



**ADDIS ABABA UNIVERSITY**  
**ADDIS ABABA INSTITUTE OF TECHNOLOGY**  
**SCHOOL OF CIVIL AND ENVIRONMENTAL**  
**ENGINEERING**

**ASSESSMENT OF POTENTIAL GROUNDWATER ZONE USING  
INTEGRATED GIS AND REMOTE SENSING TECHNIQUES IN SEKOTA  
WEREDA, NORTHERN ETHIOPIA.**

**BY: ADEM BERIHUN NURU**

**ADVISOR: ERMIAS TEFERI (PhD)**

**SEPTEMBER, 2018**

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INTEGRATED GIS AND REMOTE SENSING TECHNIQUES IN SEKOTA  
WEREDA, NORTHERN ETHIOPIA.**

**ADEM BERIHUN NURU**

**A Thesis Submitted to School of Civil and Environmental Engineering in  
Partial Fulfillment of the Requirement for Degree of Master of Science  
in Geodesy and Geomatics with Specialization in Geomatics.**

**ADDIS ABABA UNIVERSITY  
ADDIS ABABA INSTITUTE OF TECHNOLOGY  
ADDIS ABABA, ETHIOPIA  
SEPTEMBER, 2018**

## **Declaration**

**The thesis is my original work, has not been presented for a degree in any other university and that all sources of material used for the thesis have been properly acknowledged.**

**Addis Ababa University**  
**Addis Ababa Institute of Technology**  
**School of Civil and Environmental Engineering**

This is to certify that the thesis prepared by Adem Berihun, entitled: Assessment of Potential Groundwater Zone Using Integrated GIS and Remote Sensing Techniques in Sekota Wereda, Northern Ethiopia and submitted in fulfillment of the requirements for the Degree of Master of Science in Geodesy and Geomatics with Specialization in Geomatics.

Name of the student \_\_\_\_\_ Signature \_\_\_\_\_ Date \_\_\_\_\_

Signed By the Examining Committee:

Advisor \_\_\_\_\_ Signature \_\_\_\_\_ Date \_\_\_\_\_

External examiner \_\_\_\_\_ Signature \_\_\_\_\_ Date \_\_\_\_\_

Internal examiner \_\_\_\_\_ Signature \_\_\_\_\_ Date \_\_\_\_\_

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Chair of Department of Graduate Program Coordinator

## **DEDICATION**

**This thesis is dedicated to my father Berihun Nuru Mohammed-Seid and my grandfather Haji Nuru Mohammed-Seid.**

*“If I was given one wish to make and would be assured that it would come true, I would wish that you would come back to us. Daddy we miss you so much”*

## **Abstract**

Due to complex and erratic nature of groundwater occurrences in volcanic rock terrains, groundwater development in form of boreholes/wells without the necessary pre-drilling hydrogeological investigations usually results in failure. Therefore, there is the need for adequate characterization of aquifers and delineation of groundwater potential zones in such volcanic rock setting. This study employed the integration of multi-criteria decision analysis (MCDA), remote sensing (RS) and geographical information system (GIS) techniques to delineate groundwater potential zones in volcanic rock terrain of N-Ethiopia, Amhara Regional State, Wag Himra Zone of Sekota Wereda, and validation of the result with existing borehole/well yield data. The study approach involved integration of seven different thematic layers (lithology, land form, soil, drainage density, lineament density, land use and slope) based on weights assignment and normalization with respect to the relative contribution of the different themes to groundwater occurrence using Saaty's analytic hierarchy approach. Following weigh normalization and ranking, the thematic maps were integrated using ArcGIS 10.1 software to generate the overall groundwater potential map for the study area.

Finally, groundwater potential zones are classified into three categories namely low, moderate, and high zone. It is observed that 10.03% (167.5 km<sup>2</sup>) of the study area falls under 'low' groundwater potential zone. Approximately 1190.8 km<sup>2</sup> area accounting for 71.4% of the study area falls under 'moderate' category and 'high' groundwater potential zone encompasses an area of 309.8 km<sup>2</sup> accounting for 18.57 % of the total study area.

Finally, the model generated groundwater potential zones are validated with potential yield data of various wells in the study area. The validation clearly highlights the efficiency of the integrated RS and GIS methods employed in this study as useful modern approach for proper groundwater resources evaluation; providing quick prospective guides for groundwater exploration and exploitation in such volcanic rock setting.

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## List of Acronyms and Abbreviations

AHP.....	Analytical Hierarchy Process
CI.....	Consistency Index
CR.....	Consistency Ratio
DEM.....	Digital Elevation Model
EGS.....	Ethiopian Geological Survey
FAO.....	The Food and Agriculture Organization
FDRE.....	Federal Democratic Republic of Ethiopia
FCC.....	False Color Composite
GIS.....	Geographic Information System
GPM.....	Groundwater Potential Model
GWPZ.....	Groundwater Potential zone
GPS.....	Global positioning System
LULC.....	Land Use/ Land Cover
MAARD.....	Ministry of Agriculture and Animal Resource Development
MWIE.....	Ministry of Water, Irrigation and Electricity
OLI.....	Operational Land Imagery
RS.....	Remote Sensing
SRTM.....	Space Shuttle Radar Topographic Mission
SWAT.....	Soil and Water Assessment Tool
TTC.....	True Color Composite
UN.....	United Nations
UNESCO.....	United Nations Education, Science and Culture Organization
USGS.....	United States Geological Survey
UTM.....	Universal Transverse Mercator
WHO.....	World Health Organization
WMO.....	World Meteorological Organization

# CHAPTER ONE

## 1. Introduction

### 1.1. Background of the study

Water as one of the natural resources required for the survival of man, animals and plants is unevenly distributed on the earth's surface and below the earth's surface. There are a lot of variations in terms of both quantity and quality of natural water whether surface or underground. Yet people and animals need clean potable water to survive. The major sources of clean water are tap, borehole, hand pumps, open wells, streams and rivers. In the absence of available good water, people begin to use unsafe sources and encounter some health problems. Pimentel et al (1997) states that about 90% of the diseases occurring in developing countries result from lack of clean water. It is also predicted that by the year 2025, many African countries will experience water scarcity (WMO, 2002 and 2008). United Nation Environmental Programme (2006) reports that, degradation of groundwater is one of the most serious water resources problems in Africa and that is why its management is crucial.

Groundwater is an important source of water; it may provide the base flows for rivers, or act as an underground reservoir from which water can be pumped as a location into which water can be drained. And it is the purest form of water source from natural resources and meets the overall demand of rural and semi-urban people. Groundwater is considered to be the largest single fresh water source in many parts of the world that provides a risk buffer to sustain critical water demands during prolonged dry cyclical periods (S. K. and Anindita, 2016). Successful exploitation of groundwater requires in an environment a proper understanding of the area's hydrological and geological characteristics. Nature of hydrological characteristic of an area determines the groundwater quantity and quality of that area. These characteristics also determine the level of water in the aquifer. It is also stated that the water table is a function of topography and climate and the flow pattern of ground water is a function of climate, topography and geology. These three terms are called hydrological environment (Toth and Ophori, 1989).

Thapa, Ravindra and Sood (2008) also reported that to evaluate groundwater potential zones of an area various parameters namely lithology, slope, lineaments, hydro geomorphology, land use and land cover need be understood. A lineament is a linear feature whose parts are aligned rectilinear or in a slightly

curvilinear relationship, which differs a lot with neighboring features and most probably reflects a subsurface phenomenon (Singhal and Gupta, 1999). Information on soil also forms important input in mapping groundwater potential zones. For example, coarse soils are generally permeable while fine textured soils indicate less permeability (Thapa et al., 2008).

Timothy, Jerome, Mattwa and Robert (1994) also pointed out that groundwater potential zones can be obtained using remote sensing and GIS through interpretation of data based on geologic, hydrogeologic, topographic, vegetation and soil maps interpretation. Sander, Minor and Chesley (1997) added that lineaments are often visual on remote sensing data as topographic, drainage, vegetation, or soil tonal anomalies. These factors are very essential in assessing groundwater potential of an area with the help of ground truthing. Thematic layers important for assessing groundwater potential of an area include geology, geomorphology, hydrogeology/landforms, drainage density, lineament density; lithology, slope and land cover (Tesfaye, 2010).

The integration of remote sensing data and GIS technology may provide a greater hydrogeologic understanding; by combining physiographic, Geologic, hydrogeologic and geochemical data in a spatially referenced model. GIS use in water resource evaluation has recently expanded with increasing emphasis in surface and subsurface applications (Moore et al., 1991). These tools are very effective in delineating groundwater potential zones, and recharge zones. Modern tools of GIS, Remote sensing and Multicriterian analysis using AHP and ground truthing can provide efficient method for delineating groundwater prospect zones in an area and can establish relationship between geological characteristics and yield data in an area (Kavidha and Elangovan, 2013). Furthermore, the combination of remote sensing and GIS has shown promise for groundwater development in other regions of Africa (Alkali S. et al, 2011) like in Ethiopia.

The concept of integrated remote sensing and GIS has proved to be an efficient tool in groundwater studies, in facilitate better data analysis and their interpretations (Krishnamurthy et. al. 1996). In addition, the greatest advantages of using remote sensing data for hydrogeological investigations and monitoring is its ability to generate information in spatial and temporal domain, which is very crucial for successful analysis, prediction and validation (Saraf, 1999).

Hence, the aim of the study is to apply integrated GIS and remote sensing application techniques in assessing groundwater potential zones in Sekota wereda, Northern Ethiopia. Such up to date

information will be a great importance for the researchers, practicing hydro geologists and decision makers to pass right decisions timely.

## **1.2. Statement of the problem**

Groundwater is a precious resource of limited extent. For the good use of it, proper prospecting, management and assessment is required. Due to the increasing number of people living in cities and rural areas as a result of increase in world population; it becomes necessary to scout for other alternative sources of fresh water. Previous studies (King, 1997) have shown that some of the greatest water needs occur in regions underlain by fractured basement aquifers with complex hydrogeology and where the exploitation potential of groundwater has been thought to be low due to historically low drilling success rates or the high frequency of low yielding boreholes. Groundwater exploration success rates in these environments have been relatively low due to inappropriate exploration or interpretation methods resulting from an incomplete understanding of the geohydrology.

In Sekota wereda and its surrounding a large portion of the area is underlain by volcanic hard rock. In most of the area water supply comes mainly from dug wells, springs, and to some extent, from boreholes that are found along major streams and valleys. The groundwater table lies at a depth of several meters. According to Al-Garni et al., (2005), Exploration of groundwater in hard rock terrain is a very challenging and difficult task when the promising groundwater zones are associated with fractured and fissured media. In this environment, the groundwater potentiality depends mainly on the thickness of the weathered/fractured layer overlying the basement. The magnetic materials within the weathered zones are reduced as a result of the weathering processes during the geological time.

The increasing demand for drinking water in Sekota town and the surrounding rural kebeles resulting from exponential population growth rate primed the need for increased water supply. Many efforts have been made by various government institutions and Non- governmental organizations to make water available in the area through drilling of boreholes, and water point development in addition to hand dug wells. Selection of well sites for groundwater supply relies heavily on traditional field methods using known water yielding sites as guidelines. In general a systematic approach to groundwater exploration is lacking.

Remote sensing with its advantages of spatial, spectral and temporal availability of data covering large and inaccessible areas within short time has become a very handy tool in exploring, evaluating, and managing vital groundwater resources (Chowdhury et al., 2003). The hydrogeologic interpretation of

satellite data have been proved to be a valuable survey tool in areas of the world where little geologic and cartographic information exists or is not accurate (Engman and Gurney, 1991). Satellite data provide quick and useful baseline information about the factors controlling the occurrence and movement of groundwater like geology, lithology, geomorphology, soils, land use/cover, drainage patterns, lineaments, etc. (Bobba et al., 1992).

From available literature on groundwater prospecting in the study area, there is no previous study focusing on the use of remote sensing and GIS in assessing groundwater resource potential. If groundwater potential in Sekota wereda will be assessed using remote sensing, GIS and Multicriterion evaluation among others, it may assist in reducing water supply shortage in the town.

### **1.3. The research questions**

The research questions for this study are.

1. What are the determining factors for the occurrence of groundwater in Sekota Wereda?
2. What is the relative importance of factors in determining potential groundwater zones?
3. What are the characteristics of the identified potential zones?

### **1.4. Objectives**

**1.4.1. General Objective:-**The main objective of this research is to assess potential groundwater zones using integrated geographic Information system (GIS) and Remote sensing techniques in Sekota wereda, Northern Ethiopia.

#### **1.4.2. Specific Objectives:**

- To characterize factors those determine the Groundwater Potential zones for Sekota Wereda.
- To determine the relative importance of the factors in determining Groundwater potential zone.
- To map the potential Groundwater zone using GIS and Remote Sensing techniques for Sekota.

### **1.5. Significance of the study**

The research study is expected to produce a groundwater potential zone map that demarcates the study area into different zones according to their groundwater potential. The resulted detail map of the area can be one input for understanding of hydrogeological systems of the area, and used as data for further research work.

The generated, collected and digitized data organized into the logical groups of entities concerning geological factors (lithology and lineament), land form, drainage density, slope, land use/land cover and soil map, to produce properly organized Geodatabase which will enable the responsible officers to make decision and review by concerned stakeholders and subsequent researchers to properly use water resources in the area.

### **1.6. Scope of the study**

Water scarcity is a serious problem and the area relies mostly on springs, rivers, hand-dug wells and some boreholes. Groundwater would be a preferred water option in the area because of its generally availability even in drought situations and its relatively good quality. Therefore, this research is focused on assessing groundwater potential of Sekota Wereda of Wag Himra Administrative zone in Northern Ethiopia using integrated GIS and remote sensing techniques.

### **1.7. Limitations of the study**

Major limitations identified during groundwater resource trends estimation using an integrated GIS-remote sensing methodology are as follows:

- An inadequate understanding of the factors affecting for the occurrence of groundwater.
- The subjective nature of weight assignment for factors using AHP method may lead to inaccurate results.
- Lack of adequate bore hole and handdug well data that were required to validate the GIS and remote sensing based potential groundwater zone delineation.

### **1.8. Thesis Structure**

The overall thesis is organized under five chapters: Introduction, Literature review, Materials and Methods, Results and Discussions and finally Conclusions and Recommendations.

**Chapter 1** - Gives brief introduction of the research, identifies research problems, defines research objectives and questions related to the objectives, and also significance of the study and the scope of the study.

- Chapter 2** - Briefly review literature on groundwater and integrated GIS and remote sensing method using multi criteria analysis used to assess potential groundwater zone.
- Chapter 3** - Presents description of the study area, identification of factors for groundwater occurrence, the data used/sources and software types used, data preparation and analysis and result validation to reach the objectives of this research.
- Chapter 4** - Give explanation about a results and discussions of the AHP weight assignment, the input layer analysis, integration of layers and result validation analysis.
- Chapter 5** - Provides conclusions and recommendations made based on the result of the research

# CHAPETR TWO

## 2. Review of Literatures

### 2.1. Importance of Water for Life

Water is the most abundant solvent on the earth that support all forms of life. Over 70% of the earth surface is covered by water in Oceans, lakes, rivers, ponds, lagoons and other water bodies. Groundwater is part of the available water in the globe for human utilization. Animal and plant bodies contain water for their physiological systems and regulation of body temperature. Food and beverages contain significant amount of water within them. Water serves as coolants in heavy to light industries. Water is very essential to life that is why people are looking for it at all cost for their domestic, industrial and other uses. The physical reality of life is defined by water; it is the essence of our existence and is therefore the most critical resource supplied by earth systems (Robert, 2007). If drinking water is scarce or absent, people can spend much time for carrying it to their houses. This is because water is a medium of life, since man drinks it and utilizes it in many ways. Batmanghelidji (2004) in his book „Your body’s many cries for water gives a wonderful essay on water and its vital role in health and life, he „states since water we drink provide for cell functions and its volume requirements, the decrease in our daily water intake affect the efficiency of cell activity ... as a result chronic dehydration causes symptoms that equal diseases...““Water is a basic ingredient of life.

It was reported by Tanner and Roades (2003) that the human body contains from 55% to 78% water, depending on the body size and to function properly, the body requires between one and seven liters of water per day to avoid dehydration. The intake takes place through drinking, eating of beverages and other foods that contain water. From philosophical point of view, internet secret text (2010) reports that ancient Greek philosopher Empedocles held that water is one of the four classical elements along with fire, earth and air, and was regarded as the ylem or basic substance of the Universe. The classical element of water also one of the five elements in traditional Chinese philosophy, along with earth, fire, wood and metal. These show how important water is to life.

Religions obligations are fulfilled in the presence of water, it is considered as a purifier in most religious of the world. Major faiths that incorporate ritual washing include Islam, Christianity, Hinduism, Rastafari movement, Shinto, Taoism, Judaism and Wicca, These happen in the form of

washing (ablution, sacrament of Christianity called baptism and ritual washings of other religions (Marks,2001).

Generally water is regarded as life and life is regarded as water. Since all aspects of life depend on water for domestic, industrial, religious and agricultural uses, there is need to scout for available sources of water. Among the available sources groundwater seems to be the most important one. Water has always played and continues to play a central role in human societies.

## **2.2. Water Resources Development**

Water is the resource that sustains all life on earth and is a key element of sustainable development. Water is an infinite resource, worldwide there is an imbalance between water utilization and water resources management. This imbalance has brought a veritable crisis with regard to water in many regions of the world. Yatsuka (2002) reported that it is projected that by 2025, about 3.5 billion people-approximately 6.5 times as many people as in the year 2000- will live in water stressed countries. This indicates the level of water resource deterioration globally. In most regions of the world, water availability has rapidly decreased for example in Asia water availability per capita ranks as least in the world with 4,200m<sup>3</sup>/capita per year a little more than half the world average of 7,000m<sup>3</sup>. In the year 2025, water availability per capita in Asian region and the rest of the world including Africa will probably be between 15 and 35 less than that of 1950 (ADB,2001).

Water shortage and scarcity necessitated for world conferences on water. WHO report (1999) shows that ministerial conference on environment and Development in Asia and the Pacific (MCED) in the year 2000 identified conservation and integrated management of fresh water resources as one of the eight priority areas of the Asian region. Also ministerial declaration issued at the international conference on fresh water held at Bonn in December 2011 also made a call to the UN Secretary General to strengthen the coordination coherence of activities within the UN system on water issues in an exclusive manner. Outcomes of world water forum conducted by Global water partnership increases global awareness of water crisis and promote actions for sustainable use and development of water resources.

## **2.3. International Development of the Sustainability Concept in Relation to Water**

The concept of environmental sustainability was first broached at the Stockholm Conference on the Human Environment, sponsored by the United Nations in 1972. Since then, numerous international

conferences have been held to develop definitions of sustainability for a variety of circumstances, including international meetings devoted solely to water. The first major water conference was at Mar del Plata, Argentina, in 1977, and in the 1990s international water meetings began to proliferate. The first of the triennial World Water Forums happened in Marrakech in 1997, followed by The Hague in 2000, Kyoto in 2003, Mexico City in 2006, and Istanbul in 2009. World Water Week also occurs annually in Stockholm; it focuses on the implementation of international processes and programs in water and development. Despite the prevalence of such meetings, critics continue to point out that they have not measurably advanced water sustainability (Gleick, 2007).

At the World Summit on Sustainable Development in Johannesburg in 2002, participating nations agreed to a number of water actions focused first on halving, by the year 2015, both the proportion of people who are unable to reach or afford safe drinking water and the proportion without access to basic sanitation. This Plan of Action also committed the nations to, among other measures, mitigate the effects of groundwater contamination and develop and implement strategies with regard to integrated drainage basin and groundwater management (WSSD, 2002).

Various international agencies have looked at ways to promote groundwater sustainability. The United Nations Environment Programme produced “Groundwater and its Susceptibility to Degradation: A Global Assessment of the Problem and Options for Management,” which documented how over-exploited aquifers, falling water tables, and seawater contamination threaten the world’s natural underground reservoirs, upon which two billion people depend for drinking water and irrigation (UNEP, 2003). UNESCO has a large groundwater program, including the Internationally Shared Aquifer Resources Management Initiative, and has also compiled a global report on indicators used to measure groundwater sustainability (UNESCO, 2006). The Food and Agriculture Organization of the United Nations (FAO) has reported on groundwater and international law (Burchi and Mechlem, 2005). The World Bank’s Groundwater Management Advisory Team program assists developing nations with groundwater.

#### **2.4. Background on groundwater resources**

Groundwater is an appreciated natural resource for the dependable and economic provision of better quality water supply in many regions of the Earth. There is only 2.8% of the total available water on the Earth that is categorized as fresh water, with 97% of which being groundwater (Sekhri, 2013). Groundwater is important for both human consumption and the preservation of the ecological value of

many areas worldwide. Groundwater has emerged as a poverty reduction tool in many developing countries because it can be cost-effectively and uncomplicatedly distributed to poor rural areas than surface water. Approximately 34% of the overall global annual water supply is groundwater, with the surface water resource alone being insufficient to fulfill the ever-increasing population demand for water. In addition, more than 50% of the global population relies on groundwater resources to cater for their basic day-to-day water needs, while majority of farmers depend on groundwater to cater for their wellbeing and contribute to the food security of so many others (Beekman & Xu, 2003). Groundwater also represents approximately 43% of all water used in irrigation globally. It is preferred the most because it is more usually protected from the hazards of pollution; hence it requires less treatment when compared to surface water. Groundwater supplies are, nevertheless, declining, with a projected 20% of the world's aquifers presently over exploited. Approximately 40% of global groundwater abstraction occurs in arid and semi-arid regions and yet the shortage of rain in these regions implies that only 2% of groundwater recharge takes place there (Wada et al. 2010). Therefore, understanding the nature and occurrence of these resources is imperative for their sustainable utilization and management purpose.

## **2.5. Groundwater Resource and Development**

Groundwater comprises water that exists beneath the land surface, held within openings or pores of soils and geological formations. According to most classical definitions, this term refers exclusively to water occurring at or beneath a surface, known as the water table. Below the water table is a region known as saturated zone, pores are completely filled with water. Trimmer (2000) defines groundwater as water that naturally occurs in porous rock materials underground.

Groundwater is a critical underlying resource for human survival and economic development in extensive drought-prone areas of south-eastern, east and western Africa especially where the average is less than 1,000 mm/a (Stephen, Albert and Hector, 2002). Robert (2007) lamented that groundwater is a resource that make up an impressive 90% of the fresh water that is readily available for human use. This is one of the reasons why groundwater is regarded as major source of drinking water in most parts of the world. United States of America has one of the safest water supplies in the world but yet the quality of drinking water has continuously been deteriorating. USGA (2006) report that 49% of the US population depend on groundwater for its drinking water supply from either a public source or a private well. At present  $\frac{3}{4}$  of the public water supply in Germany is taken from groundwater sources and only  $\frac{1}{4}$  is taken from surface water (Theogeoge, 1997).

