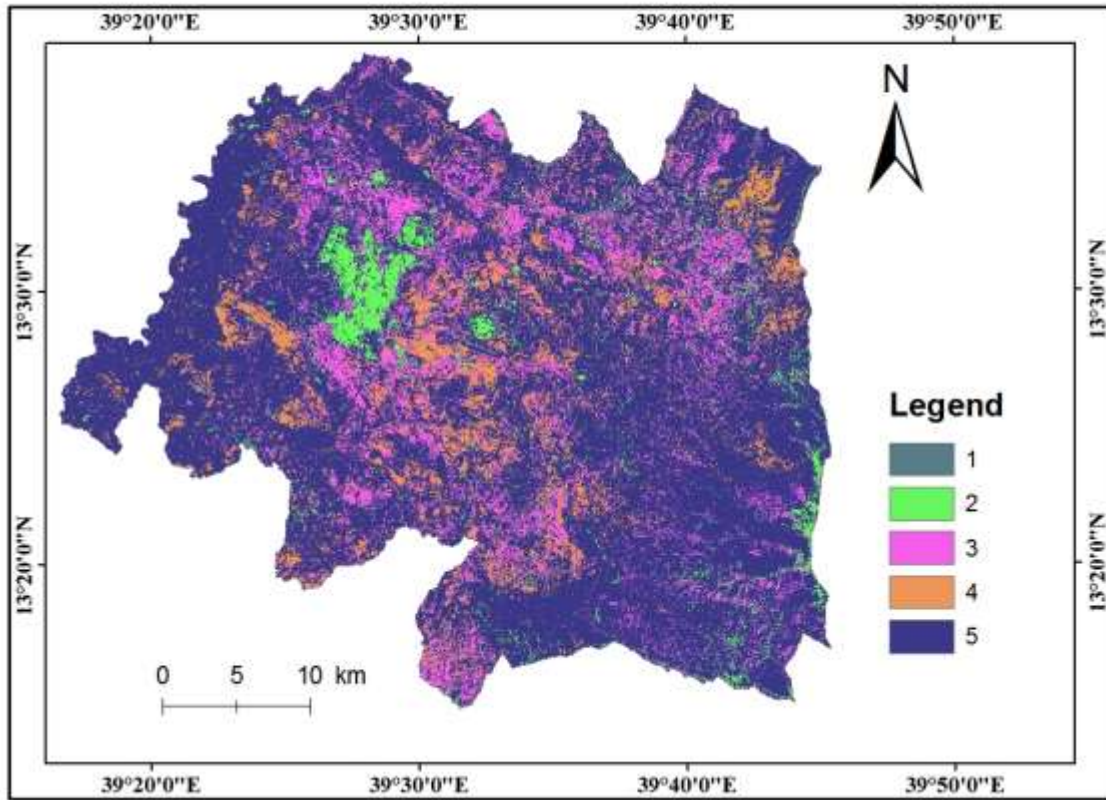


Figure 3.24: Reclassified land use land cover map of the study area

CHAPTER FOUR

4 Results and Discussion

4.1. Groundwater potential

The result of present work on the groundwater potential zone mapping was done by analysis using different thematic layers (rainfall, soil texture, slope, land-use land-cover, lineament, geomorphology, drainage density and geology) and the parameters values are given based on the saaty scale as shown in Table 4.1. Based on the pairwise comparison matrix, the relative weight matrix and normalized Principal Eigenvector were calculated. The influence percentage of thematic layers and the rank for its parameters was assigned based on the judgment of works carried out by researchers or knowledge of expert gained through similar work on groundwater potential zone mapping (Tesfaye, 2012).

4.2. Weight analysis for the thematic layers

The Relative weight for thematic layers (rainfall, slope, geomorphology, lineament density, drainage density, soil texture, land-use/land-cover and geology) were assigned according to their relative importance for each analyzed based on the judgment of works carried out by researchers or knowledge of expert gained through similar work on groundwater potential zone mapping (Tesfaye, 2012). To compare the importance of two-layer maps show that one of them has more influence to the groundwater occurrence than the other, the pairwise comparison matrix was carried out using the weighted linear combination and Analytical Hierarchical process (AHP) methods. Show table 4.1.