The potential importance of groundwater as a resource is indicated by estimates of the world's water balance. Demenico and Schwartz (1990) revealed that according to most estimates, saline oceans and seas account for 94% to more than 97% of the world's water, while another 2% is held in glaciers and polar ice caps. Although groundwater constitutes a few percentages by volume of the total water at or near the earth's surface. thus, it becomes apparent that groundwater makes up the world's utilizable freshwater resources, 95% or more by volume.

Groundwater is widely used because of its high quality. Groundwater development unfolds rapidly once a minimum level of technology and energy become widely available (Shah, 1993). Groundwater use is becoming more apparent than surface water for example UN/WWAP (2003) concludes that groundwater use often brings large economic benefits per unit volume, because of ready local availability, drought reliability and good quality requiring minimal treatment.

## **2.6. Groundwater Potential**

Groundwater potential means having a latent possibility or likelihood of occurrence of groundwater in an area. Areas or zones of abundant groundwater available for use are referred to as areas of good groundwater potential. Productive water bearing zones referred to as good groundwater potential aquifers.

The search for groundwater has become quite intense in human history. This is due to the fact that government is unable to meet the ever increasing water demand; inhabitants have had to look for alternative sources such as surface streams, shallow wells and boreholes. This can be achieved through groundwater potential studies. Matthew (2006) pointed out that the groundwater potential of United States is divided into principal aquifers of over 300,000km<sup>2</sup>, principal aquifers of over 20,000km<sup>2</sup>, principal aquifers of less than 20,000km<sup>2</sup> and non principal aquifers. Classification of areas into groundwater potential zones or classes is not a new issue in the field of hydrology.

Rai (2008) states that for sustainable groundwater development of an area, delineation of aquifers is pre-requisite for the assessment of regional and local groundwater potential. Assessment of groundwater potential in Nigeria was conducted through delineation of aquifers by many researchers.

## **2.7. Groundwater Exploration**

Groundwater exploration means searching or investigating the presence or absence of groundwater. Increasing demand on groundwater necessitated experts and researchers in the field of hydrological studies to look for more ways of groundwater exploration. In many parts of the world groundwater abstraction has exceeded safe yield, resulting in over exploitation and overstressing of the aquifer. Therefore the quantum of available groundwater resource has to be assessed accurately for its optimum extraction and utilization (Charles and Richardson, 2010).

Groundwater exploration is carried out in many ways ranging from traditional to modern methods. Everyday groundwater exploration is developing through new means and devices. Meijirik (2007) reports that exploration for groundwater using photo geology was a major field of interest in the past and still is in areas covered inadequately by geological maps. This is with regards to geological point of view. The classic work of Ray (1960) has assisted many beginners in the field of hydrogeology and identified areas with relatively warm groundwater on aircraft thermal imagery recorded during the winter in Ontario and Canada and related them to either shallow aquifers or discharge areas of deeper flow systems.

Geophysical measurements are also known for groundwater exploration using seismic methods, geophoning, schlumberger array and wenner array methods. Integrated geophysical tools, especially resistivity, electromagnetically more recently, nuclear magnetic resonance methods, are commonly used in groundwater exploration, mainly due to close relationship between electrical conductivity and some hydrological parameters (Sultan et al, 2009). Resistivity methods are used in detecting groundwater presence and differentiating subsurface layers. Julius uses schlumberger array method with borehole data to study groundwater potential and recharge zones in parts of Delta state. In this study there was no use of G.I.S or remote sensing approach. Schlumberger array method was used together with depth to water level data obtained from hand-dug wells data, elevation and locations were taken using GPS. The result revealed that 4 to 5 layer configurations were identified and weathered basement is the promising area of groundwater potential. Coker, Makinda and Olowefola (2008) conducted groundwater exploration in Oke-Bada Estate parts of Ibadan. In the study VES survey was carried out and borehole data was also used to validate the result. Four to Three layer configurations were identified. The curves were revealed to be of H, HA, QA and KH types. It is also seen that areas of low resistivity are areas of high porosity and high groundwater potential. Aquifer

units thickness maps were produced using GIS analysis where poor, moderate, and good aquifers were identified.

Vertical Electrical sounding (VES) is very useful in groundwater study especially when supported by other techniques of data collections. Emmanuel et al (2011) described VES method as a depth sounding method and have proved to be useful in groundwater studies and it is capable of investigating rock resistivity and properties which depends on lithology fluid contents. Emmanuel et al (2011) investigated groundwater condition of Moniya area in Ibadan where ABEM Terrameter SAS 300B was used; current electrode spacing (A/B) of 100m was used boreholes data was used. Result indicate that 3-4 layer configurations were identified and the major curves are A, H, KH and HA. Weathered basement is the zone of high recharge.

Groundwater exploration is often carried out using remote sensing and GIS techniques. Groundwater exploration on the other hand has many problems such as the paucity of existing data, the high cost of data gathering (subsurface and surface techniques) and relatively remote target aquifer. Remote sensing techniques and Geographic information system (GIS) techniques are considered the most appropriate new alternative tools for groundwater exploration (Moore, 1982). The main advantage of using remote sensing and GIS techniques for groundwater exploration are reduction of cost and time needed, the fast extraction of information on the occurrence of groundwater and the selection of promising areas for further groundwater exploration (Toleti et al, 2001).

### **2.7.1. Concept of Occurrence and Movement of Ground Water**

Ground water is a part of the hydrological cycle and forms a dynamic system. It comes into existence with the process of infiltration at the surface. Then, it percolates into the ground, which comprises of different rock formations having different hydrogeological properties. The storage capacity of the rock formations depends on the porosity of the rock. In the rock formation the water moves from areas of recharge to areas of discharge under the influence of hydraulic gradients depending on the hydraulic conductivity or permeability. In other words, at a given location, the occurrence of ground water depends on the storage capacity and the rate of transmission. However, the hydro-geological properties of aquifer developed at the time of formation of the rocks with the initial geometric shape ranging from tabular to lenticular to cylindrical undergo different changes as - a) The structural and erosional modifications change the thickness and, lateral continuity of most major rock units, b) The hydrothermal alteration, contact metamorphism, diagenesis, and thermal mechanical effects modify

rock-hydraulic properties to differing degrees locally, and c) The fracturing alters permeability along fault /fracture zones. These changes bring significant variations in the hydro-geological properties within the rock type thereby changing the ground water storage and transmitting abilities both horizontally and vertically (Bernard, 2013).

The framework in which the ground water occurs is as varied as that of rock types, as intricate as their structural deformation and geomorphic history, and as complex as that of the balance among the Lithologic, structural and geomorphic parameters. The entire column of subsurface acts as three dimensional frameworks of groundwater aquifers and confining units. Finally, the ground water prospects in the unit depend on the availability of the recharge which in turn depends on the prevailing hydrological conditions. Hence, the ground water regime can be defined as a combination of four factors: Lithology; Landform; Structure; recharge conditions. The possible combinations of variety and intricacy are virtually infinite and the ground water conditions at a given site are unique (Trimmer, 2000)..

### **2.7.2. Factors Affecting Groundwater Storage**

Groundwater storage depends on aquifer parameters, rate of water movement and recharge of the aquifers. Groundwater movement like surface water is affected by the nature of slope or elevation Thomas (2003) states that groundwater moves from higher elevations to lower elevations and from location of higher pressure to location of lower pressure. Typically this movement is quite slow, on order of less than one foot per day to a few tens of feet per day. Science of groundwater movement is described as groundwater hydraulics. In groundwater hydraulic, it is hydraulic head that determine groundwater movement. Groundwater movement is rapid in gravels and sands and slow in clay or in tiny rock features. The ability of a rock layer or geologic formation to move water is called hydraulic conductivity. Factors determining groundwater movement and storage in any form of aquifer are hydraulic properties or dimension of aquifers, type of aquifer confined or unconfined and climate that is in terms of rainfall recharge.

In another development Buddemeir and Schloss (2000) pointed out that groundwater development potential yield depend on aquifer characteristics such as hydraulic conductivity, aquifer thickness, storability, aerial extent, groundwater levels, available drawdown and recharge. This indicates that nature of soil, geology; climate and properties of aquifer are the major factors controlling movement and storage of groundwater in any part of the world. Groundwater recharge and storage to

shallow unconfined aquifer is complex and is dependent upon the occurrence, intensity and duration of precipitation, temperature, humidity, wind velocity as well as character and thickness of soil and rock above the water table and the surface topography, vegetation and land use. Climatic elements and geophysical factors are not the only factors that determine groundwater movement and storage. Groundwater storage depend not only on precipitation but also meteorological conditions, as well as on soil type, soil-moisture status, vegetation cover and condition, slope, cultivation practices and most of all, on evapotranspiration, which is a function of the other factors (Cheng- HauLee, Wei-ping and Ru-huanglee, 2006).

Many researches were conducted on groundwater storage, movement and recharge. Most of these studies were based on the stated factors. David et al (1997) conducted study on groundwater storage at Danville in Illinois. The researchers use driller's logs, sample descriptions, down hole geophysical logs, information from IEPA and EER data. The result indicates that thin upper layer of reverse seismic refraction is having velocity of approximately 1,25ft/s, middle layer 5,743 to 6,947ft/s and lower layer is 8,244 to 11,833 ft/s. In another development Arnold et al (2000) conducted study of groundwater storage and recharge of Upper Mississippi river basin using two methods of water balance component of SWAT model and daily stream method and data was obtained from USGS after every 5 years from 1961 to 1980. The result shows that the USGS measurements are in close agreement with SWAT simulated and normalized recharge curves were plotted for recharge, surface runoff, base flow and soil ET. A study of groundwater storage was undertaken in Taiwan by Chang-HawLee et al (2006) the study uses water balance approach together with base flow record estimation, stable base flow analysis, long term mean annual rainfall data, BFI was calculated using daily stream flow data and mapping was carried out by GIS and geostatistics. Their result indicates that mean annual groundwater is below 0°at western edge and total groundwater recharge is 18 billion tons per year.

## **2.8. Application of Remote Sensing and GIS in Groundwater Studies**

Modern technologies such as remote sensing and geographic information systems (GIS) have proved to be useful for studying geological, structural and geomorphological conditions together with conventional surveys. Integration of the two technologies has proven to be an efficient tool in groundwater studies. Satellite images are increasingly used in ground water exploration because of their utility in identifying various ground features, which may serve as either direct or indirect indicators of presence of groundwater. The Geographic Information System (GIS) has emerged as

a powerful tool in analysing and quantifying such multivariate aspects of groundwater occurrence. It is very helpful in delineation of groundwater prospect and deficit zones (Krishnamurthy et al., 1996).

Lithology, lineament, landform, slope, vegetation, groundwater recharge and discharge are common features used for many groundwater resource assessments in hard rock areas. Remote sensing data provide accurate spatial information and are cost-effective compared with conventional methods of hydrogeological surveys. Digital enhancement of satellite data improves maximum extraction of information useful for groundwater studies. GIS techniques facilitate integration and analysis of large volumes of data, whereas field studies help to further validate results. Integrating all these approaches offers a better understanding of features controlling groundwater occurrence in hard rock aquifers.

Groundwater is by definition subterranean. Though aerial photographs and satellite imagery contain information about the uppermost layer of the earth's crust only, various studies have shown how remotely sensed data can contribute to hydrogeological investigations. A few studies have attempted to establish relationships between remotely sensed data and data related to groundwater in hard rocks. In certain cases, the imagery proved to contain features which have a direct link to groundwater discharges (Kresic, 1995). In hard rock terrain where water is restricted to secondary porosity and thus to weathered zones, fractures and solution openings, the evaluation of the hydrogeological significance of remotely sensed lineaments (linear features identified as long, narrow, and relatively straight tonal alignments on aerial photographs or on satellites images) attracted immediate attention and has continued to do so. An interesting method of statistical evaluation of lineaments significance in groundwater exploration has been described by Waters (1989).

Remote Sensing and Geographic Information System has become one of the leading tools in the field of hydrogeological science, which helps in assessing, monitoring and conserving groundwater resources. It allows manipulation and analysis of individual layer of spatial data. It is used for analyzing and modeling the interrelationship between the layers. Remote sensing technique provides an advantage of having access to large coverage, even in inaccessible areas. It is a rapid and cost-effective tool in producing valuable data on geology, geomorphology, lineaments, slope, etc., that helps in deciphering groundwater potential zone. A systematic integration of these data with follow up of hydrogeological investigation provides rapid and cost-effective delineation of groundwater potential zones.

Although it has been possible to integrate these data visually and delineate groundwater potential zones, it becomes time consuming, difficult and introduces manual error. In the recent years digital technique is used to integrate various data to delineate not only groundwater potential zones but also solve other problems related to groundwater. These various data are prepared in the form of thematic maps using geographical information system (GIS) software tool. These thematic maps are then integrated using “Spatial Analyst” tool. The “Spatial Analyst” tool with mathematical and Boolean operators is then used to develop models depending on the objectives of the problem at hand, such as delineation of groundwater potential zones. In the recent years many workers such as Shahid and Nath (1999), Saraf and Choudhary (1998) have used approach of remote sensing and GIS for ground water exploration and identification of artificial recharge sites.

### **2.8.1. Multi criteria Decision Analysis**

The GIS-MCDA research has made considerable contribution to the participatory GIScience (Jankowski and Nyerges 2001). Consequently, the GIS-MCDA support systems have the potential to improve collaborative decision-making process by providing a flexible problem-solving environment where those involved in collaborative tasks can explore, understand, and redefine a decision problem (Kyem 2004).

Recent developments in spatial analysis show that geo computation (computational intelligence) offers new opportunities for GIS-MCDA (Wu 1998). Geo-computational tools can potentially help in modeling and describing complex systems for inference and decision-making. An integration of MCDA and geo-computation can enhance the GIS-MCDA capabilities of handling larger and more diverse spatial data sets. Another significant trend has been associated with developing map-centered exploratory approaches to GISMCDA (Armstrong et al. 1992). Weighted Overlay Analysis is a simple and straightforward method for a combined analysis of multiclass maps. The efficacy of this method lies in that the human judgement can be incorporated in the analysis. A weight represents the relative importance of a parameter vis-à-vis the objective. WIOA method takes into consideration the relative importance of the parameters and the classes belonging to each parameter. There is no standard scale for a simple weighted overlay method. For this purpose, criteria for the analysis should be defined and each parameter should be assigned importance (Saraf and Chowdhury, 1998).

GIS is a powerful tool to address a large number of spatial data and can be used in detection process of potential ground water areas. Recently, many studies conducted through indices of ground water potential models. Some of them are as follows: frequency ratio, weights of evidence and AHP. Analytic hierarchy process (AHP) is one of the most effective multi-criteria decision making(MCDM) techniques which helps a decision maker facing complex problems and conflict and internal multiple criteria. This method first presented by Thomas L. Saaty (1980) and like other MCDMs such as Mabeth, Electre, Smart, Promeyhee, VTAand etc. has 4 steps including 1) problem modelling and making hierarchical structure, 2) evaluating weights, 3) combining weights and 4) analyzing sensitivity. Implementing AHP method with the help of expert choice software is so easy, since accessing to it is easy and its implementation and calculation steps done automatically. In addition to the possibility of designing hierarchical diagram, decision making, designing questions, determining priorities and calculating the final weight, the above-mentioned software can analyze the sensitivity of decision making about the changes of problem parameters. In most cases, appropriate diagrams and graphs used for presenting results and performances and a user can communicate easily. (Rahimi & Moosavi, 2013).

As groundwater is dynamic and interdisciplinary in nature, Geospatial tool becomes very useful in various aspects of groundwater studies. Blending of the remote sensing and GIS techniques has been proved to be an efficient tool in groundwater studies. There is growing interest in incorporating GIS capability with multi-criteria decision-making (MCDM) processes. As GIS based MCDM becomes one of the most useful methods for spatial planning and management (Joerin et al., 2001). Application of the Analytical Hierarchy Process AHP, (Saaty, 1980) is one of the most popular methods to obtain spatial plan, resource allocation etc.

# CHAPETR THREE

## 3. Materials and Methods

### 3.1. Description of the Study area

#### 3.1.1. Geographic Location

Sekota Wereda is found in Amhara regional state, Wag himra administrative zone. It is located between  $12^{\circ} 24^1$  and  $12^{\circ} 54^1$  north latitudes, and  $38^{\circ} 50^1$  and  $39^{\circ} 19^1$  east longitudes. It extends for about 56.3 kilometers in the north-south direction and about 52.2 kilometers in the east-west direction and it has a compact shape, and has an area of  $1667 \text{ km}^2$ . It shares borders with Abergele Wereda (in the north), Ziqualla wereda (in the west), Dehana wereda (in the southwest), Asketema Wereda (in the South) Tigray National Regional State (in the east).

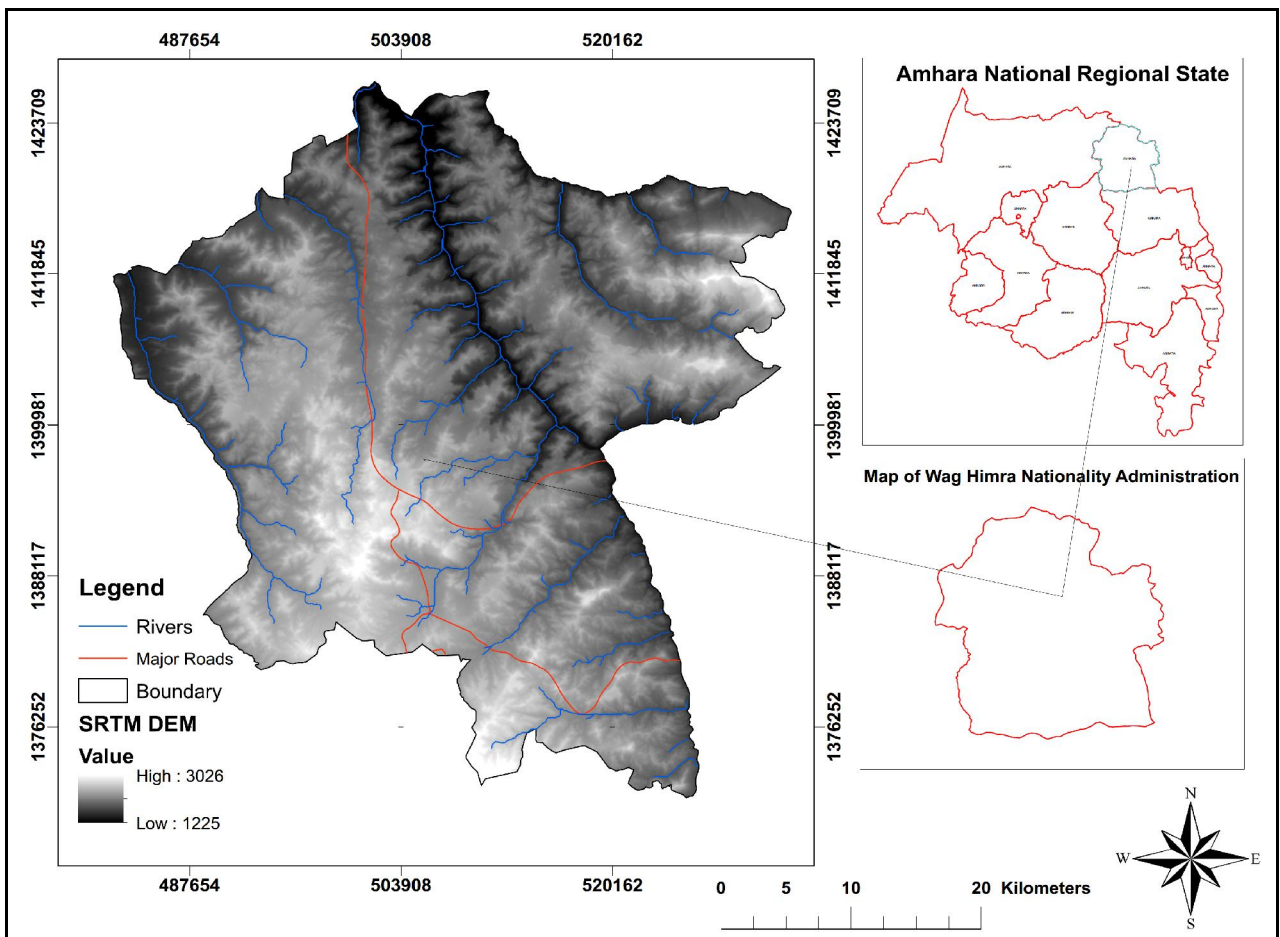


Figure 3. 1. Map of the study area

### 3.1.2. Accessibility

The study area has good road network accessibility with a poor quality. It is branched from the main asphalted road that runs from Addis Ababa, Korem to Mekelle toward the western direction of the main road, at the Korem town. From Korem town to ward to the study area there is a gravel all whether road. Other roads, from Lalibela to Sekota, which is under construction asphalt concrete road, from Sekota town to Amdewerk, Bellesa town, from Sekota town to Sehala, Gonder and from sekota to Mekelle also available. The study area is accessible throughout the year.

### 3.1.3. Topography, Elevation and Slope

The Northern part of Ethiopia is known for its mountainous and rough topography, the Sekota wereda area also shows such pronounced contrasts in the topography. Topographically, the city is characterized by different land forms, where 3.3 % hill, 33.8 % and 62.5 % plain.

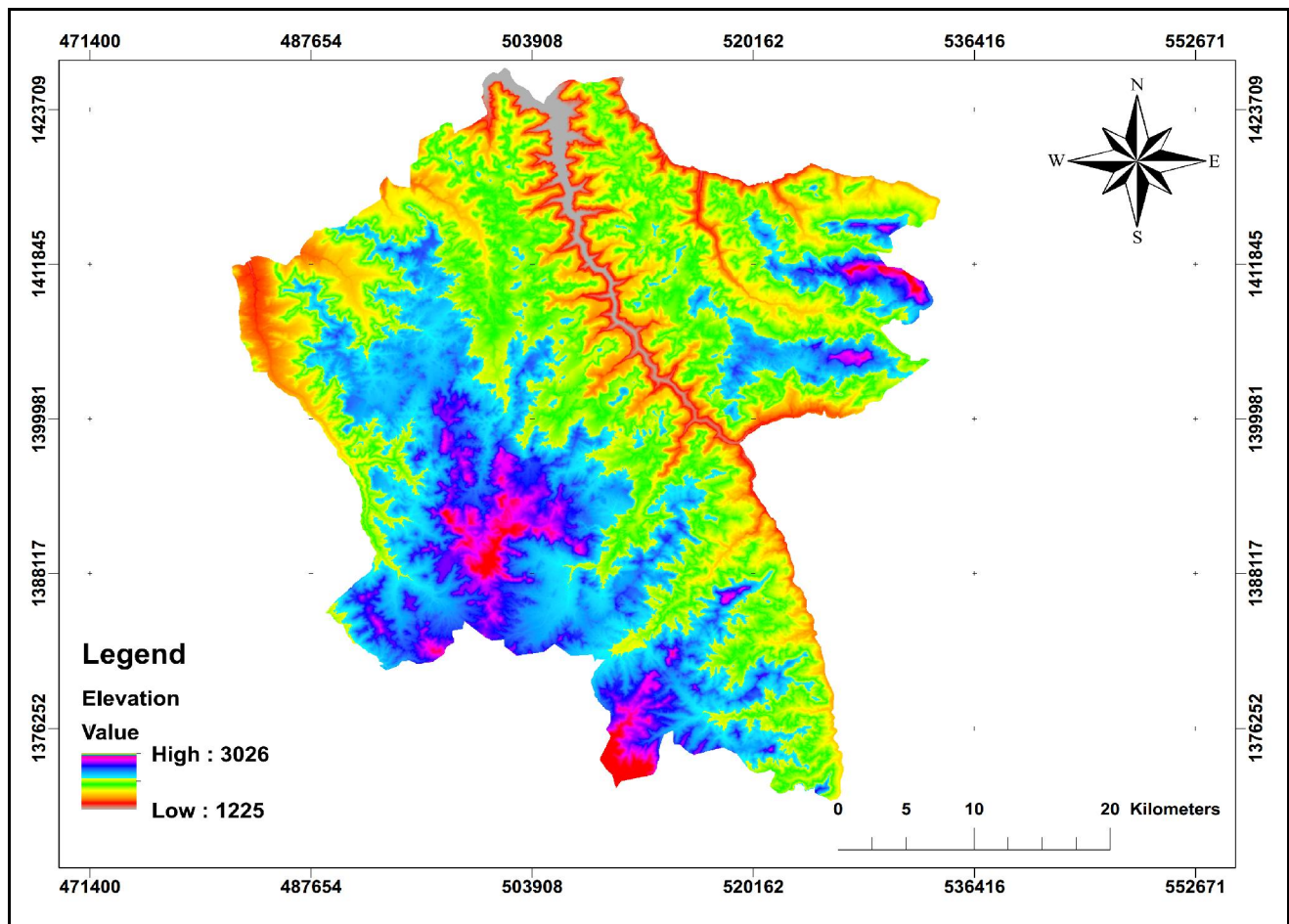


Figure 3. 2. Elevattion map of the study area.

Elevation ranges from 1225 meter to 3000 meters above sea level. Most of the wereda is lowland with an average elevation less than 2000 meters. And the south-central parts of the wereda have medium elevation while the northern, northeastern and the central parts from the lower areas of the wereda. Altitude decreases as one moves from the southwestern part to the north and east directions. And the nature of slope in the area gives an idea about the rate of infiltration and erosion. The nature of soil and rock are also affecting factor for the rate of erosion and infiltration. The studied area is characterized by a sloppy topography, which ranges from 0 to 96.41 %.

#### **3.1.4. Drainage Pattern**

There are many small intermittent rivers that drain the area. These streams originate from the surrounding highlands. The streams are dense at the area of higher slopes and sparse where the slope is relatively flat. In general, the study area has a dendritic drainage pattern. The main sources of supply for the streams are rainfall during the rainy season and to a lesser extent a group of springs that issued at the contacts, through fractures and foliation.

#### **3.1.5. Soil type**

Based on FAO soil type classification method, the soil that is found in the study area is grouped in to three different soil classes: - cambisols, leptosols and vertisols. The proportion of the area is covered by leptosols, vertisol and cambisols having 91.6%, 5.6%, and 2.75% aerial coverage, respectively.

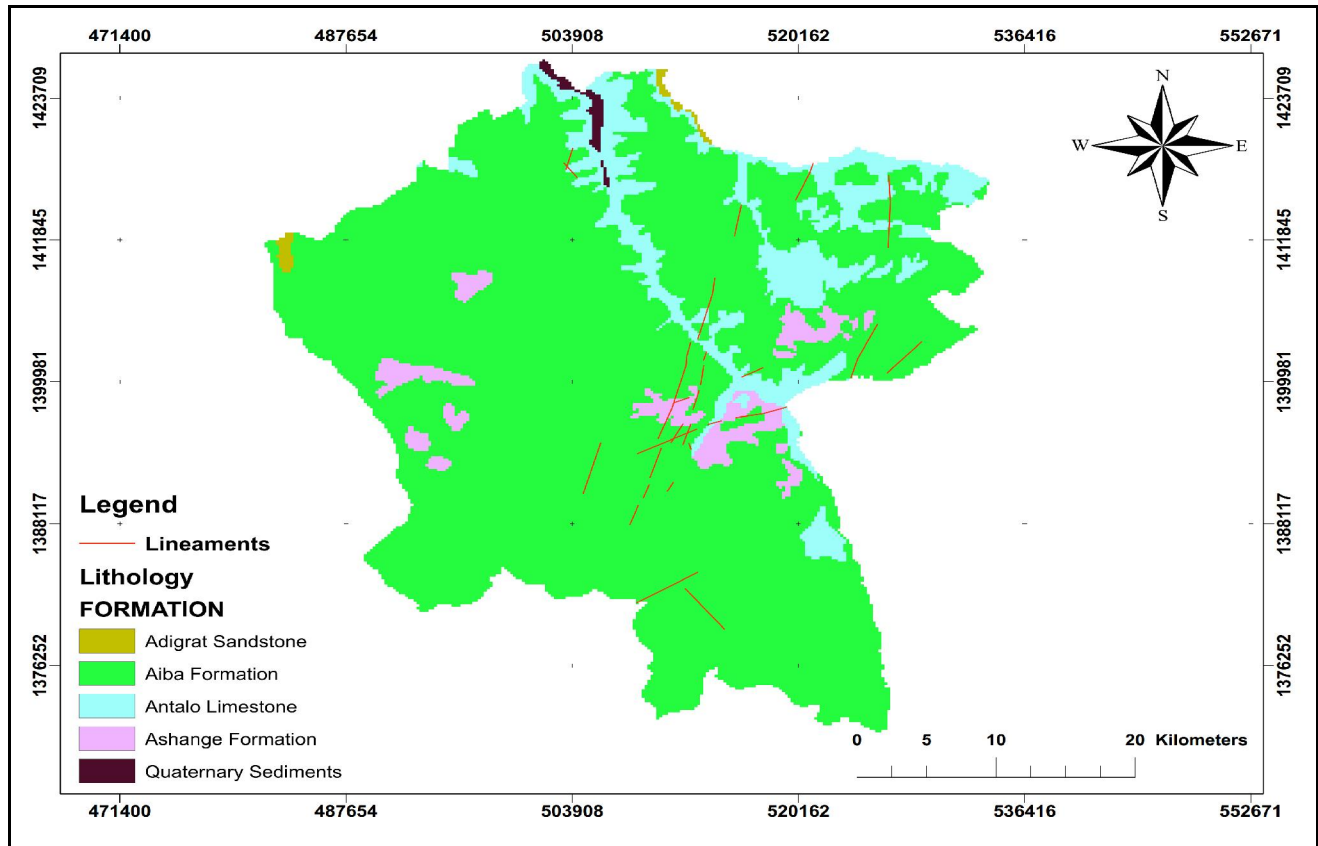
#### **3.1.6. Geology and Structure**

Sekota Wereda is found in the Upper Tekeze area which is marked by prominent uplifting, massif volcanoes, deep dissection and erosional fragmentation. The basin has undergone several changes in base levels of erosion and stream geometry. The basin is underlain by the basement complex at the base (composed of low grade meta-sediments and metavolcanics).

The Sekota complex structures: These are mainly NNW-SSE running fault systems pre-dating Cenozoic volcanic activity or contemporaneous with them. The Sekota complex is probably an old failed rift of 'basin and range' characteristics the original topography of which is masked by young volcanics and recent tectonism.

The prominent fault among the Sekota complex structures is the regional fault that run SSE ward from around Sekota and run towards Hamusit town. In this region complex stratigraphy including juxtaposition of metamorphosed limestones and sandstones with the Cenozoic volcanics is probably

related to these structures. The orientation of the May Lomi River north of Sekota also follows this regional structure.



**Figure 3. 3. Geology and Lineaments map of the study area.**

This sub-region is characterized by complex stratigraphy variously tilted sedimentary formations overlying and underlying igneous rock units. Horizontal stratigraphic lithologic interfaces, tilted beds and tectonic contacts which are also affected by faulting and dyking, doleritic intrusions, engulfing and pushing up older sequences are very distinctive (Seifu, 2013).

### 3.1.7. Climate

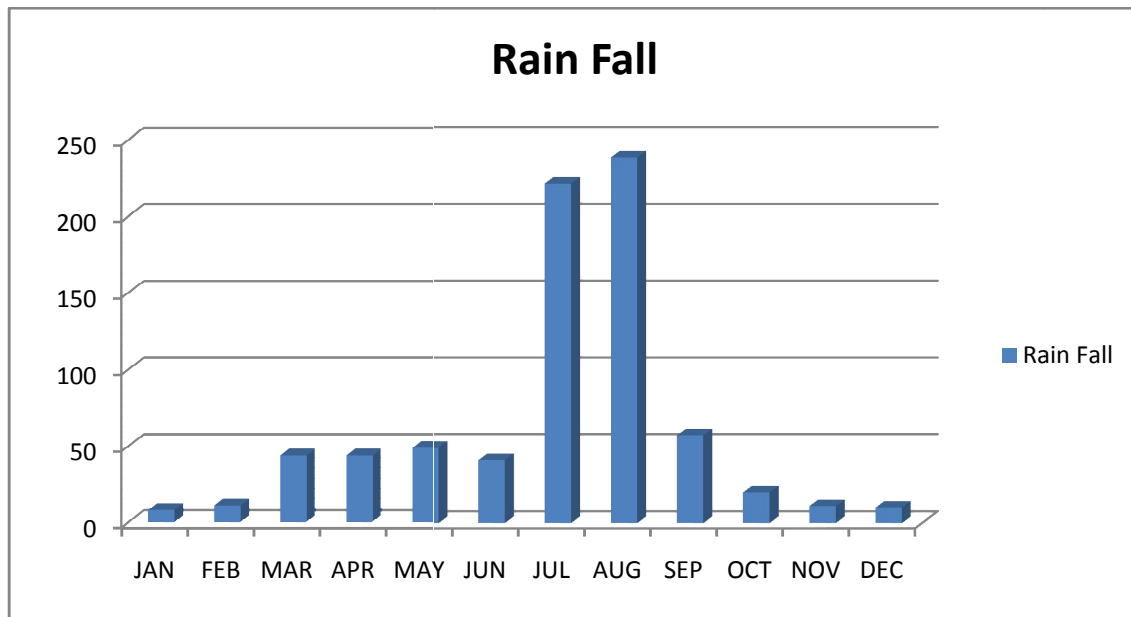
The Wereda climate is (locally called: woina dega) which receives the highest amount of annual rainfall during summer season (July, August and September). The highest rainfall season is the “kremt” /summer/ season from the month of June to September. And the wereda gets small amount of rainfall during the rest months. According to Koppen and Geiger, this climate is classified as Cwb. The average annual temperature is 18.1 °C and receives average rainfall 754 mm. the driest month is January, with 8 mm of rainfall. Most of the precipitation here falls in August, averaging 238 mm (EMA, 2013).

**Table 3. 1. Temperature and Rainfall data**

Climate	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Temperature (C <sup>o</sup> )	17	17.3	18.4	19.2	20	20.6	18.7	18.2	18.1	17.2	16.7	16.2
Rain Fall (mm)	8	11	44	44	49	41	221	238	57	20	11	10

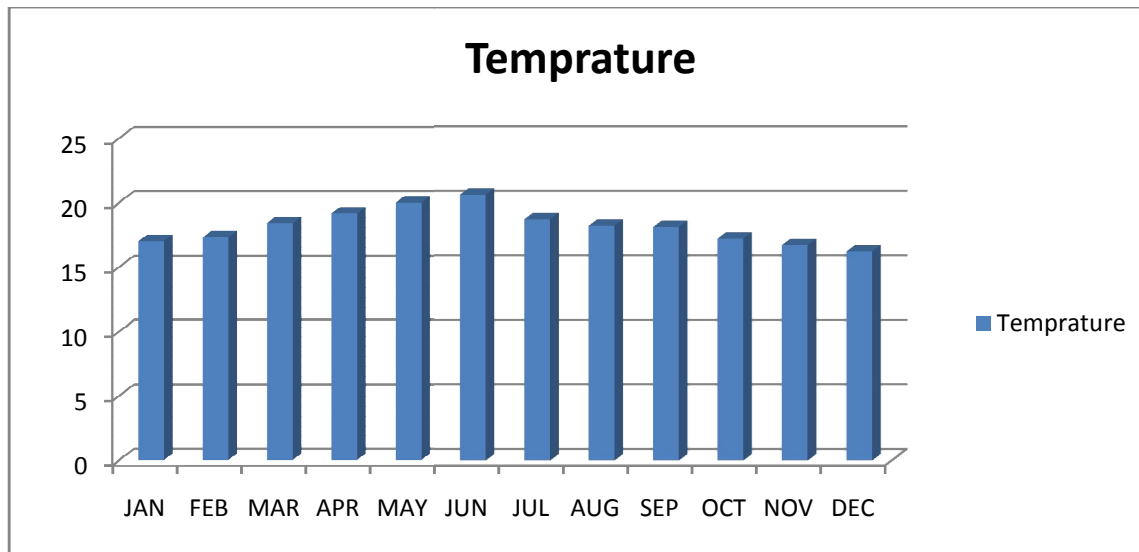
Source: CLIMATE-DATA.ORG

The warmest most of the year is June, with an average temperature of 20.6 °C. December is the coldest month, with temperatures averaging 16.2 °C.



**Figure 3. 4. Graph of Rainfall data**

The difference in precipitation between the driest month and the wettest month is 230 mm. throughout the year, temperatures vary by 4.4 °C.



**Figure 3. 5. Graph of Temperature data**

### **3.1.8. Land use and Land covers**

In a generalized manner, the land use and land cover of the area is classified in to five classes. These are cultivated land, forest, dense bushes and shrubs, open bushes shrubs and grass lands, and settlement. Most of the area especially irregular plain lands between the highlands are used for cultivation and grazing land by the local peoples and a Small area is covered by forest.

### **3.1.9. The water supply situation in the study area**

The main sources of water supply in the study area are rainfall, rivers and groundwater. Rivers are limited and rainfall is unreliable, which leaves groundwater as the only reliable source of water supply. The limited surface water supply and unreliable rainfall in this region compel a majority of the population to rely on groundwater resources for household purposes, agriculture and urban development. Increases in population, urban growth and agricultural expansion have exerted pressure on available water supply as all these developments are taking place at the expense of the existing groundwater resources.

The shortage of water within the times not allocated for water supply presented challenges in all sectors that depend entirely on water resource for their operations. Thus, groundwater quantity will continue to decline in this region if water availability and demand are not balanced through a systematic supply and water management process.

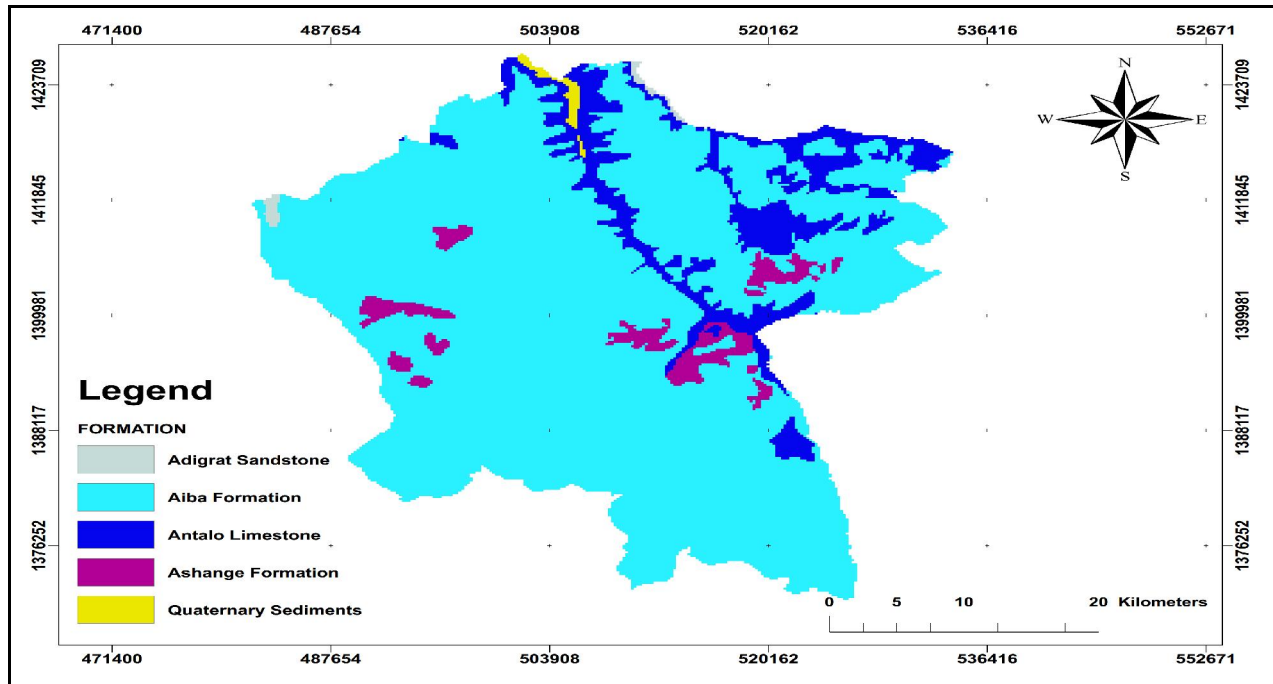
### 3.2. Methodology of the Study

The study was carried out in several stages to delineate potential groundwater zones that reveal the capability of using remote sensing and GIS in groundwater exploration study as presented schematically and described in figure.

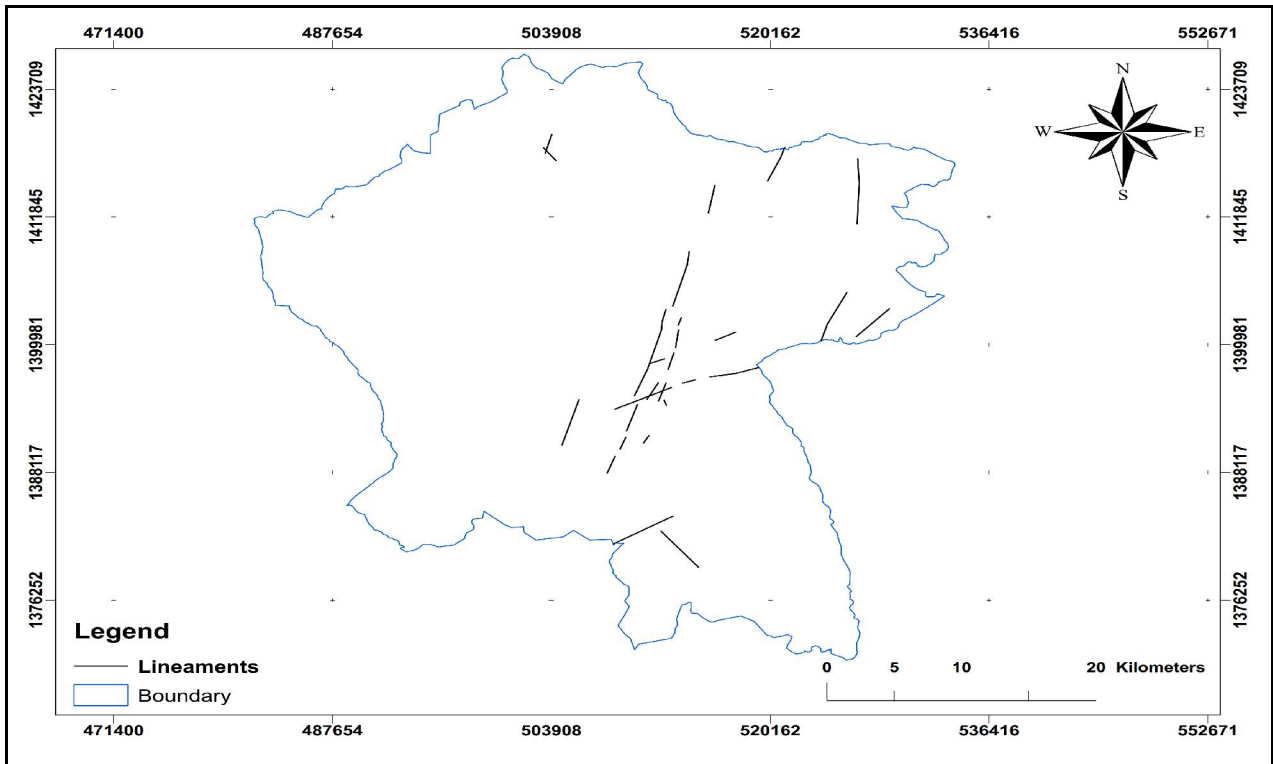
#### 3.2.1. Identification of Factors Influencing Groundwater Occurrence

There are many factors which contribute to the occurrence and movement of groundwater, such as, geology, geomorphology, soil, drainage density, lineament density, surface water body, land cover, slope, rainfall, etc. The selection of indicators mainly depends on the objective of study. Ramu, et al (2014) for the analysis of potential groundwater zone, totally nine parameters have been considered for the study such as, drainage density, elevation, geology, geomorphology, land use and land cover, lineaments-dykes, rainfall, slope and soil pattern. A groundwater potential model (GPM) was implemented based on a set of parameters that describe the natural occurrence of groundwater. This include; lineament length density, drainage length density, geological formations, elevation and slope steepness (Nezar H, 2012).