Table 4.1 :Relative weight for selected thematic layers

parameters	Rf	Sl	Gm	Ln	Dd	St	Lulc	geol
Rf	1	2.00	3.00	5.00	6.00	4.00	6.00	7.00
Sl	0.50	1	2.00	3.00	5.00	5.00	6.00	6.00
Gm	0.33	0.50	1	0.50	2.00	3.00	2.00	3.00
Ln	0.20	0.33	2.00	1	2.00	2.00	2.00	3.00
Dd	0.17	0.20	0.40	0.50	1	1.00	3.00	4.00
St	0.25	0.20	0.25	0.50	0.50	1	3.00	2.00
Lulc	0.17	0.17	0.30	0.50	0.33	0.33	1	4.00
geol	0.14	0.14	0.33	0.33	0.25	0.25	0.25	1
Total	2.76	4.54	9.38	11.33	17.08	16.58	23.25	30.00

Where **Rf** = Rainfall, **Sl** = Slope, **Geo** = geology **Gm** = Geomorphology, **Ld** = Lineament density, **Dd**= Drainage density, **St** = Soil texture, **Lulc** = Land-use/land-cover,

4.3.Weight Normalization

The weights were normalized based calculated by averaging the values in each row to get the corresponding ranking, which gives the results of normalized weights of each parameter as presented in Table 4.1. From the result, observed rainfall has the highest value rather than other parameters. Because, It indicate high rainfall have the possibility of high groundwater potential zones parameter, while low rainfall indicates low groundwater zone thus low groundwater potential zones. The main source of groundwater in the area was the rainfall of the northwestern and southeastern highlands the study area due to mountain block and slope.

Table 4. 2 :Pairwise comparison matrix and normalized weight

	Rf	Sl	Gm	Ln	Dd	St	Lulc	Lith	Wt	Wt (%)
RF	0.363	0.441	0.313	0.441	0.351	0.215	0.258	0.212	0.32	32
SL	0.181	0.221	0.209	0.265	0.293	0.269	0.258	0.212	0.238	23.8
GM	0.120	0.111	0.104	0.044	0.117	0.215	0.086	0.091	0.111	11.5
LN	0.073	0.073	0.209	0.088	0.117	0.107	0.086	0.091	0.105	10.5
DD	0.060	0.044	0.052	0.044	0.059	0.107	0.129	0.121	0.077	7.7
ST	0.091	0.044	0.026	0.044	0.029	0.054	0.129	0.121	0.067	6.7
LUL	0.060	0.037	0.052	0.044	0.019	0.018	0.043	0.121	0.049	4.9
C										
LIT	0.051	0.031	0.035	0.029	0.015	0.013	0.011	0.031	0.027	2.7
H										
TO	1	1	1	1	1	1	1	1	1	100
T										

Where, **Rf** = Rainfall, **Sl** = Slope, **Gm** = Geomorphology, **Dd**= Drainage density, **St** = Soil texture, **Lulc**, = Land-use/land-cover, **Lith** = Lithology, **Wt**= Weight

4.4.Normalized principal Eigen vectors

In order to check the weight assigned to each parameter in Table 4.2, the normalized principal Eigen vector value (λ_{max}) was computed depending on equation 5 and 6 to drive the formula of consistency ratio (equation5). This was done by multiplying the weight of the first criterion (for

example, Rainfall = 32) as shown in Table 4.2 with the total value that was found in the pairwise comparison matrix (for example, Rainfall =2.76) Table 4.1. This was applied for the rest of seven factors as per equation 8. Finally, the summation of these values gives the consistency vector (λ_{max} of = 1) as shown in Table 4.3 for calculating consistency index.

Table 4. 4: Normalized Principal Eigen vectors

Parameters	Normalized principal Eigen vectors
Drainage	0.2988
Geology	0.2165
Geomorphology	0.1374
Land use land cover	0.1002
Lineament	0.1122
Rainfall	0.0598
Slope	0.0434
Soil	0.0317
λ_{max}	1

The consistency index was computed to overcome for the formula of consistency ratio and this was done based on equation 9, which results CI = 0.120. Then, consistency ratio was computed as per equation 8 and the computed result of CR = 0.09 that is less than 0.1 and the given weights was valid for further analysis. Groundwater potential zone map (GWPZM) was computed after checking all criterions as follows:

$$\mathbf{GWPZM} = 32 * \mathbf{RRf} + 23.8 * \mathbf{RGm} + 11.1 * \mathbf{RSI} + 10.5 * \mathbf{RSt} + 7.7 * \mathbf{RLd} + 6.7 * \mathbf{RDd} + 4.9 * \mathbf{RLulc} + 2.7 * \mathbf{RLith}.$$

Where, **RRf**: Reclassified Rainfall Map, **RGm**: Reclassified Geomorphology Map, **RSI**: Reclassified Slope map, **Rst**: Reclassified Soil Texture Map, **RLd**: Reclassified Lineament Density Map, **RDd**: Reclassified Drainage Density Map, **RLulc**: Reclassified Land-use/land-cover Map and **RLith**: Reclassified Lithology Map.

Rainfall, slope, lineament density and geomorphology hold the highest value relative to the other parameters. The weight assigned for Rainfall were better than the heaviness of other, which influence the occurrence of groundwater potential zone than others parameters (Mwega, 2013;

Kamal *et al.*, 2016). The result for groundwater potential zones was classified in to very high, high, moderate, low and very low Figure 4.1.

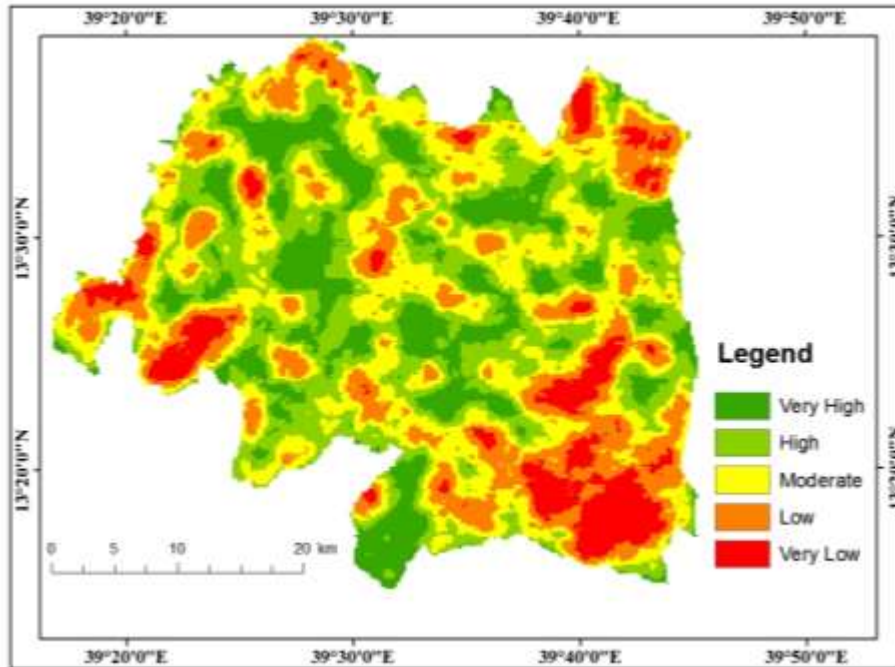


Figure 4. 2: Groundwater potential zone map of the study area

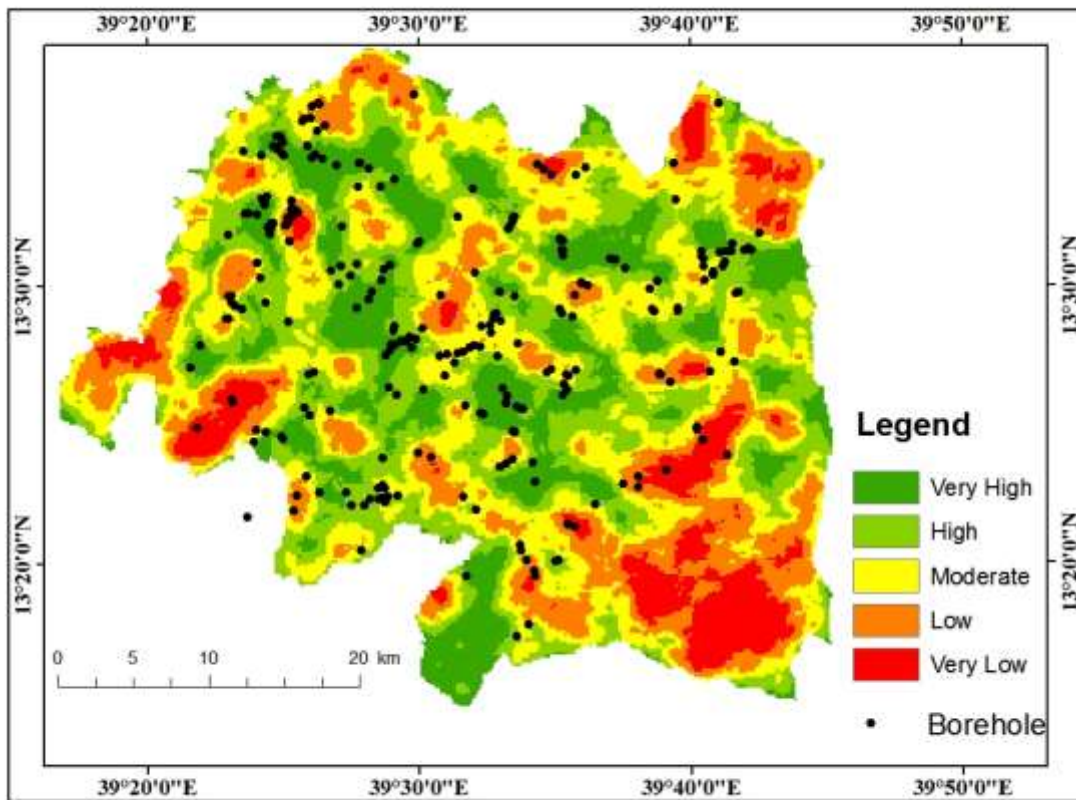


Figure 4. 2: Groundwater potential zone map validation using borehole data

The result of groundwater potential of the study area done by integration of all thematic maps to delineate groundwater potential zones. The results categorized in to five categories namely: very high, high, moderate, low and very low of groundwater potential zone Figure 4.1. Very low groundwater potentials cover almost 45% of the study area; moderate groundwater potential covers 30 % the central of the study area better, eastern part of the study area very low groundwater potential zone. Moderate groundwater potentials cover 25% of the study area low groundwater potential.