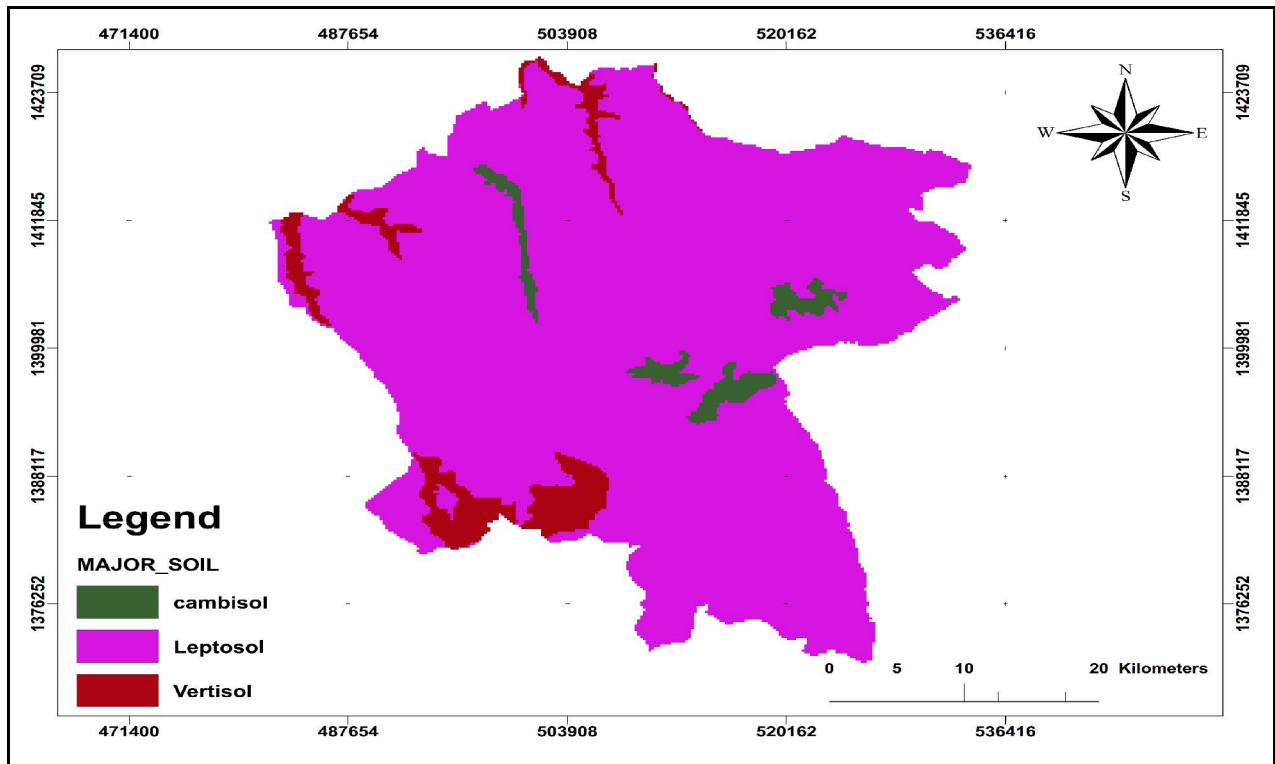
- **Maps of identified factors for GWPZ delineation.**



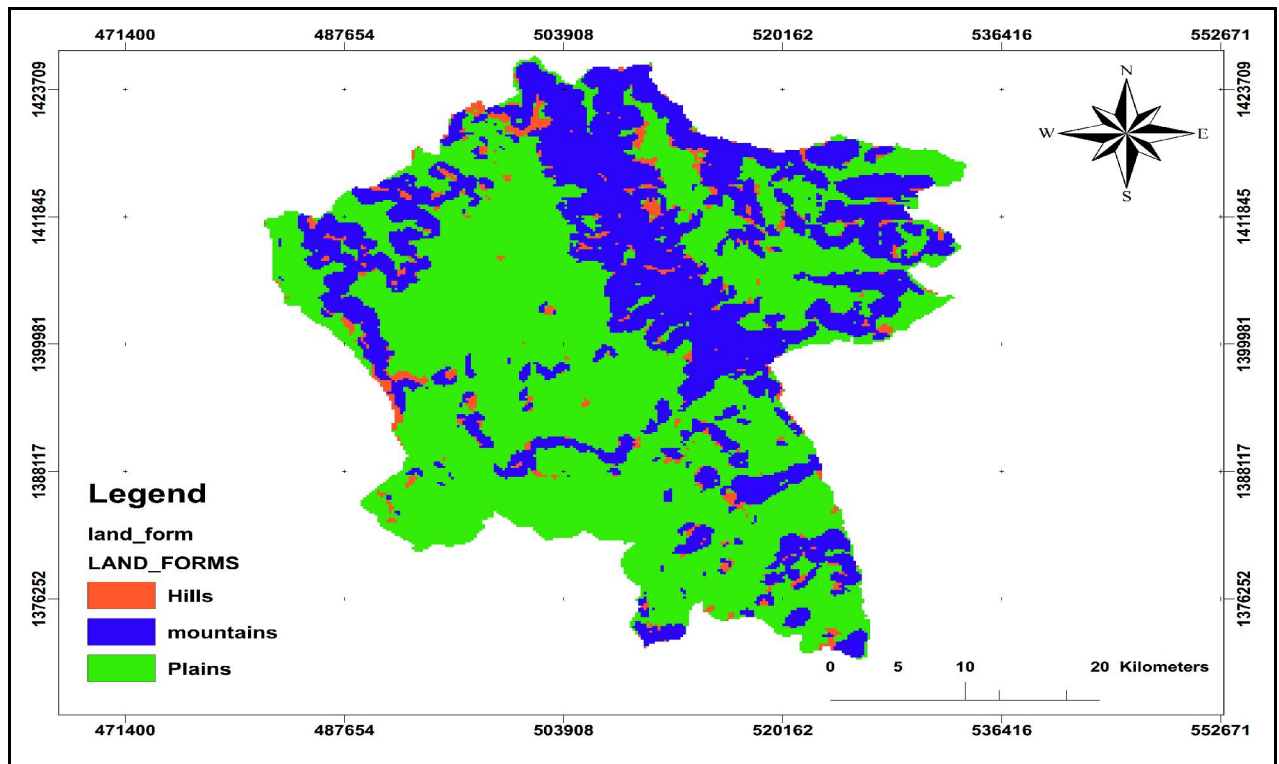
a).Map of Lithology



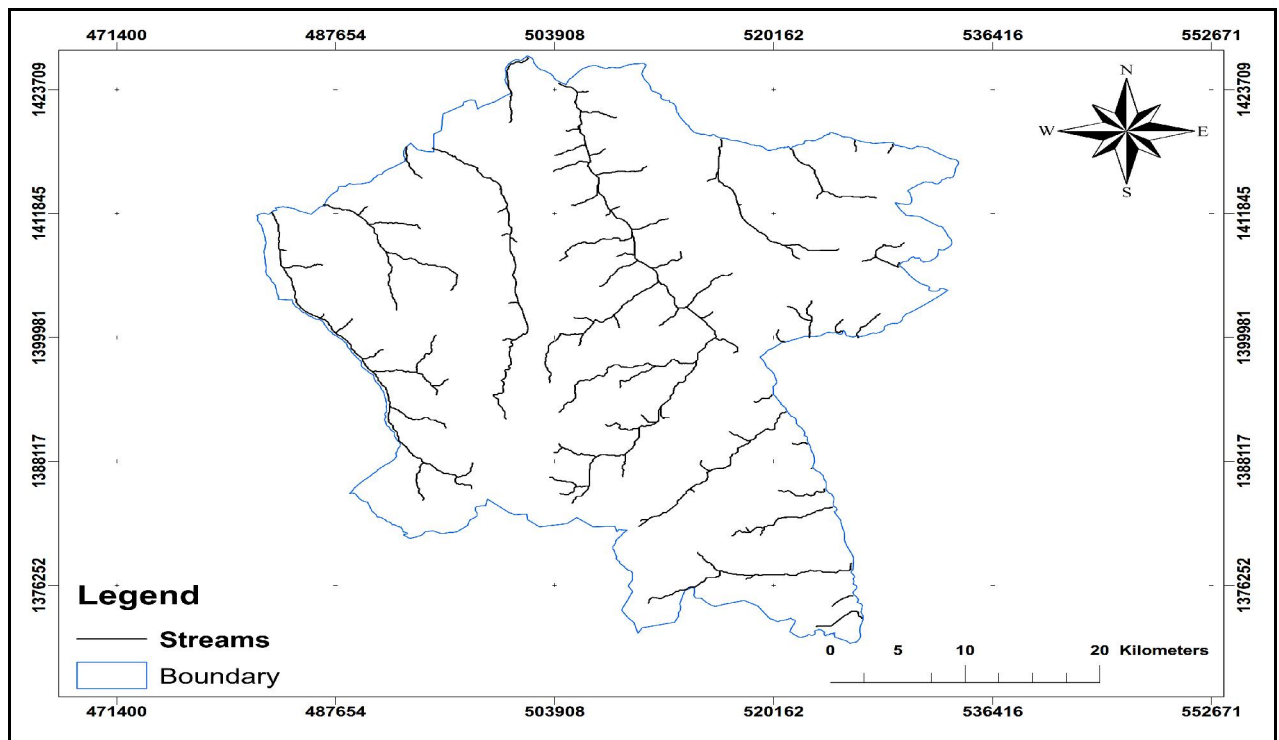
b). Map of Lineaments



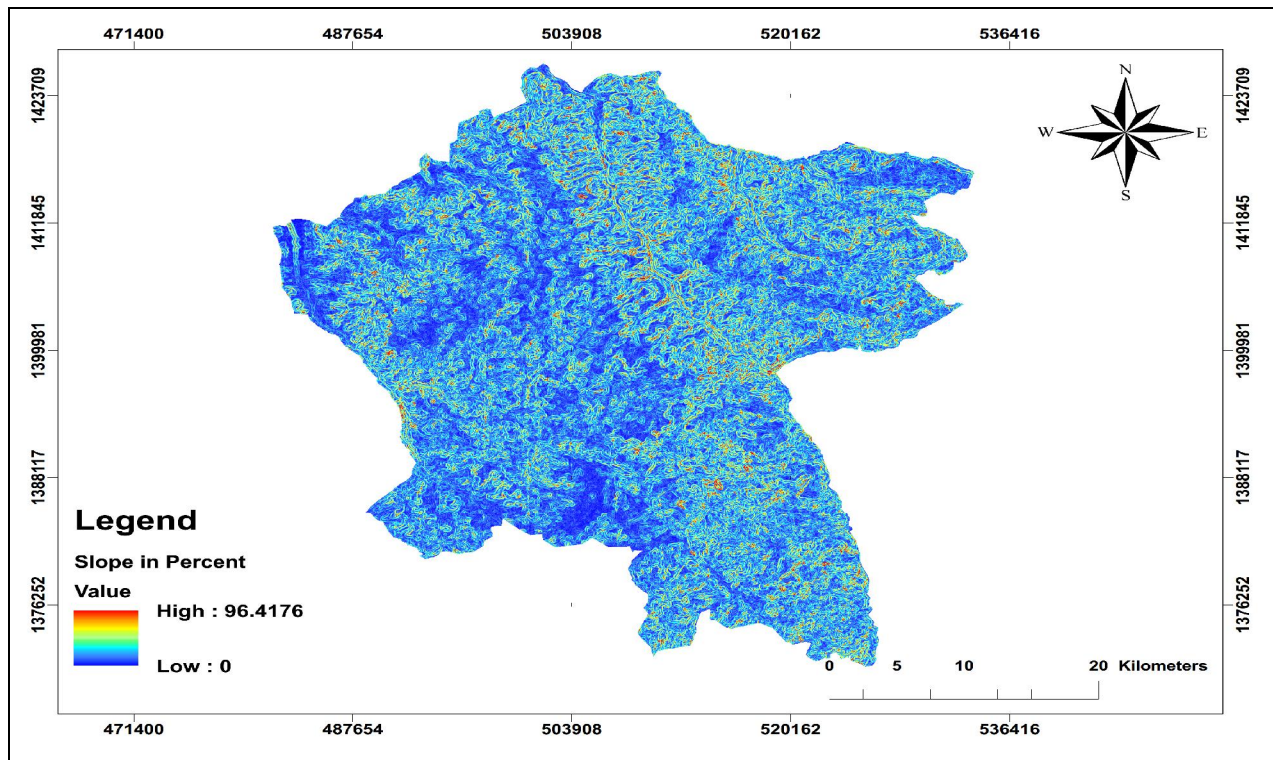
c). Map of Major Soil Types.



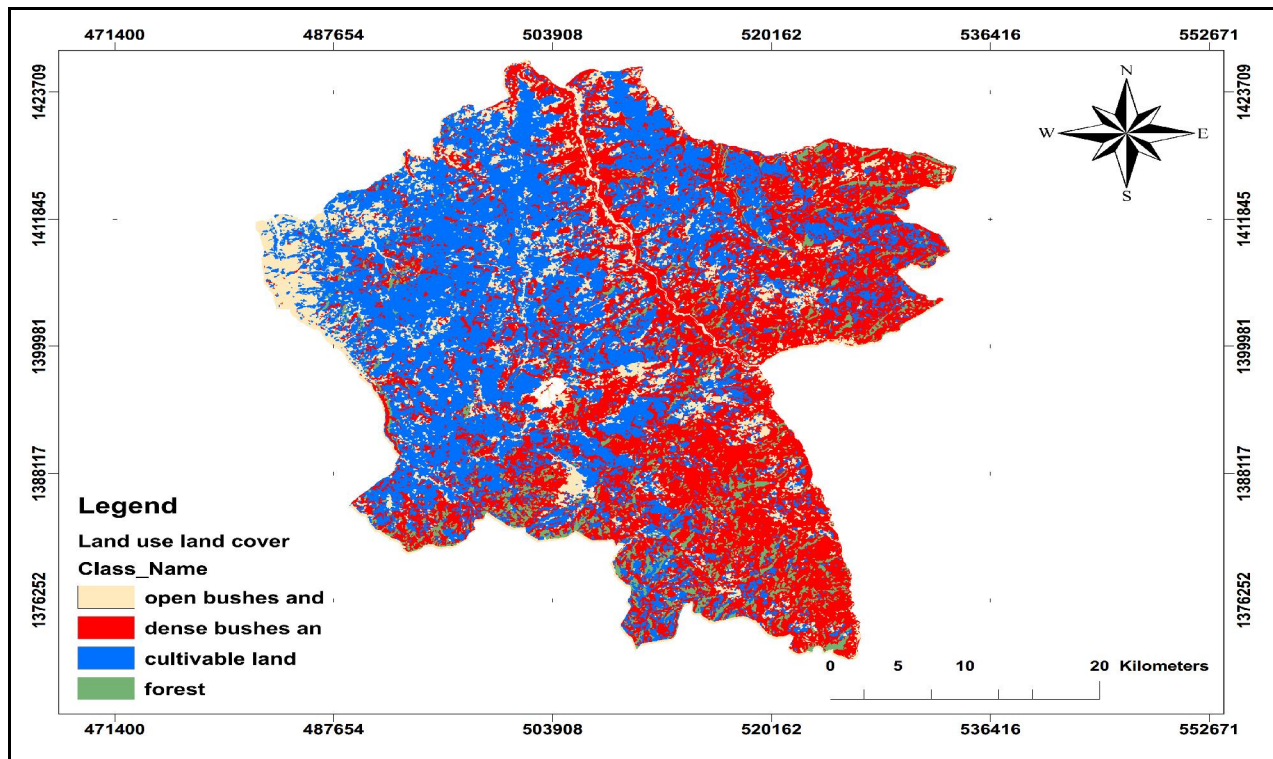
d). Map of Land Forms



e). Map of the Streams Network



f). Map of the Slope in Percent Rise.



g). Map of Land Use Land Cover.

Therefore, this study have been identified and selected seven factors for the occurrence and movement of ground water controlling factors, such as geology (lithology and lineaments), geomorphology/landform, soil, slope, drainage density, and land use/land cover maps. These seven thematic layers are taken into consideration after deep literature review and because of only available data along with field expert advice. Then, following the identification of factors for the study, reliable and appropriate data are collected, processed and analyzed to reach on the intended objectives of the study.

### **3.2.2. Data used/Data sources**

The following data were used for the ground water potential zones delineation and Assessment of the study area.

- River flow data obtained from FDRE Ministry of Water, Irrigation and Electric.
- Digital Geological Maps (Lithology and Lineament) were collected from FDRE Ministry of Water, Irrigation and Electric.
- Soil Map of the study area from (FAO classification) from FDRE Ministry of Agriculture and Animal Resource Development.
- Landsat 8 OLI (with path and row 169/51 scene) from the year 2017 image from USGS website address.
- Space Shuttle Radar Topographic Mission DEM from USGS website.
- Borehole and hand dug well yield data from the concerned organizations.
- Personal fieldwork experience in the area and field visited to verify ground truth data.
- Published and non published literatures and maps.
- Different software's such as ArcGIS 10.1, ERDAS Imagine 9.1, ENVI, Google Earth, MS Word, Excel, etc and instruments like Garmin handheld GPS were used.

### **3.2.3. Data Preparation and Thematic Mapping**

The thematic maps for the investigated groundwater potential zones, controlling factors were prepared using integrated GIS-remote sensing techniques:

Some of the important activities were: delineating of the study area was initially done by extracting the Wereda boundary from shape file data of Ethiopian Administrative Boundary on Wereda level, which have a Projected Coordinate System, UTM, Adindan datum, zone 37 N. After delineating the study

area, base map preparation for each variable was undertaken from Existing digital maps, Satellite Imagery and DEM image. This task is started with bringing all data sources in to a similar spatial reference system as a study area boundary shape file layer. To evaluate groundwater prospect of the area, identification and preparation of the basic baseline maps of land form, soil, lineament density, drainage density, land use land cover (LULC), elevation, slope and lithology of the area was done in which they were used in simulation of the groundwater map suitability.

### **I. Lithology, Lineament and Soil Maps;**

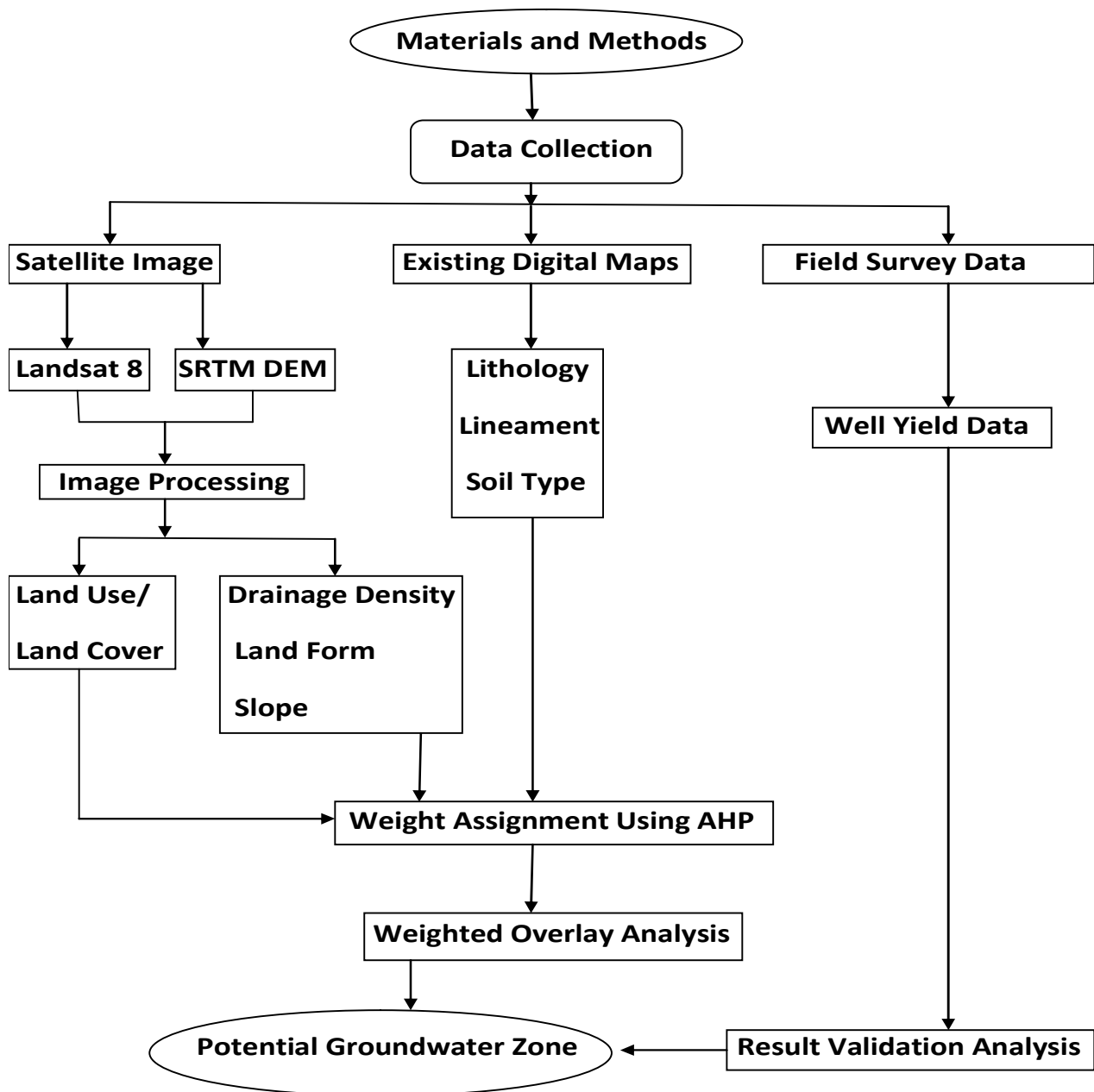
Geology/Lithology plays a vital role in determining the groundwater potential of an area. Shaban et al. (2006) reported that groundwater recharge is greatly influenced by the rocks types, exposed to the surface. Higher fault and lineament density can be used to speculate secondary porosity as most of the faults or fracture system serves as conduits for movement and storage of groundwater. Krishnamurthy et al. (2000) pointed out that a buffer zone of 300 m around fracture system of faults and lineaments are treated as appropriate groundwater recharge and availability zone. And Soil texture has a valuable role in groundwater potential. High permeability levels are observed in gravels and coarse sand; fine sand and loamy soils exhibit moderate permeability whereas lowest permeability is shown by clay and silt soils (Saunders, 2001).

Databases for digital maps of Lithology and Lineament from ministry of WIE and map of Soil type from ministry of AARD were collected. All layers were obtained in a similar spatial reference system, which is Projected Coordinate System, UTM, Adindan datum, zone 37 N. Then by using the study area boundary, that is a shape file format of polygon feature, these maps are clipped on Arcmap 10.1 on Geoprocessing tool.

Lineament density map was computed in and expressed in terms of length of the lineament per unit area (km/km<sup>2</sup>) in the GIS software. Soil map of the study area is clipped from FAO Soil Unit map of Ethiopia. And all these layers are stored in raster format for further analysis.

### **I. Land form, Slope and Drainage Density Maps;**

Geomorphology is the study of the form of the earth (landform), its description and genesis (Gupta, 2003). The geomorphic imprints can be considered as surface indicators for identification of subsurface water conditions.



**Figure 3. 6. Flow chart of the research methodology**

This information provides a reliable base for effective planning, development and management of groundwater resources of an area (Preeja et al.,2008). Land form/ Geomorphology are a study of earth structure and also depict the various landforms relating to the Ground water potential zones and also structural features. With the advent of computer processing and availability of digital elevation models (DEMs), several researchers have since developed digital landform models to map the distribution of physiographic regions using Hammond’s classification.

These models have been applied in number of areas with varying size and physiographic complexity, and have emphasized different classification criteria and raster processing techniques.

Hammond's (1954) landform classification methodology was considered "systematic, relatively objective, applicable to all types of terrain, suitable for medium and small scale mapping and useful for individual and comparative landform studies" (Zakrzewska, 1967). Then by using Digital Elevation Modeling (SRTM DEM) of the area, land form map is prepared on Arc map by employing the Hammond's land form model using a procedure suggested by the Missouri Resource Assessment Partnership (MORAP). Then the extracted land form features are generalized in to major land forms of hills, mountains and plains.

Slope is an important factor for the identification of groundwater potential zones. Higher degree of slope, results in rapid runoff and increased erosion rate with feeble recharge potential (Magesh et al., 2011). For a Slope preparation of the area, a digital elevation model (DEM) with 30 m spatial resolution was used as an input for slope extraction in the ArcMap of ArcGIS, spatial analysis tool. The other determinant factor controlling groundwater occurrence is drainage density. In general, high drainage density reflects high runoff and low infiltration while low drainage density denotes low runoff and high infiltration (Chow, 1964). It was calculated and mapped directly in the Arc map using arc hydro tools and spatial analysis extension tool using SRTM DEM of 30 m spatial resolution.

## **II. Land use/Land cover Map;**

Land use/Land cover is a significant factor affecting recharge processes. Remote sensing and GIS technique provide reliable information for land use/land cover mapping (Selvam and Sivasubramanian 2012). The true color composite (TCC) and false color composite (FCC) images of Landsat 8 OLI were produced for the study area's land use/cover types and served as bases from which land use/cover types were extracted. The supervised image classification, maximum likelihood was utilized to categorize land use/cover types, based on the site knowledge and spectral properties of features present. The remote sensing image classification accuracy assessment was performed to determine if the spectral classes match the information classes as observed during the field survey. For each of land covers about 50 sample land uses were collected randomly on the field using handheld GPS for accuracy assessment. The image classification accuracy assessment was reasonably high; having 80 for both producer and user accuracy, and the overall accuracy of 87.50% and the Kappa Statistics are 0.8069 was achieved.

#### **2.2.4. AHP and weight assignments**

Subsequent to the preparation of all the different thematic maps (including drainage density, soil, land use, slope, lithology, land form, and lineament density thematic maps) with varied attributes, the maps were converted into raster format and then assigned suitable weights in order of their hierarchy in groundwater potentiality using the analytic hierarchy process (AHP) (Saaty1980, 1992).

The weightage employed is in accordance with the respective importance of the map theme to groundwater occurrence following the approach of Saraf and Choudhary (1998). The weights of the individual themes and their associated features were then normalized by the Saaty's AHP and the eigenvector technique was used to reduce the subjectivity associated with the assigned weights. Further, the pair-wise comparison matrices of the assigned weights of the different thematic maps were constructed and computed.

The Consistency Index (CI) of the assigned weights was calculated following the procedure suggested by Saaty (1980) while the Consistency Ratio, which indicates the probability that the matrix ratings were randomly generated, was also computed using the values of Random Consistency Index (RI) which is the average value of CI for random matrices using the Saaty scale was obtained based on the following relations:

$$\mathbf{CI = \lambda - n / n - 1. (7.60 - 7) / (7 - 1) = 0.01}$$

Where n is the number of criteria or factors.

Then, Consistency ratio is calculated as:

$$\mathbf{CR = CI / RI. 0.1 / 1.32 = 0.076}$$

It should be noted that the CR value should be less than 0.10 for consistent weights; otherwise, corresponding weights should be re-evaluated to avoid inconsistency (Saaty 1980, 1986, 1992). For this study, the CR was estimated to be **0.076** which is below the threshold consistency value of 0.10. Furthermore, each of the thematic maps was then assigned weight in the range of 1–1/9 according to Saaty's scale of assignment, which depicts the relative importance of the respective themes to groundwater availability.

### 2.2.5. Integration of layers using Groundwater Potential Model (GPM)

After categorization, a GIS model will be implemented using weighted overlay technique to derive the groundwater promising areas that are suitable for exploration. Determination of the groundwater potential value for a given area involves multiplying each scale value of reclassified layer (parameter) by its weight (or percent influence). The resulting cell values will be to produce the final output raster that represent potential groundwater areas.

This method considers the relative significance of groundwater controlling features and the classes belonging to each feature (Riad et al. 2011) using the following equation.

$$\sum = LitxLity + DLxDLy + SOxSOy + LFxLFy + DDxDDy + SLxSLy + LULCxLULCy$$

Where GWPZ represents the groundwater potential zonation, 'x' and 'y' represents factor maps and factor subclass, respectively, Lit represents Litholgy, DL represents Distance to Lineament, SO is Soil type, LF is Land Form, DD is drainage density, SL is Slope, LULC is land use land cover. From the analysis, groundwater potential zones will be grouped into good, moderate and low prospects.

### 2.2.6. Result validation analysis

Barring few, most studies are ad hoc in nature and demonstrate merely the use of RS data and/or GIS software. Standard methodology and the validation of RS- and GIS-based results with field data are usually missing (Madan K et.al, 2006). Therefore, after the grids in the integrated layer grouped in to different groundwater potential zones by a suitable logical reasoning and conditioning, Second groundwater potential map was produced from existing water sources data and actual well yield data which reflects the actual groundwater potential verified the first groundwater potential map generated by GIS analysis to ascertain the validity of the model develop. For this purpose about 48 groundwater sources (borehole and hund dug wells) were collected from field survey and data from concerned government offices (Sekota town water resource development and sewerage management office and Sekota Wereda Water Resource Development Office), which are developed and managed these water institutions. The obtained data has entered in to Microsoft Excel, then by importing into Arcmap the map was generated that shows the actual wells yield and availability of groundwater of the study area for result validation of delineated potential groundwater zone map using integrated GIS and remote sensing techniques. For a better analysis and visualization of the model validation, the results of both maps were displayed using a graph.

## CHAPTER FOUR

### 4. Results and Discussion

Assessment of potential groundwater zones are being increasingly implemented in the recent years because of increased demand for water. The indicators of groundwater occurrence are related to land use, geology, slope and drainage features of the area. In order to delineate the groundwater potential zones, different thematic maps were prepared. These include lithology, soil type, drainage density, land use land cover, land form, slope and lineament density. Integrated assessment of thematic maps using weighted index overlay method, developed based on GIS techniques has been found to be suitable for delineating groundwater potential zones.

#### 4.1. Analytical hierarchy process and weights assignments

The analytic hierarchy approach (AHP) developed by Saaty (1980) was used in this study as a decision aiding method to finalize the weights assigned to different themes and their respective features used in deciphering groundwater potentiality. AHP is a simple mathematical matrix-based technique that allows users to assess the relative weight of multiple criteria in an intuitive manner. It allows efficient group decision-making, where group members can use their experience, values and knowledge to breakdown a problem into a hierarchy and solve it by AHP steps (Chowdhury et al. 2009). It also incorporates systematic checks on the consistency of judgments, which is one of the strongest points over the other multi-attribute value processes.

##### 4.1.1. Deriving the weights using Analytic Hierarchy Process (AHP)

The weights of each factor were computed statistically using multi-influencing factor (MIF) technique followed by experts' knowledge driven method for assigning ranks to each layers and its sub-classes. The interrelationship among factors classes and assigning of ranks to factor's sub-classes was established based on author's expertise as well as literature review. The methodology for deriving the weights to the thematic layers and their corresponding classes involves three steps viz. Construction of pairwise-comparison matrix, computation of the criterion weight/ priority vector, and the estimation of consistency ratio. These procedures are described as Venkateswaran S. et al (2016) used and explained.

##### Pairwise-Comparison Matrix

The pairwise comparison method was developed by Thomas L Saaty in 1980 for weighting each criterion. In this approach the decision maker has to express his opinion about the value of one single

pairwise comparison at a time. The main problem with the pairwise comparisons is how to quantify the linguistic choices selected by the decision maker during their evaluation.

All the methods which use the pairwise comparisons approach eventually express the qualitative answers of a decision maker into some numbers which, most of the time, are ratios of integers (Evangelos and Stuart 1995). Hence, we require a scale of numbers that indicates how many times more important or dominant one element is over another element with respect to the criterion or property with respect to which they are compared (Saaty, 2008). The pairwise comparison procedure is carried out in three steps: formation of the pairwise comparison matrix, computation of the criterion weights, and estimation of the consistency ratio. The construction of pair wise comparison matrix of factors was prepared by recommendations of four experts from Ministry of Water, Irrigation and Electricity, those who are directly related with the study objective.

### I. Construction of the pair wise comparison matrix

Prior to integration of the datasets, individual class weights and map scores were assessed based on Satty’s Analytic Hierarchy Process (AHP) (Table 4.1); in this method the relative importance of each individual class with in the same map were compared by each other by pair-wise and seven importance matrices were prepared for assigning weight to each class.

**Table 4. 1.The continuous rating scale developed by Saaty (1977)**

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

#### **Construction procedure**

1. Let us consider the criteria that influence the groundwater occurrence process. The factors are disintegrated into various thematic layers that reveal spatial information of the corresponding factors. Here, slope, soil type, lithology, land form, lineament density, drainage density and land use land cover of the study area are considered as the most important influencing factors of the potential groundwater occurrence.
2. The seven criteria are written at top row and in the left column in a 7 by 7 sized- square matrix in such a way that the criteria listed on the left are one by one compared with the each criterion listed on the top of the matrix.

3. The relative importance of each thematic layer is assessed from the linguistic choices (verbal opinion) of a committee of experts and assigned with scores ranging from 1 to 1/9 as per the Saaty scale. These scores are given as inputs at appropriate cells in the matrix. After a left column cells ( the shaded matrix cells by grey color) are assigned a scores by the experts, then the upper triangular matrix is filled with the reciprocal values of the opponent triangle by the researcher (Table 4.2). From the completed matrix of pairwise comparisons, we need to find out eigen vector or priority vector (normalized weight). The diagonal elements of the matrix are always assigned with the number 1. Only upper triangular matrix or lower triangular matrix needs to be filled with relative importance numbers, the other remaining triangle is filled with the reciprocal values of the opponent triangle. Comparison matrix using Saaty's relative importance values and Calculation of Eigen vector/Geometric mean values are shown in table 4.2 and table.4.3.

**Table 4. 2. Comparison matrix using Saaty's relative importance values assigned by Experts.**

layer	dl	lith	so	lf	dd	sl	lulc
distance to lineaments (dl)	1	1	2	3	3	5	9.09
lithology (lith)	1	1	1	3	5	7.14	8
soil (so)	0.5	1	1	2	5	5	6.25
land form (lf)	0.33	0.33	0.5	1	3	3	3
drainage density (dd)	0.33	0.2	0.2	0.33	1	2	5
slope (sl)	0.2	0.14	0.2	0.33	0.5	1	3
lulc	0.11	0.125	0.16	0.33	0.2	0.33	1
<b>Total</b>	<b>3.47</b>	<b>3.795</b>	<b>5.06</b>	<b>9.99</b>	<b>17.7</b>	<b>23.47</b>	<b>35.34</b>

## II. Computation of the criterion weight/ priority vector

This computation operation is carried out in three steps:

1. The values of ratio in each column of the pair wise comparison matrix are summed and written at the bottom of each relevant column.
2. Each element in the matrix is divided by its column total. The resulting matrix is known as normalized pair wise comparison matrix.

- The average of the elements in each row of the normalized pair wise comparison matrix is computed by dividing the sum of normalized scores for each row with the total number of criteria involved in the matrix. The relative weights of the criteria are the average values of the elements in each row of the matrix. That is, if the relative weight of criterion is higher than others, it gets first place among all other criteria.

### III. Estimation of Consistency Ratio

This operation tells us whether our judgments over the factors are consistent or inconsistent. It is done in the following steps.

- The weight of the first criterion is multiplied with the elements in the first column of the original pair wise comparison matrix.
- The weight of the second criterion is multiplied with the elements in the second column of the original pair wise comparison matrix.
- The weight of the third criterion is multiplied with the elements in the third column of the original pair wise comparison matrix and so on.
- Finally the values in each row are summed and each summed value is divided by the corresponding criterion weights determined previously.

**Table 4. 3. Calculation of Eigen Vector/ Geometric mean.**

layer	dl	lith	so	lf	dd	sl	lulc	EV/GM (WEIGHT)	Weight*100
<b>distance to lineaments (dl)</b>	0.29	0.26	0.40	0.30	0.17	0.21	0.26	0.27	27.00
<b>lithology (lith)</b>	0.29	0.26	0.20	0.30	0.28	0.30	0.23	0.27	27.00
<b>soil (so)</b>	0.14	0.26	0.20	0.20	0.28	0.21	0.18	0.21	21.00
<b>land form (lf)</b>	0.10	0.09	0.10	0.10	0.17	0.13	0.08	0.11	11.00
<b>drainage density (dd)</b>	0.10	0.05	0.04	0.03	0.06	0.09	0.14	0.07	7.00
<b>slope (sl)</b>	0.06	0.04	0.04	0.03	0.03	0.04	0.08	0.05	5.00
<b>lulc</b>	0.03	0.03	0.03	0.03	0.01	0.01	0.03	0.03	3.00
<b>Total</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	1	100.00

To find out consistency index (CI), lambda should be found from averaging the values of consistency vector. If the pair wise comparison is a consistent matrix, lambda should be equal to number criteria under consideration (n).

In this study, the lambda value is found out by multiplying the priority vector of each row with the sum of the each column of the original matrix (table.4.2). i.e. the priority vector of first row should be multiplied with the sum of the first column of table.4.1 and so on.

The term “Consistent Index” measures deviation from consistency. Estimation of consistency ratio value is shown in table 4. 4.

**Table 4. 4. Estimation of Consistency Ratio.**

Sum of column in PWC	Eigen vector	Sum of Column * EV
3.47	0.27	0.94
3.795	0.27	1.02
5.06	0.21	1.06
9.99	0.11	1.10
17.7	0.07	1.24
23.47	0.05	1.17
35.34	0.03	1.06
<b>λ (lambda)</b>		<b>7.60</b>

Ultimately, the consistency ratio (CR) is calculated to judge whether the original pairwise matrix scores should be revised or not. The consistency ratio is designed in such a way that if  $CR < 0.1$ , it indicates a reasonable level of consistency in the pairwise comparison matrix and if  $CR > 0.1$ , it indicates inconsistent judgments. Random Inconsistency (RI) indices by Saaty (1980) values are shown in table 4.5.

**Table 4. 5. Random Inconsistency (RI) indices by Saaty (1980).**

N	3	4	5	6	7	8	9	10
<b>RI</b>	<b>0.58</b>	<b>0.9</b>	<b>1.12</b>	<b>1.24</b>	<b>1.32</b>	<b>1.41</b>	<b>1.45</b>	<b>1.49</b>

**CR = 0.1 / 1.32 = 0.076**

From the consistent ratio (CR), it is proved that the judgment is consistent because  $CR < 0.1$  and our pairwise comparison matrix is suitable.

## 4.2. Analysis of input layers for Multi Criteria Evaluation

### 4.2.1. Lithology

Lithology is another factor controlling the quantity and quality of groundwater occurrence in a given area (Bhuvaneshwaran et al. 2015). The lithology influences on both the porosity and permeability of aquifer rocks (Chowdhury et al. 2003). The characteristics of the above mentioned lithologic units with regard to groundwater are;

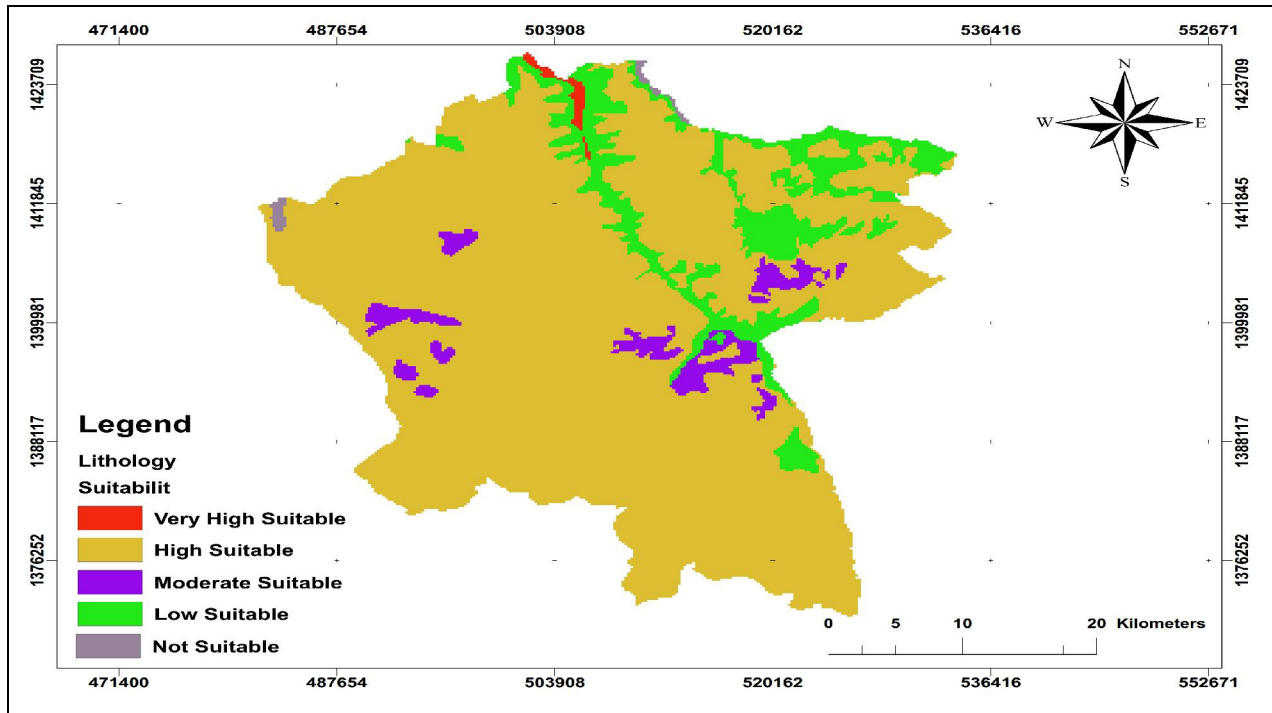
According to Seifu et.al (2018), the lithology of the study area comprises the following five formations. The Aiba Basalts aquifer forms the most productive of the volcanic aquifers in Ethiopia. The Aiba Formation has dual porosity, with groundwater occurring in joints, fractures and scoriaceous layers. Deep boreholes show the presence of narrow but extensive fracture zones with high permeability and low storage. Transmissivity varies between 0.5 and 1400 m<sup>2</sup>/day. Borehole yields range from 5 to 150 l/s, and it is the most productive of the volcanic aquifers. The Antalo Formation has a moderate permeability and productivity. Evidence from boreholes in highland and midlands areas, where the aquifer crops out, shows that groundwater levels can be very deep. In general, these aquifers are typically 500 to 1000 m thick, and are unconfined to semi-confined. The water table is usually 200 to 400 m deep; typical borehole depth is 300 m. In high rainfall highlands, recharge could reach 200 mm/yr. In arid regions it varies between 10 mm/yr and 50 mm/yr.

**Table 4. 6. Assigned weights (according to Saaty's Analytical Hierarchical Process) for Lithology.**

Factor	Classes	Area in Km <sup>2</sup>	Area in %	Groundwater Prospect	Satty Relative Weight (%)	Rank	Consistency Ratio (satty)
<b>Lithology</b>	Quaternary Sediments	6.79	0.41	Very High Suitable	44	5	0.008
	Aiba formation	1411.11	84.6	High Suitable	26	4	
	Ashenge formation	63.19	3.79	Moderate Suitable	17	3	
	Antalo limestone	181.03	10.85	Low Suitable	8	2	
	Adigrat sandstone	5.91	0.35	Not Suitable	5	1	

The basal sequence (Ashangie) aquifer thickness varies up to 500 m. The rugged topography means that the aquifer is not laterally extensive. Depressions in the rugged terrain are areas of groundwater discharge. The aquifer is usually unconfined to semi-confined. Typical borehole yields are between 0.5 and 20 l/s. Transmissivity ranges between 0.5 and 85 m<sup>2</sup>/day. The water table depth is typically

between 100 and 200 m, and borehole depths are typically 150 to 200 m. The contact between this unit and the upper basalt above is characterized by spring discharge.



**Figure 4. 1. Suitability map of Lithology**

The highly cemented Adigrat Formation has low primary porosity, and the top part has been altered by heating by Cenozoic volcanism. Fracturing has created secondary porosity and permeability. The emergence of springs at the contact of the Adigrat sandstone and the overlying volcanic rocks is indicative of the low permeability of the Adigrat Formation. This aquifer is typically 200 to 1000 m thick and is unconfined to semi- confined. The water table is usually 200 to 400 m deep; typical borehole depth is 300 m. In highlands areas with high rainfall, recharge could reach 200 mm/yr. In arid regions it varies between 10 mm/yr and 50 mm/yr.

The productivity of Quaternary Sediments aquifer is controlled by the intergranular permeability of the unconsolidated gravels, sand and clay. They are typically high productivity aquifers, with boreholes up to 60 m depth recorded as yielding more than 6 l/s. The previous investigation aided with drilling on the lake floor shows the occurrence of indicates stiff clay up to 80 m depth. It has moderate to high productivity. According to the previous studies and literatures the most suitable groundwater potential areas are found in the lithology class of quaternary sediments and aiba formations because of its relative good capacity of infiltration and water recharge.

The quaternary sediments found in the northern part of the area, which accounts 6.79 Km<sup>2</sup> (0.41 %) from the total area of the wereda. The second productive aquifer aiba formation covers large area about 1411.11 Km<sup>2</sup> (84.6 %), this formation found in all parts of the area, Adigrate sandstone identified as the least productive aquifer for the occurrence of groundwater, this class accounts about 5.9 Km<sup>2</sup> (0.35 %) from the total area, and it is found along the north and north east part.