Based on the normalized weighting of the individual features of the thematic layers, very high and high groundwater potentials was fallen in the flood plains in in the western part of the study area percent respectively. Moderate groundwater potentials were found in foothills to the northwestern and southeastern highlands of the study area.

CHAPTER FIVE

5 Conclusion and Recommendation

5.1. Conclusion

In this present study, the result of groundwater potential zone by using GIS and remote sensing techniques through Analytical Hierarchy decision methods were identified and delineated based on the significant factors for groundwater potential and recharge zone. In this research, eight parameters were selected which have more affects the occurrence of groundwater potential and zone prior to overlay analysis. By assigning quantitative weights, it is possible to make important criteria that have a greater impact on the result than other criteria. In The AHP, approaches were adapted in Table 4.1 and 4.5 to give the value for each factor. This approach allows decision makers to give the judgments in order to reduce complexity in decision-making processes.

The results of consistency ratio in this study were 0.09 groundwater potential zone map. If the result of consistency ratios are greater than 0.1, the value is unaccepted and it must be re-evaluated. In this case, the consistency ratio for groundwater potential zone was less than 0.1 and the value was accepted for further analysis.

The delineated Groundwater potential and recharge zone were classified into five zones namely, 'very low', 'low', 'moderate', 'high' and 'very high'. Very low zone shows that the low suitable area for groundwater prospect. Whereas very high zone indicates the most suitable area for groundwater prospect. Very high potential areas present in floodplain, valley, the denudation hill, which coincide with the low slope and high lineament density of the study area. Very low groundwater potential falls in the area low landform, bare lands, high slope and high drainage density. The acceptable results were done by comparing the borehole yield data with the Groundwater potential zone map of the study area.

The effective parameters in the area for groundwater potential and recharge are rainfall, slope, geomorphology, lineament density, drainage, density and drainage density in Pairwise Comparison matrix analysis indicates that all parameters are significant.

Most of the area, around 45% zone under very high groundwater potential and the next very Moderate groundwater potential zone where 30% covers, the third coverage of the area are moderat less part 25 low groundwater potential. High potential groundwater recharge area was

identified to the northwestern part of the study area and low suitable for groundwater recharge was present in eastern part of the study area.

In this research, integrated GIS and remote sensing techniques are very useful, time and cost effective tool for the identification and delineation of groundwater potential and recharge zones and analysis.

5.2. Recommendation

Based on the findings obtained and conclusions reached the following recommendations were forward as follow:

- ❖ The same appropriate methods were recommended for complex areas to delineate groundwater potential and recharge zone in the small area.
- ❖ The groundwater potential map along with other thematic maps forms serve as resource information database that can be updated from time to time by adding new evidence.
- ❖ For further validation, field geophysical inquiries on the potential well drilling sites are recommended.