However, each one of those lithological units has no equal importance in determining and controlling groundwater. So, similar approach was used to determine weighted value among lithological units (Table 4.6). And the results are put in order as: Quaternary sediments > Aiba formation > Ashenge formation > Antalo limestone > Adigrat sandstone, respectively.

#### 4.2.2. Lineaments Density

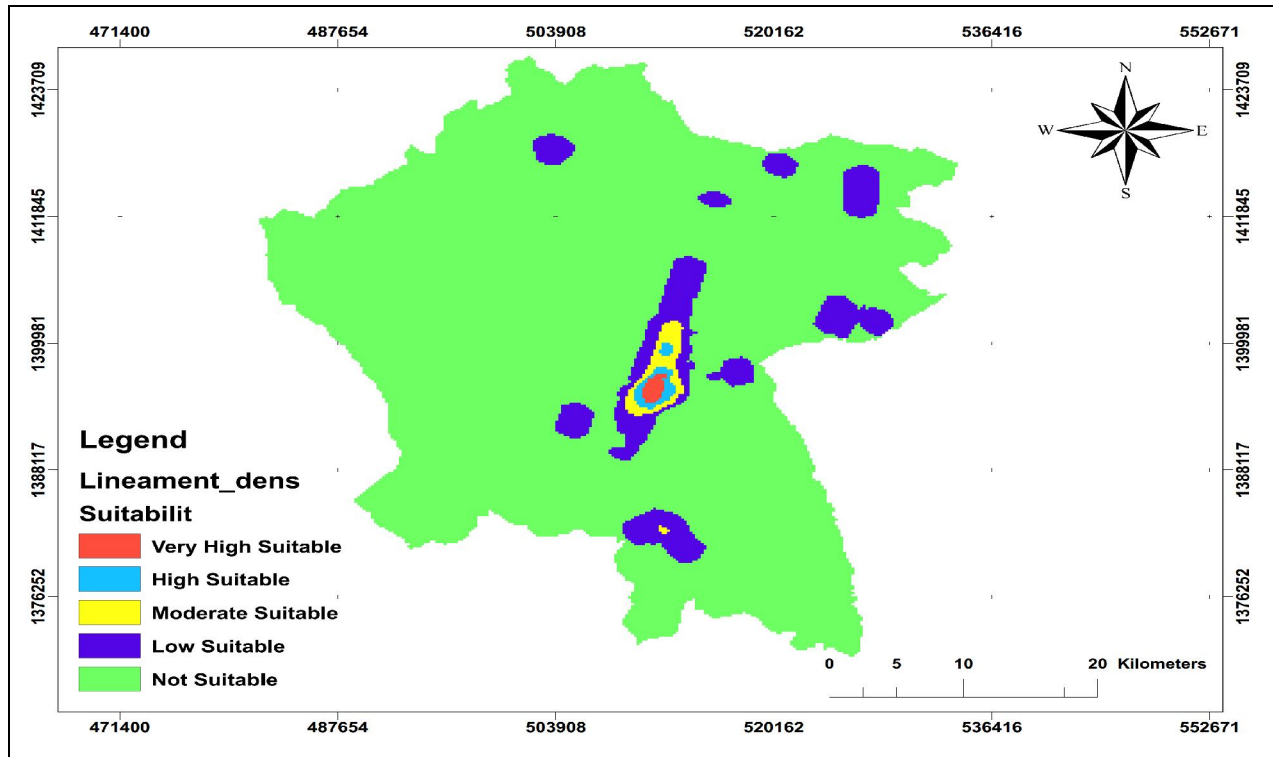
Lineaments like joints, fractures and faults are hydrogeologically very important and may provide the pathways for groundwater movement (Sankar, 2002). The lineament-density map reveals the variations in the potential for obtaining groundwater in the area. According to Stephen Mabee et al., (1994), from a study of regional-scale lineament analysis for fractured bedrock aquifers, concluded that wells located on or near fracture-correlated lineaments are generally more transmissive. High porosity and hydraulic conductivity zones are associated with lineaments have found that the normalized transmissivity near the lineaments is high. A good relationship exists between higher fracture densities and higher well yields.

**Table 4. 7. Assigned weights (according to Saaty's Analytical Hierarchy Process) for Lineament Density.**

Factor	Classes	Area in Km <sup>2</sup>	Area in %	Groundwater Prospect	Satty Relative Weight (%)	Rank
<b>Lineament Density</b>	0.9 to 1.075	3.5	0.21	Very High Suitable	55	5
	0.75 to 0.9	5.81	0.34	High Suitable	27	4
	0.4 to 0.75	12.89	0.78	Moderate Suitable	14	3
	0.2 to 0.4	112.03	6.71	Low Suitable	5	2
	0.0 to 0.2	1534.2	91.95	Not Suitable	4	1

Generally, it is expected that the thickness of weathered/fractured rocks is greater along the lineaments hence, the lineaments are assumed to have a control on the availability of groundwater. A number of NW–SE running faults are also observed in the Sekota area. The prominent fault among the Sekota

complex structures is the regional fault that run SSE ward from around Sekota and run towards Hamusit town.



**Figure 4. 2. Suitability map of lineament density.**

The faults are responsible for block rotation, lateral disruption of lithologies, and emergence of springs in the area (Seifu, 2013). The lineaments present in the study area have varying dimensions. Based on the concentration and length of lineaments, a lineament density map was prepared. Lineament density map is a measure of quantitative length of linear feature expressed in (Km/Km<sup>2</sup>).

Lineament density of an area has direct influence on groundwater prospectiveness of that area. In present study area very high lineament density is observed in the Eastern direction from Sekota town with a value ranging from 0.9 to 1.09 km/km<sup>2</sup> having good groundwater potential, whereas area with very low lineament density (0-0.25) is having poor groundwater potential. The entire map classified in five categories as shown in Fig.4.2.

### **4.2.3. Land from**

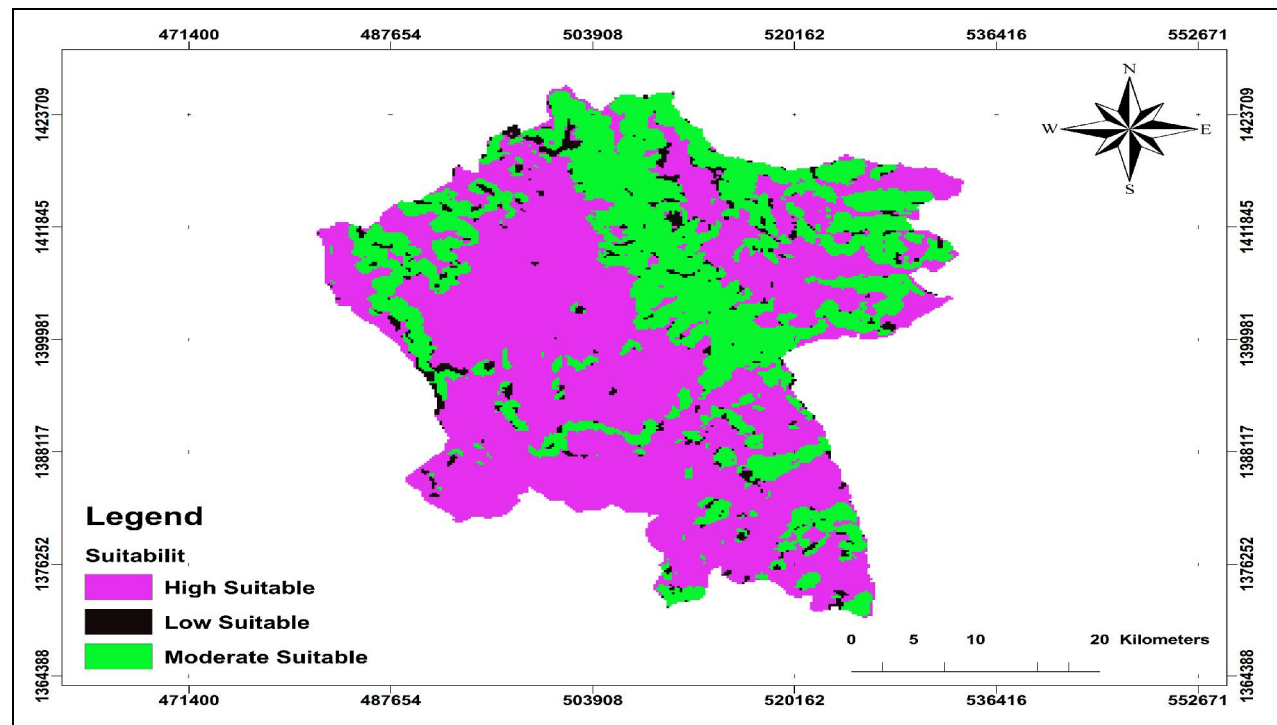
Geomorphology is the systematic description and analysis of landscapes and the processes that change them. It is considered as one of the highly influencing factors in groundwater occurrence. The geomorphic imprints can be considered as surface indicators for identification of subsurface water

conditions. This information provides a reliable base for effective planning, development and management of groundwater resources of an area (Preeja et al., 2008).

**Table 4. 8. Assigned weights (according to Saaty's Analytical Hierarchy Process) for Land Form.**

Factor	Classes	Area in Km <sup>2</sup>	Area in %	Groundwater Prospect	Satty Relative Weight (%)	Rank	Consistency Ratio (satty)
Land Form	Plain	1041.82	62.46	High Suitable	67	5	0.02
	Mountain	564.04	33.8	Moderate Suitable	24	3	
	Hills	62.2	3.72	Not Suitable	9	1	

The volcanic terrain of Ethiopia comes in variety of landforms that is of significant importance to groundwater occurrence and movement (Seifu, 2013). In this study, three main geomorphological units were identified and delineated. These are plains, mountains and hills covering about 1041.82 km<sup>2</sup> (62.46 %), 62.2 km<sup>2</sup> and 564.04 km<sup>2</sup> (33.8 %) of the study area, respectively.



**Figure 4. 3. Suitability map of Land from.**

Plains are relatively level area of the Earth's surface exhibiting gentle slopes and small local relief. Plains vary widely in size. The smallest occupy only a few hectares, whereas the largest cover hundreds of thousands of square kilometers.

Mountains are Landform that rises prominently above its surroundings, generally exhibiting steep slopes, a relatively confined summit area, and considerable local relief. Mountains generally are understood to be larger than hills, but the term has no standardized geological meaning. Very rarely do mountains occur individually. In most cases, they are found in elongated ranges or chains.

On the other hand, hills are usually rounded natural elevation of land lower than a mountain – lower in altitude and having less local relief. It has very little level land surface; however, it is usually much less steep than a mountain (Umeuduji, 2017). These geomorphological features based on the respective significance with respect to groundwater occurrence are weighted (see Table 4.8).

#### 4.2.4. Drainage Density

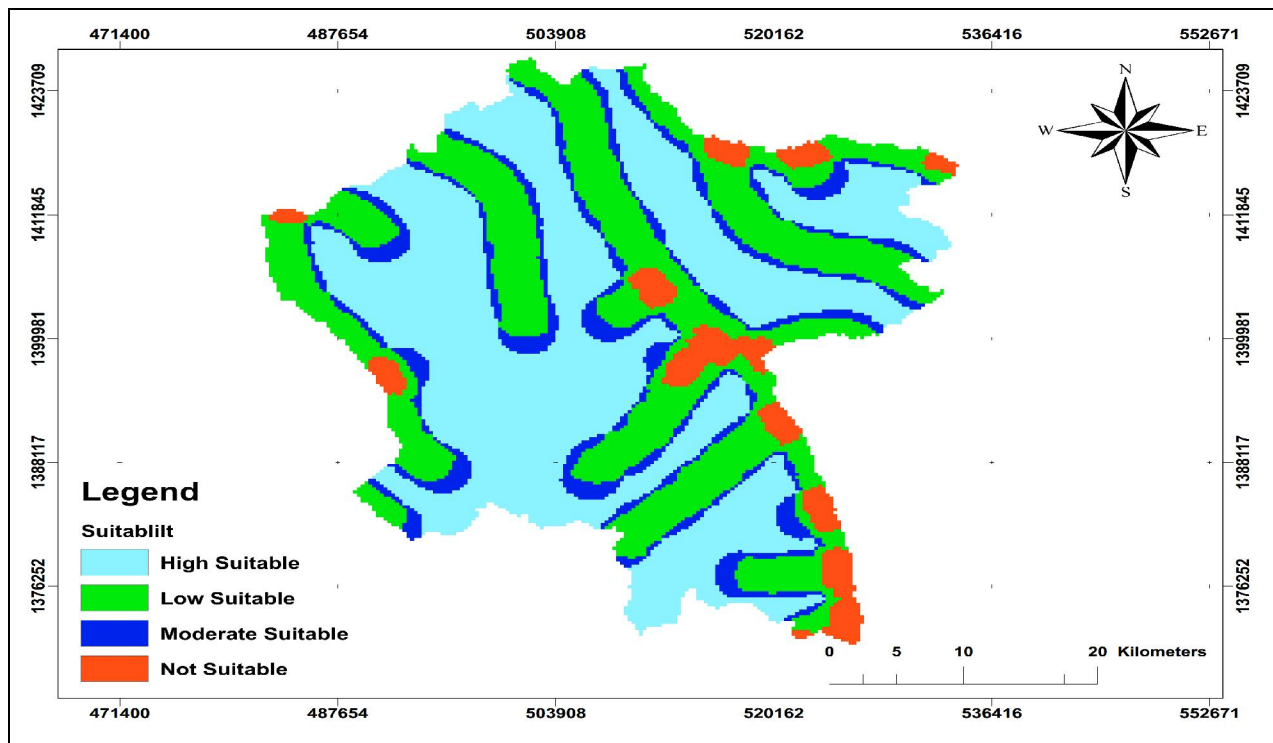
Drainage can be defined as the design formed by the aggregate of drainage ways in an area regardless of whether they are occupied by permanent streams. Drainage density plays a crucial role in groundwater occurrence. It characterizes the run off in the area and contributes to groundwater recharge. It is the overall length of the streams and rivers divide by catchment area (Sajjad et al. 2014).

**Table 4. 9. Assigned weights (according to Saaty's Analytical Hierarchical process) for Drainage Density.**

Factor	Classes	Area in Km <sup>2</sup>	Area in %	Groundwater Prospect	Satty Relative Weight (%)	Rank	Consistency Ratio (satty)
<b>Drainage Density</b>	0 to 0.1	809.29	48.51	High Suitable	59	5	0.09
	0.1 to 0.2	208.22	12.48	Moderate Suitable	26	4	
	0.2 to 0.4	551.54	33.1	Low Suitable	10	3	
	0.4 to 0.76	99.22	5.95	Not Suitable	5	1	

Drainage density is an important groundwater occurrence parameter as it determines the amount of water the rate of runoff after a rainfall period. It provides a numerical measurement of landscape dissection and runoff potential (Ramu and Vinay, 2014). The low drainage density indicates the prevalence of highly resistant/impermeable strata, whereas, a high drainage density prevails in

the weak/permeable rocks in a region (Magesh et al. 2012). the higher the drainage density, the higher would be runoff and the lower the drainage density, and the higher is the probability of recharge or potential of groundwater occurrence. Figure 6, shows a stream network from which drainage density was derived, and drainage density classes on the basis of their significance in groundwater occurrence. The drainage density of a study area was investigated and categorized into four subclasses, i.e., not suitable, low, medium and high.



**Figure 4.4. Suitability map of Drainage Density.**

A high suitable area was found in a very low drainage density that covers 48.51% of the study area, while a very high drainage density occupies 5.95 % of the area that is not suitable for occurrence of groundwater. Moderate and low suitable areas also found to occupy 12% and 33.1% of the study area, respectively (see Table 4.9). By implication, groundwater is expected to be more in the regions of low and very low drainage density, fair in the region of moderate drainage density, and low in areas of high and very high drainage density. Therefore, a low chance of groundwater occurrence was expected in the eastern and south-eastern fringe of the study area compared to other parts of the study area.

#### 4.2.5. Soil Type

Soil is formed from the weathering of rocks and minerals. Soil moisture consists of organic and inorganic materials, water and air (CGWB, 2008). Soil type is one of the principal factors that determine the occurrence of groundwater (Ramu and Vinay, 2014). The permeability of the soil is directly related to the effective porosity of the soil and is greatly influenced by grains shape, size grains, adsorbed water, voids ratio, the degree of saturation and impurities present (Punmia et al, 2005).

The infiltration of surface water into the ground is dependent on the porosity and permeability of the soil in a particular area. Porous or permeable area containing large amount of sand or gravel permits approximately 50% of precipitation to infiltrate the ground and contribute to groundwater (Nagarajan and Singh, 2009). Less permeable areas have as little as five percent of water seeping in (Ramu and Vinay, 2014). The rest becomes runoff or evaporates.

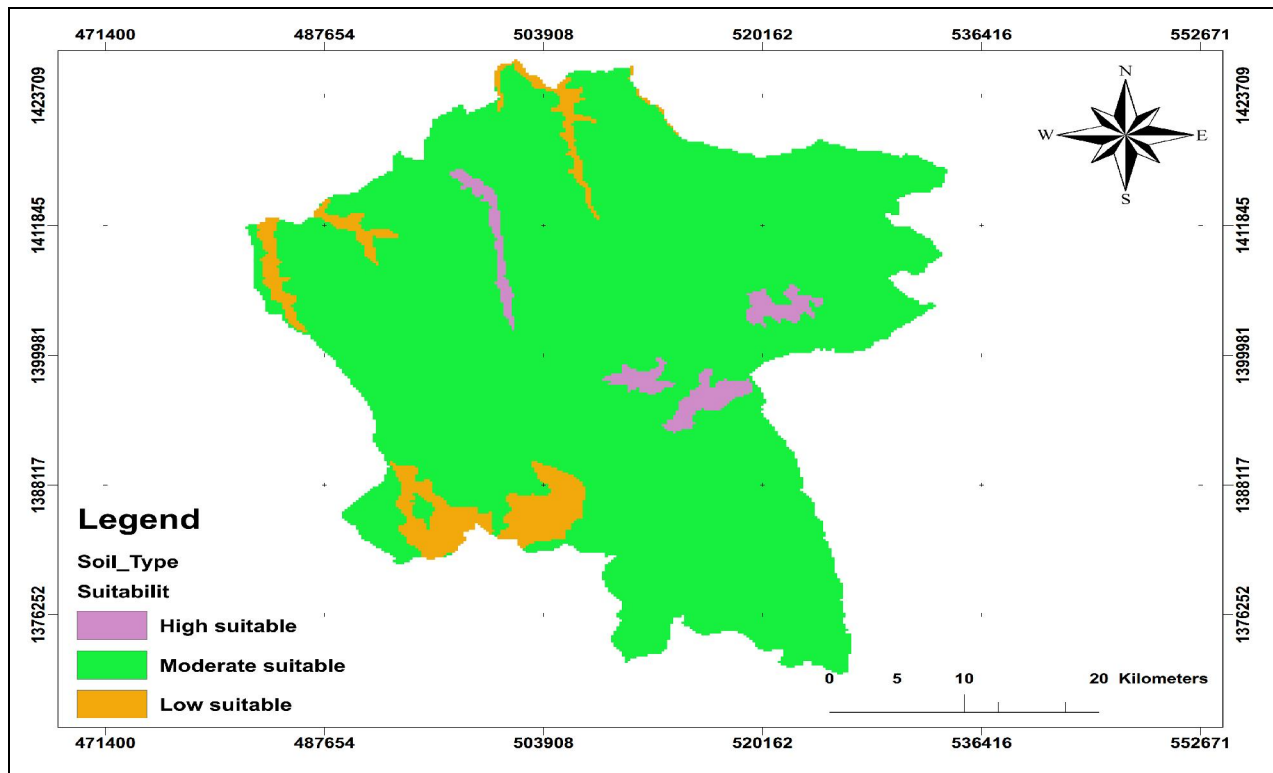
**Table 4. 10. Assigned weight (according to Saaty's Analytical Hierarchy process) for Soil Type.**

Factor	Classes	Area in Km <sup>2</sup>	Area in %	Groundwater Prospect	Satty Relative Weight (%)	Rank	Consistency Ratio (satty)
Soil Type	Cambisol	45.9	2.75	High Suitable	67	5	0.017
	Lepthosols	1528	91.6	Moderate Suitable	24	4	
	Vertisols	94.24	5.6	Low Suitable	9	1	

In line with FAO and according to the Ethiopian Ministry of Water Resources, Irrigation and Electricity Soil classification, the prevailing soil types in the study area were classified in to three major groups, namely, cambisols, lepthosols and vertisol soils covering 45.91 km<sup>2</sup> (2.75 %), 1528.06 km<sup>2</sup> (91.6 %) and 94.24 km<sup>2</sup> (5.65 %) of the total study area, respectively.

Lepthosol includes soils that are very shallow (less than 25 cm) with continuous rock occurring at or near the surface, and soils that are very gravelly (with less than 20 percent soil particles) (FAO, 2014). Vertisols are expansive clayey soils that shrink and swell extensively with changes in moisture content. Cracking, gilgal microrelief, and high clay content are common attribute of vertisols, but these properties are not exclusive to them (Ahmad, 1983). And Cambisols are young soils with beginning

subsurface soil development. The typical parent material is medium and fine-textured, derived from a wide range of rocks, mostly in colluvial, alluvial or Aeolian deposits (FAO 2014).



**Figure 4. 5. Suitability map of Soil Type.**

The movement and infiltration of water in these three types of soil is not same so based on its property the weightages have been assigned by the experts’ opinion and by referring written materials. Therefore higher weightage was given to soils with relatively higher permeability; thus cambisols units are assigned a weightage factor of 0.67 compared with that of vertisol with a factor of 0.09 indicating lower groundwater potentials, while leptosols have intermediate value of 0.27 representing moderate groundwater potential. (Table 4.10).

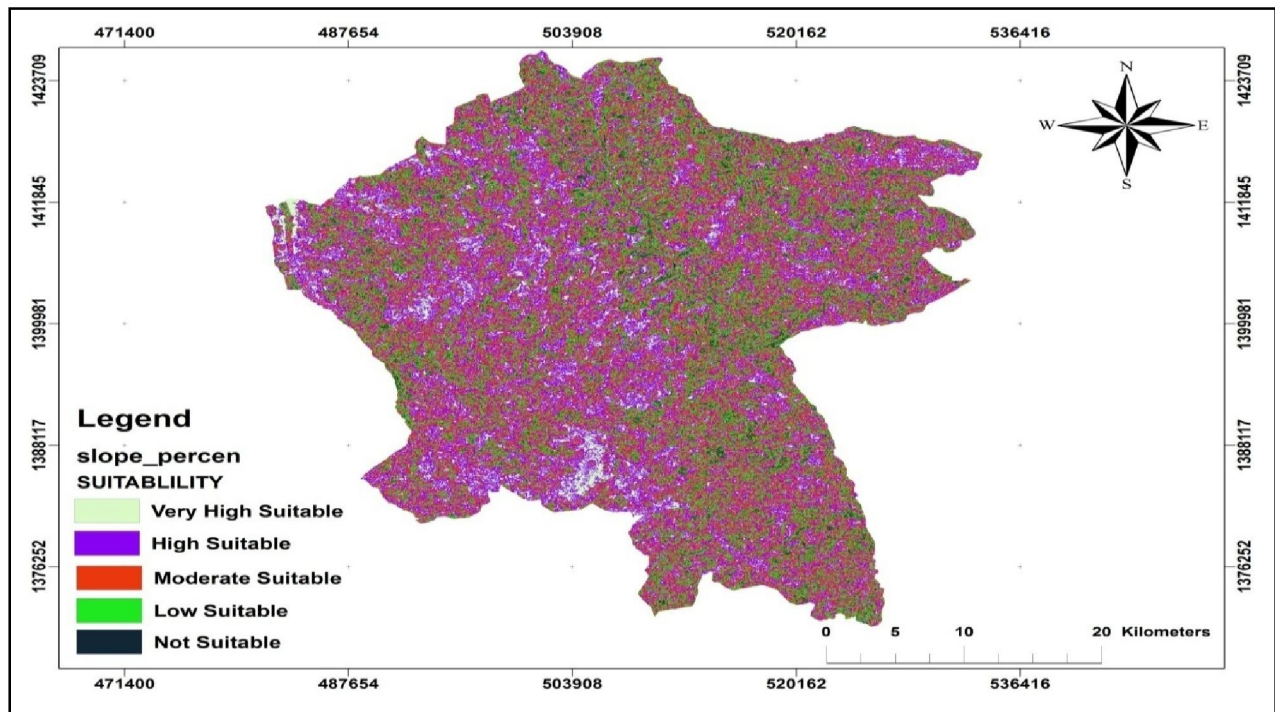
#### **4.2.6. Slope**

Slope influences the surface and sub-surface flow of rainwater and its recharge to the groundwater storage. The gentle slope areas have slow surface runoff, which allows more time for water to infiltrate the ground, whereas, the areas with steep slope facilitates high runoff, thereby permitting less residence time for rainwater and hence reasonably less infiltration (Krishnamurthy et al. 1996).

**Table 4. 11. Assigned weights (according to Saaty's Analytical Hierarchy process) for Slope.**

Factor	Classes	Area in Km <sup>2</sup>	Area in %	Groundwater Prospect	Satty Relative Weight (%)	Rank	Consistency Ratio (satty)
Slope (%)	0 to 3	570.17	34.2	Very High Suitable	49	5	0.05
	3 to 8	521.17	31.2	High Suitable	27	4	
	8 to 15	336.88	20.2	Moderate Suitable	14	3	
	15 to 30	194.19	11.63	Low Suitable	7	2	
	>30	46.19	2.77	Not Suitable	3	1	

The gradient of slope is one of the factors that directly influence the infiltration of rainfall in that steeper slopes generate less recharge because water runs rapidly off the surface during rainfall, allowing insufficient time to infiltrate the surface and recharge the saturated zone. Slope is an important factor for the identification of ground water potential zones in any region. A steeper slope causes less recharge because of rapid runoff during rainfall, allowing insufficient time to infiltrate the surface and recharge the saturated zone (Rokade et al. 2007). Rainfall is the main source of groundwater recharge in this area.



**Figure 4. 6. Suitability map of Slope.**

Based on the FAO classification of slope percents, states that areas with 0-3% of slope are excellent from the point of view of groundwater occurrence, while the areas with greater than 30% slope have poor groundwater prospect.

The slope amount derived from DEM has shown that suitable area is found in the central part with slope 0 % to 8% in plain area. In the nearly level slope area (0-3) percent, the surface runoff is slow allowing more time for rainwater to percolate and consider good groundwater potential zone, where as strong slope area (> 30 %), facilitate high runoff allowing less residence time for rainwater hence comparatively less infiltration and poor groundwater potential. The entire slope map is divided into five categories. Figure 4.6, provides the slope condition of the study area. The slope value of the study area was observed to range from 0.0 % to 96.4 %. Table 4.11 shows that the study area is dominated by the slope categories that was good for groundwater occurrence, with 0.00 to 8 % slope occupying 65.4% of the area, that facilitated very high chances of groundwater occurrence. The slope category of >30% occupying only 2.77 % of the study area, that was poor for groundwater occurrence.

#### 4.2.7. Land use land cover

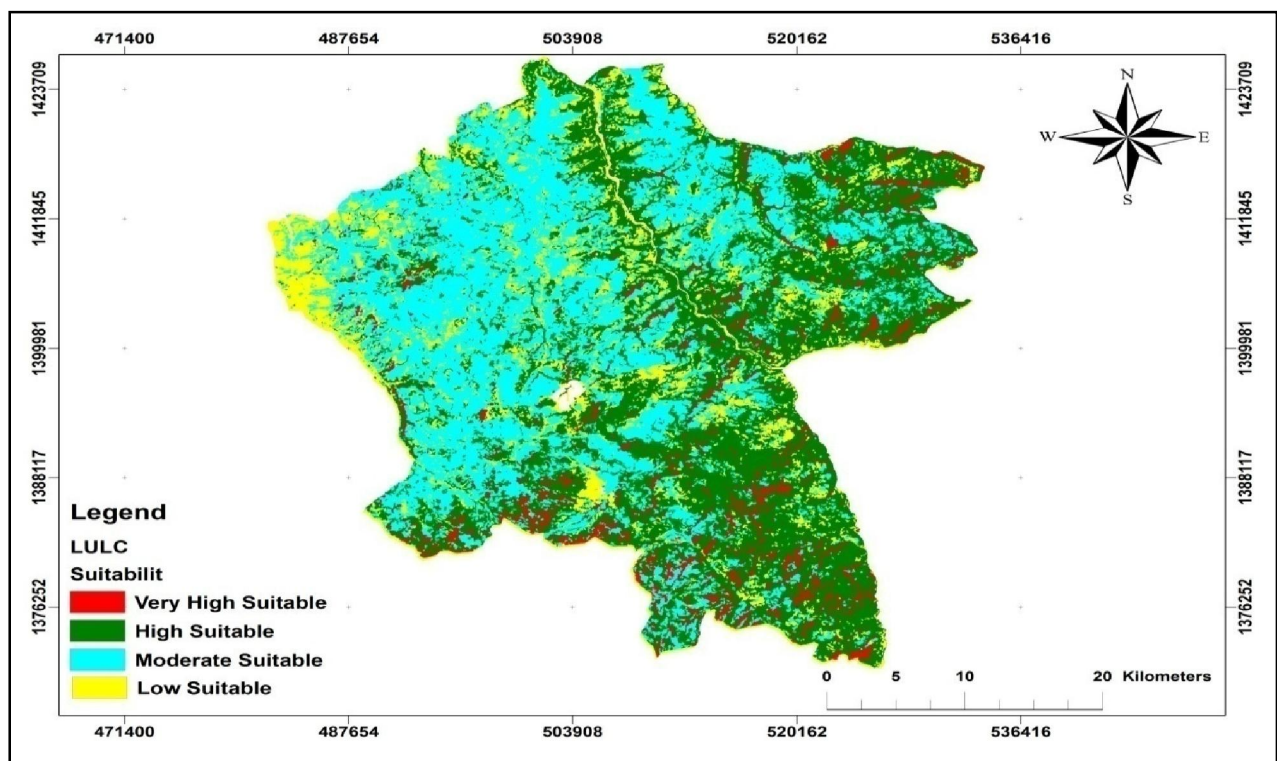
Land use can be defined as the use of lands by humans, usually with emphasis on the functional role of land in economic activities. Land use in an abstraction not always directly observable by even the closest inspection. One cannot see the actual use of a parcel of land, only the physical artifacts of that use (Campbell, 2002). In contrast, land cover, in its narrowest sense, often designates only the vegetations, either natural or manmade, on the earth's surface at a specific time of observation.

**Table 4. 12. Assigned weights (according to Saaty's Analytical Hierarchy process) for LULC.**

Factor	Classes	Area in Km <sup>2</sup>	Area in %	Groundwater Prospect	Satty Relative Weight (%)	Rank	Consistency Ratio (satty)
<b>Land Use / Land Cover</b>	Forest	96.49	5.78	Very High Suitable	58	5	0.06
	Dense BSH Land	666.1	39.92	High Suitable	26	4	
	Cultivated Land	669.78	40.15	Moderate Suitable	12	3	
	Open BSH Land	229.3	13.74	Low Suitable	5	1	
	Masked(built up)	6.7	0.40	No data	0	0	

In a much broader sense, land cover designates the visible evidence of land use, to include both vegetative and non vegetative features. In this meaning, sense forest, powered land, urban structures all constitute land cover. Whereas land use in concrete, and therefore is subject to direct observation Discrimination of different land use/land cover classes is feasible using multi-spectral data from satellites with its synoptic coverages near real time, base line information and its relative economy over other methods of survey (Gautam and Narayanan; 1983).

Using remotely sensed data, the accurate assessment of existing land use/land cover patterns and their spatial extent in the study area is essential for conservation and management of water and natural resources. Remote sensing provides excellent information with regard to spatial distribution of vegetation type and land use in less time and low cost in comparison to conventional data.



**Figure 4. 7. Suitability map of Land Use/Land Cover.**

LULC of study area has been analyzed for Landsat 8 image using false color composite of band 5, 4, and 3 images. Supervised classification using maximum likelihood algorithm is used. The study area shows that major portion in land use is cultivated land covering area 669.78 km<sup>2</sup> with 40.15 % of area coverage. Dense bushes and shrubs land covering 666.1 km<sup>2</sup> (39.91%) of an area, open bushes, shrubs and grass lands together covers area of 13.74%, and masked areas for built up and some river course of

an area has an aerial coverage of 0.40% from a total study area as depicted in Fig.4.7. Masking of built up area and some river course areas was done to differentiate these two land uses from grass land having similar signature during image classification process.

Forest, dense bushes and shrubs land and cultivable land, contribute from highly to moderately for rainfall infiltration, thus suggesting a better chance of groundwater occurrence. Open bushes and shrubs land and grassland facilitated high runoff and evaporation, implying a low contribution to groundwater occurrence (Table 4.12).

### 4.3. Integration of layers using Groundwater Potential Model (GPM)

The groundwater potential map was produced from an integration of the layer maps of the groundwater controlling features and an assigning of the weighted values based on their significance in groundwater occurrence. The GIS-based Weighted Overlay Analysis method was employed to integrate the groundwater controlling parameters according to their respective weights and to drive a groundwater potential zones map.

The groundwater potential zones were, therefore, determined after a consideration of the weightage of each class of each groundwater controlling parameter and fusing them with all the GIS layers. Table 7 provides information regarding the weight of each investigated parameter, and the score of their respective categories.

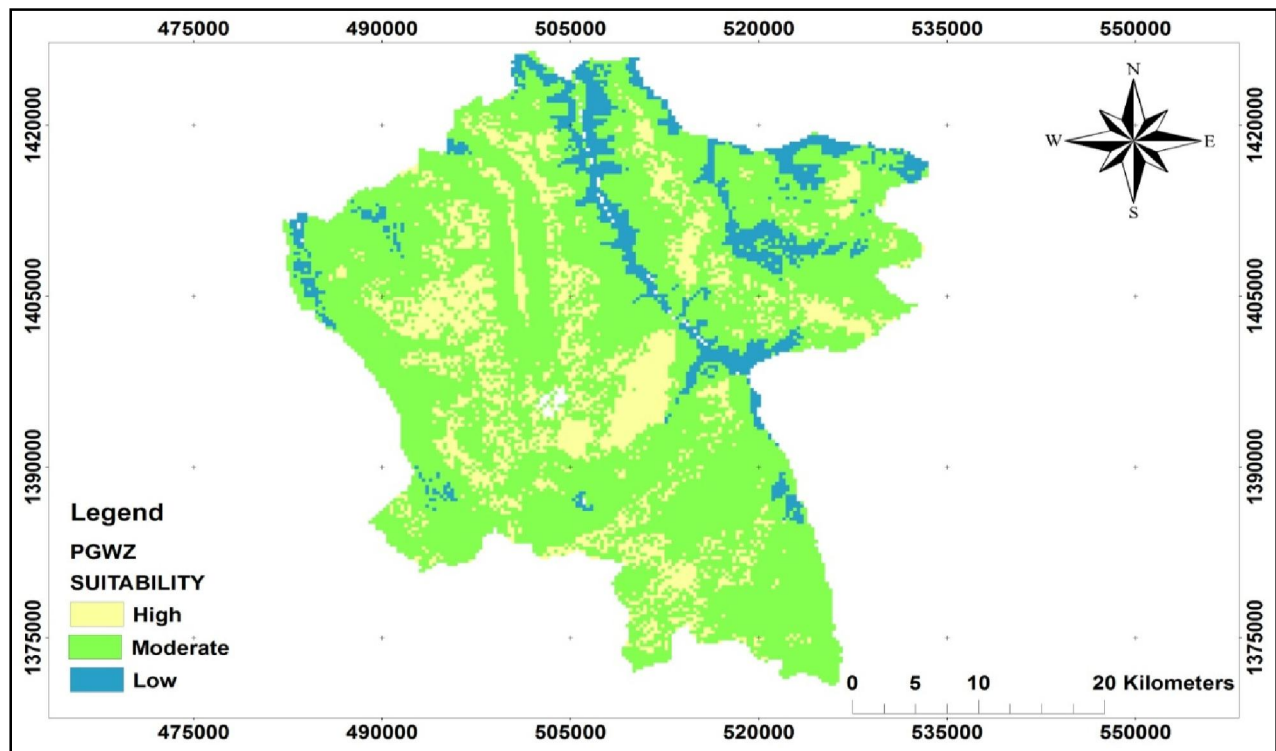
**Table 4. 13. Groundwater Potential Zones.**

R.N	GW Potential	Area in km <sup>2</sup>	Area in %
1	HIGH	315	18.57
2	MODERATE	1196	71.4
3	LOW	157	10.03
TOTAL		1668	100

The groundwater potential zones for the study area were generated through the integration of various thematic maps viz., drainage density, slope, lithology, soil, lineament density, land form and land use land cover using remote sensing and GIS techniques. The demarcation of groundwater potential zones for the study area was made by grouping of the interpreted layers through weighted multi influencing factor and finally assigned different potential zones.

The groundwater potential zone of this study area can be divided into three grades, namely High, Moderate and low. The groundwater potential map (Fig. 4.9) demonstrates that the high groundwater potential zone is concentrated highly in central and the south-eastern region of the study area due to the distribution of plains and agricultural land with moderate to high infiltration ability.

As the result shows that high potential in cultivable land is due to the land that has been used for cultivation is relatively in areas with low drainage density, the land form is plain, having low slope and the soil is relatively having better permeability. Moreover, lithologically this zone is related to Aiba formation and Ashenge formation and its slope is very gently sloping (3-8 percent). High lineament density is found in this area of the study. As the field observation and well yield data shows, two shallow wells namely Dibeshenu and Akimatslya have a high potential groundwater with 5.1 and 5.6 liters per second is found on this area. Therefore, additional and deep explorations should be conducted in this zone, because it is near or at a few distances from the Sekota town which faces a drinking water supply shortage.



**Figure 4. 8. Map of Potential Groundwater Zone.**

And also another high and moderate potential area is delineated towards the southern part of the study area, from a factors point of view it is located far from lineaments or in area with low lineament

density, specifically it is around Woleh rural Kebele, currently it is served as the major and only source of drinking water for the neighbor Sekota town. The zone without required potential is located in areas where slope is strongly sloping; geologically it is found at antalo formation, which has poor productive for the groundwater occurrence. This indicates that, lineament, lithology and slope play a vital role in groundwater augmentation.

Moreover, the concentration of drainage density and lineament density also helps the infiltration ability of the groundwater system. Finally, the cumulative effect of the weighted multi influencing factors through overlay analysis in GIS platform revealed the mapping of groundwater potential zones in the study area.

#### 4.4. Validation of the model

For validation purpose a total number of 48 groundwater sources data from boreholes and hand dug wells existed in the study area have been collected. Among these boreholes and handdug wells, only 24 wells have a depth and yield data, while the remaining 24 wells are with no reliable data, that is no longer considered for groundwater level monitoring. The data was received in a Microsoft Excel file and imported onto ArcMap 10.1 to create a shape file for boreholes.

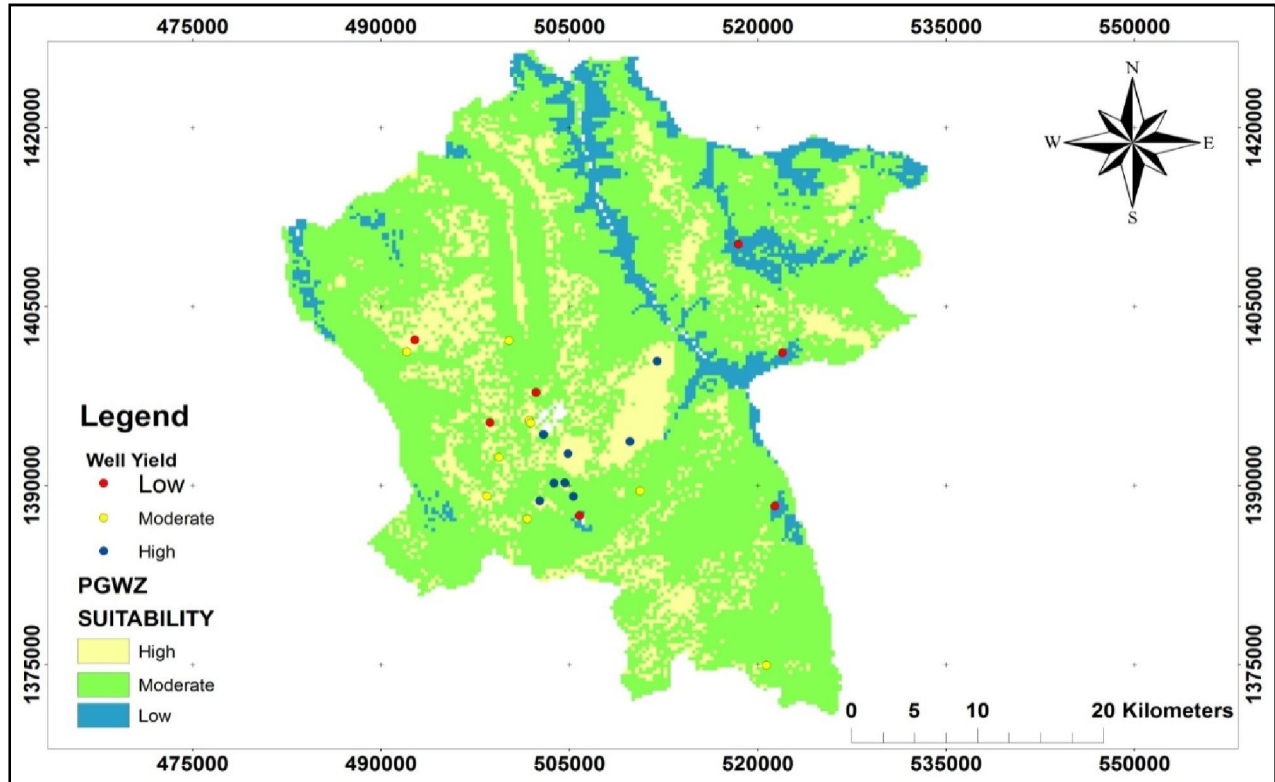


Figure 4. 9. Map of Potential Groundwater Zone with Wells Yield Location.

**Table 4. 14. Comparison of actual yield data of water point with model result.**

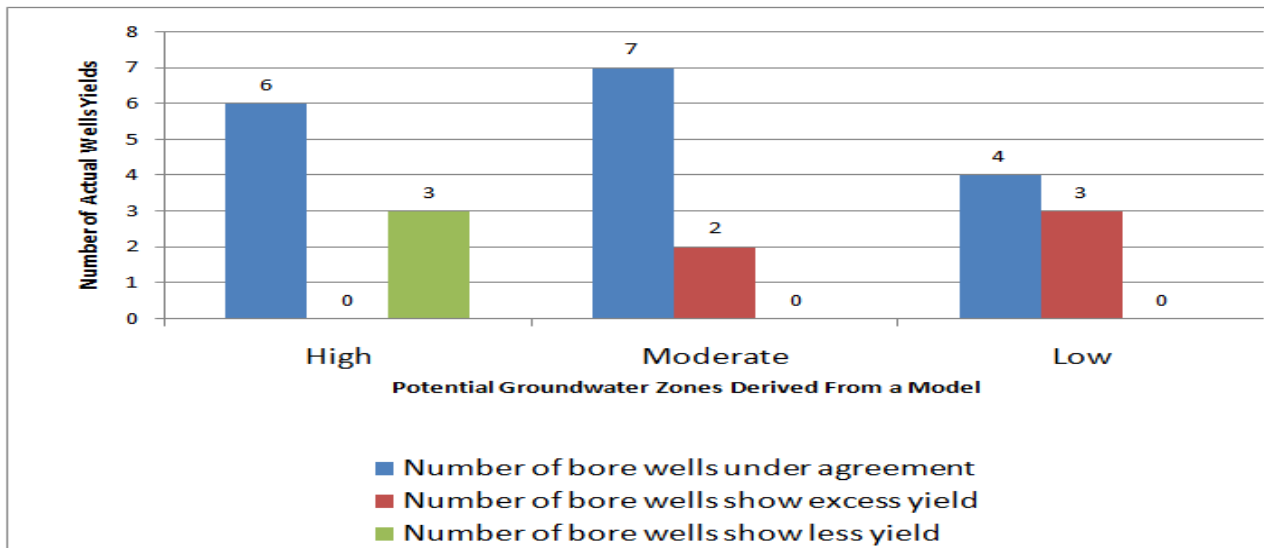
R. N	Kebele Name	Well Type	Easting	Northing	Elevation	Well depth in meter	Well Yield		GW potential model result
							lit/sec	Class	
1	Woleh	Bore Hole 6	504645	1390228	2086	310	5	HIGH	MODERATE
2	Woleh	Bore HoleNew	503980	1388842	2091	455	8	HIGH	HIGH
3	Woleh	Bore Hole 7	505333	1389074	2098	360	15	HIGH	MODERATE
4	Woleh	Bore Hole 8	503766	1390208	2131	360	11	HIGH	HIGH
5	Wukir	Shallow well	504883	1392676	2557	50	3.2	HIGH	HIGH
6	Dibeshinu	Shallow well	509817	1393697	2087	18	5.1	HIGH	HIGH
7	Akimatslya	Shallow well	511987	1400414	2591	23.5	5.6	HIGH	HIGH
8	Condominum (sekota)	Shallow well	502952	1394277	2534	44	5.8	HIGH	HIGH
9	Aba yohanis	Shallow well	499407	1392358	2314	48	1.6	MODERATE	HIGH
10	Tiya	Hand dug well	510638	1389540	2594	9.3	0.6	MODERATE	MODERATE
11	Maybulit	Shallow well	501814	1395441	2532	60	2.1	MODERATE	MODERATE
12	Mikael church	Shallow well	501920	1395229	2546	60	1.7	MODERATE	MODERATE
13	Babena	Hand dug well	500023	1387274	2356	16	1	MODERATE	MODERATE
14	zuqalshmen	Hand dug well	502288	1383375	2205	7.25	0.4	LOW	MODERATE
15	Kulkual diken	Hand dug well	498423	1389091	2432	7.95	0.6	MODERATE	HIGH
16	Tsaskew	Hand dug well	520058	1375387	2089	10.5	0.4	LOW	LOW
17	Derenzeba	Hand dug well	520405	1374939	2123	9.65	0.6	MODERATE	MODERATE
18	Heyeku	Hand dug well	492037	1401191	2113	17.5	0.5	MODERATE	MODERATE
19	SelamKetema	Hand dug well	492698	1402186	2094	9.3	0.4	LOW	HIGH
20	Ginkaba	Hand dug well	500193	1402145	2048	8.4	0.9	MODERATE	MODERATE
21	Zawela	Hand dug well	503646	1385138	2136	15.6	0.04	LOW	LOW
22	Tsata	Hand dug well	521989	1401129	2648	10.2	0.07	LOW	LOW
23	Tiskaru	Hand dug well	498670	1395253	2245	13.7	0.2	LOW	MODERATE
24	Zanziba	Hand dug well	518453	1497759	2613	9.4	0.08	LOW	LOW

The groundwater point's data in the study area are unevenly distributed. They are concentrated in the south-western part of the study area, while the large part of the study area does not have a data (Figure 4.10). As a result, it is difficult to monitor the groundwater level trends in the entire study area.