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Appindex I

No	X	Y	Site_Name	Type	Current status	Yield
1	543953.94805	1482623.50872	KeyehDera	SP	Productive	0.431
2	538978.49227	1486873.59181	Arato	SHW	Productive	0.25
3	539614.91744	1488367.52774	Metgo	DW	Productive	18
4	541452.22317	1490139.80826	Maekeladi	DW	Productive	18
5	541343.99138	1490139.63984	May Ayni	SHW	Dry	
6	541883.75709	1491025.22773	Tahetayhabaeit	SHW	Productive	0.235
7	541883.75709	1491025.22773	May ayneidmu	SHW	Productive	0.25
8	542425.25134	1490804.90019	May Ayni	HDW	Productive	2.13
9	545825.01232	1477395.61900	May Ayni	HDW	Productive	0.5
10	545659.75668	1497998.84987	May Ayni	SHW	Productive	3.5
11	542653.09609	1497186.49890	grbehashw	SHW	Productive	3.5
12	543928.92179	1497774.73206	Grbkfela	SHW	Productive	3.5
13	545660.90153	1497335.28790	helthsentr	SHW	Productive	2.53
14	545682.38943	1497423.80015	geraraesi	SHW	Productive	3.1
15	545769.67807	1497003.69385	habait	SHW	Productive	2.5
16	546093.90596	1497225.44432	GerebDingur	SHW	Productive	
17	545877.30744	1497335.66206	Beles	SHW	Productive	0.27
18	544235.19116	1495795.61437	AdiBiez	HDW	Productive	0.25
19	545577.85929	1495289.15815	Beles	HDW	Productive	0.26
20	549017.10269	1496312.76208	Melekeгна	HDW	Productive	0.3
21	547922.93398	1502979.60576	LalayGereb	SHW	Productive	0.22
22	547061.24097	1500876.75785	LalayAdi	SHW	Productive	0.25
23	547277.22220	1501098.33260	May Dur	SP	Productive	0.14
24	546735.30463	1501650.33994	AdiAnkele	HDW	Productive	0.11
25	573002.98774	1482078.74262	May Debri	SHW	Productive	1.5
26	570593.68947	1480136.83205	May Kesel	HDW	Productive	0.1
27	570827.25488	1485976.97335	MaydaAdiSewuhi	HDW	Productive	0.12
28	573466.65705	1486702.99642	GerebGereb	HDW	Productive	0.12
29	574199.31423	1487943.72364	Korakus	HDW	Productive	0.14
30	561890.16471	1479307.96811	Secondary School	SHW	Productive	4.5
31	575132.03714	1487304.86699	Health Post	SHW	Productive	3.2
32	570176.42727	1486472.94097	kyhdera	HDW	Productive	0.123
33	572632.82987	1482829.79740	gragrb	SHW	Productive	4
34	570165.42760	1486539.27035	gragefan	SHW	Productive	5
35	560540.03495	1482611.67372	AdiAsgedom	SHW	Productive	3.5
36	544463.41375	1501646.41469	Adiaytkros	SHW	Productive	3.5

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37	544788.34459	1501425.77573	May Ado Mariam	SP	Productive	0.09
38	545221.84681	1500984.13797	MuluGiba	SP	Productive	4
39	543707.21662	1500981.58737	May Ayni	HDW	Productive	5
40	532978.36939	1463132.72072	May Ayni	HDW	Productive	4
41	542663.92170	1463190.46802	Gereb Arese	HDW	Dry	
42	532989.10918	1463210.14666	May Mucha	HDW	Productive	0
43	532468.68213	1463541.28776	May Meso	HDW	Productive	4
44	532414.46014	1463585.45878	DihriGerebAnderta	HDW	Productive	0.25
45	532465.49445	1353154.75621	AndertaKidmiGereb	HDW	Productive	0.1
46	532760.72731	1463928.70363	Saeni Alba	HDW	Productive	0.3
47	532913.07011	1463375.93898	Tsemur	HDW	Productive	0.11
48	533010.85788	1463143.81924	MengediBetekrtian (momona)	HDW	Productive	0.14
49	533839.33989	1459053.02019	Kasel 1	SHW	Productive	0
50	546687.26049	1479708.49038	School	SHW	Productive	0.23
51	547522.87770	1478637.20933	GerebZahtelam	SHW	Productive	0.39
52	551752.30907	1480867.96525	Merawocha	HDW	Productive	0.14
53	550356.20458	1474782.68486	May Gundele	SHW	Productive	0.3
54	551866.14350	1477992.75676	SiraZekena	SHW	Productive	0.25
55	552731.53294	1478436.81738	SiraZekena	SHW	Productive	22
56	551973.99733	1478214.15211	Berakito	SP	Productive	0.25
57	550567.17354	1477769.09098	Nifshet	HDW	Productive	4
58	569808.26986	1490641.49283	BirhanDikor	HDW	Productive	3.5
59	569808.26986	1490641.49283	MediberiaMiteam	HDW	Productive	3.5
60	569479.52066	1492188.99633	May Goygoy	DW	Productive	
61	570019.49282	1492632.80458	Giraba May Hiyet	SHW	Productive	6
62	563735.77937	1495381.89528	Embay	SP	Productive	6
63	563519.08724	1495491.97178	TahtayAdi	SP	Productive	7
64	563737.37455	1494718.31927	adishira	HDW	Productive	2.5
65	563738.17188	1494386.53138	may ayni	SHW	Productive	0.312
66	563629.15828	1494718.05941	Habesti (Mengediarho)	SHW	Productive	0.33
67	563497.83786	1490802.63161	MengediGerinHawerya	SHW	Productive	0.33
68	573697.65013	1493195.74877	May Daero	SP	Productive	0.18
69	548238.64136	1484024.36826	Afrak	SHW	Productive	0.25
70	560004.07308	1485043.55756	GerebAwuse	SHW	Productive	0.2
71	572936.12829	1494631.42448	Gerebhun	SHW	Productive	0.25
72	572937.04064	1494299.63175	May ma tsabat	SHW	Productive	0.25

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73	573045.56485	1494189.33194	May ma tsabat	HDW	Productive	0
74	573047.08713	1493636.34418	May ma tsabat	SHW	Productive	0.27
75	573697.34310	1493306.34639	May Kemem	SHW	Productive	0.25
76	574345.75735	1493639.95034	May Aragure	DW	Productive	15
77	574453.04910	1493972.04715	May Weyni	SHW	Productive	0.25
78	574126.68554	1494579.42597	May Aragure	SHW	Productive	0.25
79	574884.06124	1494636.85295	May Zina	HDW	Productive	0
80	574979.89437	1495190.11813	May Sirakot	SHW	Productive	0.2
81	576290.58767	1494751.46075	May Guhto	SHW	Productive	0.23
82	576182.36918	1494751.14965	May Guhto	SHW	Productive	0.2
83	576731.01830	1495880.84429	May Gundule	SP	Productive	11
84	573157.74766	1492751.86213	GerebShimbra	SHW	Productive	0.28
85	573697.95714	1493085.15115	May Gudguad	HDW	Productive	0.25
86	575216.55097	1491872.82375	Giramichael	SHW	Productive	
87	575324.46748	1491983.72816	Dekenomle	SHW	Productive	0.25
88	575432.69707	1491984.03520	Dekenomle	SHW	Productive	
89	560370.75295	1480863.89046	Miquadir	SHW	Productive	0.25
90	574640.60214	1481098.94121	Ezabie (mihrae)	SHW	Productive	0.35
91	561713.88772	1480623.64305	May Ayni	SHW	Productive	0.35
92	559581.52418	1480342.32740	May shneka	HDW	Productive	0.25
93	571080.58694	1500521.27460	TahtayGereb	SHW	Productive	3.5
94	571069.79731	1500510.18572	TahtayGereb	SHW	Productive	3.5
95	566877.04828	1494173.06507	Fitka	SP	Productive	10
96	559954.56161	1539733.84443	HzaetiAfras	SHW	Productive	0.1
97	547552.52751	1504416.66666	Ayniablo	SHW	Productive	0.6
98	567201.98566	1494063.28894	AdiHayara	SHW	Productive	0.25
99	546571.07348	1484253.65488	DaboMesnu	SP	Productive	0
100	547498.32078	1504482.92573	Ayniabalro	SHW	Productive	1
101	538989.30058	1486884.66684	AdiAsgedom	SHW	Productive	0.24
102	560860.14307	1475136.18952	Mskiela	DW	Productive	19
103	564071.34020	1486358.04058	MeydaHizaeti	SHW	Productive	0.3
104	563801.93097	1485848.65352	Shilnet	SHW	Productive	0.2
105	563717.04516	1485129.57751	AdiMereu	SHW	Productive	0.2
106	562955.31819	1486797.76656	May Atate	SHW	Productive	0.3
107	557223.37011	1484362.82539	SewhiKahenat	SHW	Productive	0.28
108	563952.02617	1486457.29065	clinic	SHW	Productive	0.28
109	563801.93097	1485848.65352	Shilnet	SHW	Productive	0.3
110	563976.14224	1485428.80608	Shilnet	SHW	Productive	0.28
111	562652.61253	1486631.15997	Enda Michael	SHW	Productive	0.29
112	560958.76250	1484149.89826	May Raheya	SHW	Dry	
113	558209.50049	1483911.51749	GerbeSredo	SHW	Productive	0.25