**Table 4. 15. Comparison of Derived GWPZ with actual wells yield.**

I. No	Groundwater Prospect zones / Actual yield	High	Moderate	Low
1	Number of wells modeled under different PGWZ using a model.	8	9	7
2	Number of bore wells under agreement	6	7	4
3	Number of bore wells show excess yield	0	2	3
4	Number of bore wells show less yield	2	0	0

Therefore, the model generated output map of groundwater potential zone is further validated with the data related to yield potentialities of different borehole and handdug wells in the area, the pictorial representation of the yield data location points is overlaid upon final groundwater potential zonation map, a map prepared from actual wells yield data for validation was categorized in to three potential areas according to experts opinion for reclassification, then where out of 24 wells yield data about 17 wells are determined as high and moderate groundwater potential zones, where as about 7 wells are grouped as a low potential zone.



**Figure 4. 10. Graph of a result validation for a model result with the actual wells yield.**

As shown in the figure 4.10, the occurrence of number of most of wells with different yield of cut across the different rock units. However, the high frequency of wells yields ranges from moderate to

high is found within the aiba formation and near to lineaments, and low yield wells are far from lineaments, which are fits with the model results.

From eight high potential wells, about six wells are fit or overlaid on high potential zone of the model, while the remaining the two wells are match with the moderate zone. From nine moderate potential of a wells, the seven wells are fitted with the model moderate zone results, and two moderate wells yield points are on high potential zone. However, about seven low potential of a well yield is found in the study area, these yields are overlaid on high, moderate and low potential zones of the model result. Generally, from 24 well yields, about 17 wells, which accounts 70.1 % are fitted with the model result, this shows a good correlation with the final output map of a GIS and Remote Sensing based result.

## CHAPTER FIVE

### 5. Conclusions and Recommendations

#### 5.1. Conclusions

A cost-effective methodology for assessment of groundwater potentiality of the Sekota wereda, that utilizes GIS and remote sensing techniques, was developed in this study. This methodology was established through an evaluation of groundwater controlling variables. The study confirmed that integrated GIS-remote sensing techniques are suitable and reliable tools for locating possible sites of groundwater occurrence. Their reliability helps on the rapid assessment of groundwater potentiality and in cutting the cost associated with conventional methods of monitoring site groundwater potentiality. This may also be useful in the establishment of an effective and efficient groundwater exploitation strategy, and to ensure a long-term sustainability in the utilization and management of this resource.

Therefore, in this study Ground water potential zone map have been produced using seven thematic maps from satellites images, exiting data and field data. Produced ground water potential zone map were compared and validated by existing well yield data obtained from different localities of the study area. The result showed fairly significant correlation or agreement with the discharge data. And this study has shown that spatial variability of ground water potential. This variability closely followed variability in the structure, geology, land form, soil, slope, drainage density and land use/cover in the study area. The most promising potential zone in the area is related to aiba formation which is affected, by secondary structure, with plain geomorphic feature. Most of the zones with low groundwater potential lie far from lineaments.

This study generally demonstrates that GIS and Remote sensing techniques in combination with field data could be used for the assessments of ground water potential zones in an area with little primary porosity and low bedrock hydraulic conductivity and where hydrogeological properties are mainly determined by secondary factors fracture zones and associated weathering. It can be considered as a time and cost-effective tool for delineations and identification of high ground water potential target area.

## 5.2. Recommendation

In the light of the findings obtained and conclusions reached the following recommendations are forwarded.

- The groundwater potential map along with other thematic maps forms serve as resource information database which can be updated from time to time by adding new information.
- Filed data indicates that water supply in the study area highly dependent on groundwater sources thus groundwater modeling study is recommended to determine the sustainable exploitations of this resource.
- Recharge may occur naturally from precipitation, rivers, canals, lakes, or as man induced phenomena (irrigation and urban recharge). Possible source for recharge of groundwater in the study area is gained only from precipitation. Therefore artificial recharge of groundwater should be achieved by putting surface water in basins, furrows, ditches, or other facilities where it infiltrates into the soil and moves downward to recharge aquifers and a wide works should be done on soil and moisture conservations.

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# Appendixes

## Appendix 1. Questionnaire prepared for Experts.

My name is Adem Beihun Nuru and I am a student at the Addis Ababa University Institute of Technology, School of Civil and Environmental Engineering, Stream of Geodesy and Geomatics, Specialization in Geomatics. I am doing a research on the **Assessment of Potential Groundwater Zone Using Integrated GIS and Remote Sensing Techniques in Sekota Wereda, Northern Ethiopia**. This research will be used Multi criteria analysis of factors. Therefore weighted overlay analysis method will be employed using Satty's Analytical Hierarchy Process (AHP) for weight assignment of factors and their classes; I request your participation in this research for assignment of weights among factors and its classes using pair wise comparison matrix. The information that you are going to provide will be used anonymously and only for the purpose of this study.

### I. Personal information

1. Name.....Organization..... Position .....
2. Name.....Organization..... Position .....
3. Name.....Organization..... Position .....
4. Name.....Organization..... Position .....
5. Name.....Organization..... Position .....

### II. Weight Assignment

Factors affecting for the occurrence of groundwater in the study area has been selected and listed below, therefore by considering their relative importance among each others, please assign reliable weights and classify the factors into appropriate class ranges using the provided minimum and maximum values of a classes. Please assigned with scores ranging from 1 to 1/9 as per the Saaty scale on the cells.

**The continuous rating scale developed by Saaty (1977)**

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

**Factors**

- Lineament Density
- Lithology
- Drainage Density
- Slope
- Land Form
- Soil Type
- **Land Use/ Land Cover**

**Pair wise Comparison matrix using Saaty's relative importance values**

Factors							

## 1. Lithology classes

- Quaternary sediments
- Aiba formations
- Adigrat sandstone
- Antalo limestone
- Ashenge formation

Classes						

## 2. Lineament Density ( $\text{km}/\text{km}^2$ )

- Minimum lineament density value, **0.00**
- Maximum lineament density value, **1.075**

Classes						

### 3. Slope in percent

- Minimum lineament density value, **0.00**
- Maximum lineament density value, **76.86**

Classes					

### 4. Soil Type

- Cambisol
- Lephthosols
- Vertisol

Classes			

### 5. Land Form

- Hills
- Mountains
- Plains

Classes			

## 6. Drainage Density (km/km<sup>2</sup>)

- Minimum lineament density value, **0.00**
- Maximum lineament density value, **0.76**

Classes					

## 7. Land Use/Land Cover

- Forest
- Dense bushes and shrubs land
- Cultivable Land
- Open bushes, shrubs and grass lands.

Classes			

## Appendix 2. Weight Calculation

### AHP pair wise comparison and weight assignment of Factors

Pair wise comparison matrix using saaty's relative importance values

layer	lith	so	dl	lf	dd	sl	lulc
lithology (lith)	1	1	2	3	3	5	9.09
soil (so)	1	1	1	3	5	7.14	8
distance to lineaments (dl)	0.5	1	1	2	5	5	6.25
land form (lf)	0.33	0.33	0.5	1	3	3	3
drainage density (dd)	0.33	0.2	0.2	0.33	1	2	5
slope (sl)	0.2	0.14	0.2	0.33	0.5	1	3
lulc	0.11	0.125	0.16	0.33	0.2	0.33	1
<b>Total</b>	<b>3.47</b>	<b>3.795</b>	<b>5.06</b>	<b>9.99</b>	<b>17.7</b>	<b>23.47</b>	<b>35.34</b>

Calculation fo Eigen vector / geometric mean

layer	lith	so	dl	lf	dd	sl	lulc	EV/GM (WEIGHT)	Weight*100
lithology (lith)	0.29	0.26	0.40	0.30	0.17	0.21	0.26	0.270	27.00
soil (so)	0.29	0.26	0.20	0.30	0.28	0.30	0.23	0.266	26.00
distance to lineaments (dl)	0.14	0.26	0.20	0.20	0.28	0.21	0.18	0.211	21.00
land form (lf)	0.10	0.09	0.10	0.10	0.17	0.13	0.08	0.109	11.00
drainage density (dd)	0.10	0.05	0.04	0.03	0.06	0.09	0.14	0.072	7.00
slope (sl)	0.06	0.04	0.04	0.03	0.03	0.04	0.08	0.046	5.00
lulc	0.03	0.03	0.03	0.03	0.01	0.01	0.03	0.026	3.00
<b>Total</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1.000</b>	<b>100.00</b>

Estimation of Consistency Ratio

Sum of column in PWC	Eigen vector	Sum of Column * EV
<b>3.47</b>	0.27	0.94
3.795	0.27	1.02
5.06	0.21	1.06
9.99	0.11	1.10
17.7	0.07	1.24
23.47	0.05	1.17
35.34	0.03	1.06
$\lambda_{max}$		7.60

$CI = \lambda - n / n - 1$	0.099291667
$CR = CI / RI$	0.07522096
<b>CR &lt; 0.1 Therefore, it is at reasonable level of consistency</b>	

## Weight for Lineament density

Pair wise comparison matrix using saaty's relative importance values					
Distance in Km	0.0--0.2	0.2--0.4	0.4--0.75	0.75--0.9	0.9--1.075
0.9 to 1.075	1.000	3.000	5.000	7.040	9.100
0.75 to 0.9	0.333	1.000	3.000	5.000	7.040
0.4 to 0.75	0.200	0.333	1.000	3.000	5.000
0.2 to 0.4	0.142	0.200	0.333	1.000	0.333
0.0 to 0.2	0.111	0.140	0.200	0.333	1.000
<b>Total</b>	<b>1.786</b>	<b>4.673</b>	<b>9.533</b>	<b>16.373</b>	<b>22.473</b>

Calculation fo Eigen vector / geometric mean							
Distance in Km	0.0--0.2	0.2--0.4	0.4--0.75	0.75--0.9	0.9--1.075	EV/GM (WEIGHT)	Weight* 100
0.9 to 1.075	0.56	0.64	0.52	0.43	0.40	0.51	51.23
0.75 to 0.9	0.19	0.21	0.31	0.31	0.31	0.27	26.68
0.4 to 0.75	0.11	0.07	0.10	0.18	0.22	0.14	13.88
0.2 to 0.4	0.08	0.04	0.03	0.06	0.01	0.05	4.66
0.0 to 0.2	0.06	0.03	0.02	0.02	0.04	0.04	3.56
<b>Total</b>	<b>1.00</b>	<b>1.00</b>	<b>1.00</b>	<b>1.00</b>	<b>1.00</b>	<b>5.00</b>	<b>100.00</b>

Estimation of Consistency Ratio		
Sum of column in PWC	Eigen vector	Sum of Column * EV
1.786	0.51	0.91
4.673	0.27	1.26
9.533	0.14	1.33
16.373	0.05	0.82
22.473	0.04	0.90
$\lambda_{max}$		5.22

CI= $\lambda - n / n - 1$	0.05619
CR=CI/RI	0.050169643
<b>CR &lt; 0.1 Therefore, it is at reasonable level of consistency</b>	

## Weight for Lithology

Pair wise comparison matrix using saaty's relative importance values					
	Quaternary Dipoited	Aiba Formation	Ashange formation	Antalo limestone	Adigrat Sandstone
Quaternary Dipoited	1.000	2	3.000	5.000	7.040
Aiba Formation	0.500	1.000	2.000	3.000	5.000
Ashange formation	0.333	0.500	1.000	3.000	3.000
Antalo limestone	0.200	0.333	0.333	1.000	2.000
Adigrat Sandstone	0.140	0.200	0.333	0.500	1.000
Total	<b>2.173</b>	<b>4.033</b>	<b>6.666</b>	<b>12.500</b>	<b>18.040</b>

Calculation fo Eigen vector / geometric mean								Estimation of Consistency Ratio		
	Quaternary Dipoited	Aiba Formation	Ashange formation	Antalo limestone	Adigrat Sandstone	EV/GM (WEIGHT)	Weight* 100	Sum of column in PWC	Eigen vector	Sum of Column * EV
Quaternary Dipoited	0.46	0.50	0.45	0.40	0.39	0.44	43.93	<b>2.173</b>	0.44	0.96
Aiba Formation	0.23	0.25	0.30	0.24	0.28	0.26	25.90	4.033	0.26	1.05
Ashange formation	0.15	0.12	0.15	0.24	0.17	0.17	16.67	6.666	0.17	1.13
Antalo limestone	0.09	0.08	0.05	0.08	0.11	0.08	8.31	12.5	0.08	1.00
Adigrat Sandstone	0.06	0.05	0.05	0.04	0.06	0.05	5.19	18.04	0.05	0.90
Total	<b>1.00</b>	<b>1.00</b>	<b>1.00</b>	<b>1.00</b>	<b>1.00</b>	<b>1.00</b>	<b>100.00</b>	$\lambda_{max}$		5.04

CI= $\lambda - n / n - 1$	0.00998
CR=CI/RI	0.008910714
<b>CR &lt; 0.1 Therefore, it is at reasonable level of consistency</b>	

## Weight for Land Form

Pair wise comparison matrix using saaty's relative importance values			
	Plain	Mountain	Hills
Plain	1.000	3.000	7.040
Mountain	0.333	1.000	3.000
Hills	0.140	0.333	1.000
Total	<b>1.473</b>	<b>4.333</b>	<b>11.040</b>

Calculation fo Eigen vector / geometric mean					
	Plain	Mountain	Hills	EV/GM (WEIGHT)	Weight*100
Plain	0.68	0.69	0.64	0.67	66.96
Mountain	0.23	0.23	0.27	0.24	24.29
Hills	0.10	0.08	0.09	0.09	8.75
Total	<b>1.00</b>	<b>1.00</b>	<b>1.00</b>	<b>1.00</b>	100.00

Estimation of Consistency Ratio		
Sum of column in PWC	Eigen vector	Sum of Column * EV
<b>1.473</b>	0.67	0.99
4.333	0.24	1.04
11.04	0.09	0.99
$\lambda_{max}$		3.02

$CI = \lambda - n / n - 1$	0.010215
$CR = CI / RI$	0.017612069
<b>CR &lt; 0.1 Therefore, it is at reasonable level of consistency</b>	

## Weight for Slope

Pair wise comparison matrix using saaty's relative importance values					
	0 - 3	3--8	8--15	15--30	>30
0 - 3	1.000	3.000	4.000	7.040	9.010
3--8	0.333	1.000	3.000	5.000	7.040
8--15	0.250	0.333	1.000	3.000	5.000
15--30	0.140	0.200	0.333	1.000	3.000
>30	0.111	0.140	0.200	0.333	1.000
Total	<b>1.834</b>	<b>4.673</b>	<b>8.533</b>	<b>16.373</b>	<b>25.050</b>

Calculation fo Eigen vector / geometric mean							
	0 - 3	3--8	8--15	15--30	>30	EV/GM (WEIGHT)	Weight*100
0 - 3	0.55	0.64	0.47	0.43	0.36	0.49	48.91
3--8	0.18	0.21	0.35	0.31	0.28	0.27	26.67
8--15	0.14	0.07	0.12	0.18	0.20	0.14	14.15
15--30	0.08	0.04	0.04	0.06	0.12	0.07	6.78
>30	0.06	0.03	0.02	0.02	0.04	0.03	3.48
Total	<b>1.00</b>	<b>1.00</b>	<b>1.00</b>	<b>1.00</b>	<b>1.00</b>	<b>1.00</b>	100.00

## Estimation of Consistency Ratio

Sum of column in PWC	Eigen vector	Sum of Column * EV
<b>1.834</b>	0.49	0.90
4.673	0.27	1.26
8.533	0.14	1.19
16.373	0.07	1.15
25.05	0.03	0.75
$\lambda_{max}$		5.25

$CI = \lambda - n / n - 1$	0.06315
$CR = CI / RI$	0.056383929
<b>CR &lt; 0.1 Therefore, it is at reasonable level of consistency</b>	

## Weight for Drainage Density

Pair wise comparison matrix using saaty's relative importance values				
	0--0.1	0.1--0.2	0.2--0.4	0.4--0.76
0--0.1	1.000	3.000	7.040	9.100
0.1--0.2	0.333	1.000	3.000	7.040
0.2--0.4	0.142	0.333	1.000	3.000
0.4--0.76	0.110	0.142	0.333	1.000
Total	<b>1.585</b>	<b>4.475</b>	<b>11.373</b>	<b>20.140</b>

Calculation fo Eigen vector / geometric mean						
	0--0.1	0.1--0.2	0.2--0.4	0.4--0.76	EV/GM (WEIGHT)	Weight*100
0--0.1	0.63	0.67	0.62	0.45	0.59	59.30
0.1--0.2	0.21	0.22	0.26	0.35	0.26	26.17
0.2--0.4	0.09	0.07	0.09	0.15	0.10	10.02
0.4--0.76	0.07	0.03	0.03	0.05	0.05	4.50
Total	<b>1.00</b>	<b>1.00</b>	<b>1.00</b>	<b>1.00</b>	<b>4.00</b>	100.00

Estimation of Consistency Ratio		
Sum of column in PWC	Eigen vector	Sum of Column * EV
<b>1.585</b>	0.59	0.94
4.475	0.26	1.16
11.373	0.1	1.14
20.14	0.05	1.01
$\lambda_{max}$		4.24

CI= $\lambda - n / n - 1$	0.080983333
CR=CI/RI	0.089981481
CR < 0.1 Therefore, it is at reasonable level of consistency	

## Weight for Soil Type

Pair wise comparison matrix using saaty's relative importance values			
	Cambisol	Lepthosol	Vertisol
Cambisol	1.000	3.000	7.040
Lepthosol	0.333	1.000	3.000
Vertisol	0.140	0.333	1.000
Total	<b>1.473</b>	<b>4.333</b>	<b>11.040</b>

Calculation fo Eigen vector / geometric mean					
	Cambisol	Lepthosol	Vertisol	EV/GM (WEIGHT)	Weight*100
Cambisol	0.68	0.69	0.64	0.67	66.96
Lepthosol	0.23	0.23	0.27	0.24	24.29
Vertisol	0.10	0.08	0.09	0.09	8.75
Total	<b>1.00</b>	<b>1.00</b>	<b>1.00</b>	<b>1.00</b>	100.00

## Estimation of Consistency Ratio

Sum of column in PWC	Eigen vector	Sum of Column * EV
<b>1.473</b>	0.67	0.99
4.333	0.24	1.04
11.04	0.09	0.99
$\lambda_{max}$		3.02

$CI = \lambda - n / n - 1$	0.010215
$CR = CI / RI$	0.017612069
<b>CR &lt; 0.1 Therefore, it is at reasonable level of consistency</b>	

## Weight for Land Use Land Cover

Pair wise comparison matrix using saaty's relative importance values				
	Forest	Cultivated Land	Dense BSH Land	Open BSH Land
Forest	1.000	3.000	5.000	9.010
Dense BSH Land	0.333	1.000	3.000	5.000
Cultivated Land	0.200	0.333	1.000	3.000
Open BSH Land	0.110	0.200	0.333	1.000
Total	<b>1.643</b>	<b>4.533</b>	<b>9.333</b>	<b>18.010</b>

Calculation for Eigen vector / geometric mean						
	Forest	Cultivated Land	Dense BSH Land	Open BSH Land	EV/GM (WEIGHT)	Weight*100
Forest	0.61	0.66	0.54	0.50	0.58	57.66
Dense BSH Land	0.20	0.22	0.32	0.28	0.26	25.56
Cultivated Land	0.12	0.07	0.11	0.17	0.12	11.72
Open BSH Land	0.07	0.04	0.04	0.06	0.05	5.06
Total	<b>1.00</b>	<b>1.00</b>	<b>1.00</b>	<b>1.00</b>	<b>1.00</b>	100.00

### Estimation of Consistency Ratio

Sum of column in PWC	Eigen vector	Sum of Column * EV
<b>1.643</b>	0.58	0.95
4.533	0.26	1.18
9.333	0.12	1.12
18.01	0.05	0.90
$\lambda_{max}$		4.15

$CI = \lambda - n / n - 1$	0.05066
$CR = CI / RI$	0.056288889
<b>CR &lt; 0.1 Therefore, it is at reasonable level of consistency</b>	