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114	558209.50049	1483911.51749	GerebSerede	SHW	Productive	0.2
115	560666.03685	1484337.24382	May serom	SHW	Productive	0.2
116	559961.86375	1484556.84408	HzaetiAfras	SHW	Productive	0
117	545391.17160	1496881.38897	sewuhi	SHW	Productive	2.35
118	570165.60217	1486472.91249	Geragfan	SP	Productive	0.25
119	552082.06406	1478324.95505	FelsiTabya	SHW	Productive	4.5
120	551431.31785	1478876.66588	Beles	SHW	Productive	3.5
121	551431.31785	1478876.66588	AmeteDingil	SHW	Productive	0.26
122	573002.98774	1482078.74262	May Aqualat	SHW	Productive	0.25
123	525127.72282	1458833.45541	May Shihshahta	HDW	Productive	0.14
124	546918.40646	1483734.47524	Gilazhan	SHW	Productive	0
125	558426.16425	1483845.63349	GerebSerdi	SHW	Productive	0.2
126	534584.61912	1460922.92430	Gojaju	SHW	Productive	0.3345
127	534638.62424	1461055.70091	Meemferes	SHW	Productive	0.16
128	534280.34876	1461630.31320	Mskiela	SHW	Productive	0.35
129	567852.71725	1493511.95853	Gerger	SHW	Productive	0.25
130	542505.81657	1501300.34824	may nihug	SHW	Productive	0.34
131	546039.85339	1478402.37810	GerebHashew	HDW	Productive	0.13
132	549320.41489	1478585.15835	GerebTsahtelam	SHW	Productive	0.28
133	527218.94710	1458890.76254	Mefasis(gerebzahil)	HDW	Productive	0.13
134	561295.59247	1474141.82761	may quaquat	SHW	Productive	
135	551864.43271	1478877.50012	School	SHW	Productive	3.5
136	551755.72701	1479098.47681	Gurungur	SHW	Productive	3.5
137	551432.59031	1478213.10865	May Nehidir	HDW	Dry	
138	550891.18365	1478212.07612	May Miche	SHW	Productive	3.5
139	549700.90965	1477767.47259	Gedebeyti	HDW	Productive	3.5
140	565366.34042	1492399.75100	ShiginTabia	SHW	Productive	0.2
141	571173.81156	1498044.12077	Gerkon/afi-ato	SHW	Productive	1.3
142	574088.01964	1504511.11399	Dalgiena	SHW	Productive	1.8
143	582500.74424	1526236.28205	Michael Kelti	SHW	Productive	1.6
144	574591.90199	1494624.96977	Grabomehamd	DW	Productive	0.3
145	543394.25555	1493903.07554	may egam	SHW	Productive	0.13
146	534638.24329	1461354.29296	Secondary school	SHW	Productive	
147	557931.17010	1477452.19530	secondary school	SHW	Productive	0.25
148	575749.49544	1494749.90967	Guhuto	SHW	Productive	0.25
149	575749.49544	1494749.90967	Guhuto	SHW	Productive	0.24
150	545445.63459	1496671.35399	kekel	SHW	Productive	2.5
151	544363.83826	1496514.68849	GerebArko	SHW	Productive	
152	573002.98774	1482078.74262	xxx	HDW	Productive	0.11
153	544678.73540	1502266.10588	Mefeelay	SHW	Productive	0.31

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154	531833.92978	1478127.39736	Gerebkokhi	SHW	Dry	
155	531942.82807	1477607.74967	mstah	SHW	Productive	0.253
156	544690.78986	1501536.20455	tahtaymomona	HDW	Productive	0
157	545112.14677	1501868.70408	momona	HDW	Productive	0.34
158	544299.50641	1496160.68095	Filhi	SHW	Productive	2.3
159	544126.22694	1496248.86671	GerebErib	SHW	Productive	0.11
160	544310.32717	1496160.69904	GerebErib	SHW	Productive	2.5
161	543394.25555	1493903.07554	may egam	HDW	Productive	0.11
162	544461.22379	1496514.85179	GerebErib	SHW	Productive	2.4
163	543612.32431	1492908.09259	may sewuhi	SHW	Productive	0.19
164	544895.02541	1502310.71078	miskalhibey	SHW	Productive	0.32
165	544981.75997	1502200.26426	konfitif	SHW	Productive	0.23
166	545327.11941	1496372.54747	may abadit	SHW	Productive	0.34
167	545327.11941	1496372.54747	may werekit	HDW	Productive	2.5
168	545273.05380	1496350.33625	may werekit	SHW	Productive	0.233
169	542826.31067	1497131.48174	MaydaTebib	HDW	Productive	0.5
170	572599.98967	1482962.42511	xx	HDW	Productive	0.21
171	545037.68206	1501127.59563	chirikrik	SP	Productive	0.22
172	531833.92978	1478127.39736	gerebkokhi	SHW	Productive	
173	531942.82807	1477607.74967	mstah	SHW	Productive	
174	572599.98967	1482962.42511	May Bearedom	SHW	Productive	0.25
175	544987.06749	1447236.00705	mifililay	SHW	Productive	0.34
176	547055.12404	1504305.17873	May Beles	SHW	Productive	0.32
177	552446.04278	1513240.44439	Fistiha	SHW	Productive	0.52
178	546407.82969	1503308.67924	LaelayMumatyile w	SHW	Productive	0.34
179	544036.29443	1498272.58266	Enda Michael	SHW	Productive	2.5
180	559753.99731	1485529.61536	May Berber	SHW	Productive	0.235
181	543701.06054	1498161.43296	may gundi	SHW	Productive	2.53
182	546515.81311	1503419.46412	TahitayMumatyile w	SHW	Productive	0.33
183	572632.82987	1482829.79740	Godagudi	SHW	Productive	0.25
184	5409500.00000	1504910.00000	Asegera	SHW	Productive	0.2
185	553785.00000	1505059.00000	Emobateu	SHW	Productive	0.32
186	546948.32875	1503530.82553	May Ayni	SHW	Productive	0.32
187	547382.62972	1502646.84540	Chaechaeto	SHW	Productive	2000
188	566897.14515	1442304.00869	Mengdi	SHW	Productive	0.41
189	566897.14515	1442304.00869	xx	SHW	Productive	0.43
190	559970.79060	1480575.44516	May gudegade	SHW	Productive	0.25
191	564932.89576	1492619.88122	Kokehie	SHW	Productive	0.3
192	564932.89576	1492619.88122	school	SHW	Productive	0.231

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193	564933.16614	1492509.28521	health post	SHW	Productive	0.3
194	54107.69533	1495841.81170	Semha	SHW	Productive	0.2
195	561839.63006	1473037.12673	may deabere	SHW	Productive	0.23
196	533608.61766	1461618.41413	Serdie	SHW	Productive	0.2
197	543918.13841	1497752.59540	Adifirsi	HDW	Productive	2.3
198	533348.32921	1461828.21358	Maydengur	SHW	Productive	0.2
199	564502.14386	1491734.05914	Semha	SHW	Productive	0.3
200	564397.39747	1490296.05139	Dara	SHW	Productive	0.2
201	563639.22781	1490515.41930	GerebDimu	SHW	Productive	0.2
202	571322.95419	1490866.70734	Chechet	HDW	Productive	0.1
203	571323.54744	1490645.51337	Chechet	SHW	Productive	0.3
204	532763.98670	1461230.31758	Maydur	SHW	Productive	0.1
205	560485.77742	1482666.84849	MaekelAdi	SHW	Productive	0.25
206	560345.00834	1482677.58999	MaekelAdi	SHW	Productive	0.35
207	541666.26049	1491688.44389	dembekena	SHW	Productive	0.17
208	541666.95397	1491246.07301	dembekena	SHW	Productive	0.18
209	543972.19843	1491249.78622	may regihe	SHW	Productive	2.5
210	543432.34083	1497077.17217	May Azwe	HDW	Productive	1.2
211	563461.58125	1474146.84967	alahgo	HDW	Productive	0.12
212	563245.24204	1474035.74534	alahgo	HDW	Productive	0.345
213	563997.28659	1476581.21131	may sarika	SP	Productive	0.52
214	564105.84046	1476470.87496	gerebadi	HDW	Productive	0.31
215	564539.26776	1476361.31761	may kot	HDW	Productive	0.33
216	565835.23394	1477802.20544	berbero	SHW	Productive	0.285
217	560657.24548	1469053.04661	EkliAdiAgebo	SHW	Productive	
218	561413.72182	1469828.91596	MaydaAdi Abo Kidanu	SHW	Productive	0.25
219	560054.77345	1496147.47240	Nora tahteway	HDW	Productive	
220	560162.73213	1496258.31343	Nora Laeaway	HDW	Productive	
221	560378.39467	1496590.59253	GerebBeles	HDW	Productive	
222	560485.84494	1496922.62628	May Egam	SP	Productive	0.52
223	557744.11687	1498796.63419	MeseboHadushAdi	SP	Productive	0
224	562963.27646	1501684.06549	May Mekden	SP	Productive	0.2
225	562968.02264	1499693.33166	May Tamba	DW	Productive	8
226	564590.96178	1499697.24828	May Tamba	SP	Productive	
227	561992.44455	1500465.20237	MaydaMesanu	HDW	Productive	0
228	565238.77323	1500251.82605	Saeni Alba Tahteway	HDW	Productive	0
229	539384.90273	1482870.75136	GuraGirum	SHW	Productive	0.3
230	541785.58617	1484610.69574	May Tiemti	SHW	Productive	0.3

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231	543304.19368	1482733.04122	May Tienti	HDW	Productive	
232	545080.34558	1482348.90194	Adizkunay	SHW	Productive	0.31
233	545145.58384	1482183.12292	Gerbyto	SHW	Productive	0.29
234	543953.94805	1482623.50872	May Ayni	SHW	Productive	0.32
235	538978.49227	1486873.59181	AdiAsgedom	SHW	Productive	0.24
236	539614.91744	1488367.52774	AdiAsgedom	HDW	Productive	0.12
237	541452.22317	1490139.80826	rahya	HDW	Productive	0.15
238	541343.99138	1490139.63984	rahya	HDW	Productive	0.1
239	541883.75709	1491025.22773	adimishekelom	HDW	Productive	0.0
240	541883.75709	1491025.22773	masheanano	HDW	Productive	0.0

D E C L A R A T I O N

I the undersigned declare that this thesis is my original work and has not been presented for a Degree in any other university and that all sources of materials used for the thesis have been duly acknowledged.

Kindeya KidanuTadesse

Signature _____ Date_____

School of Earth Science

June, 2016

This thesis has been submitted for examination with my approval as university advisor.

Dr. K. V. Suryabhagavan

Signature _____ Date_____