



Addis Ababa University

**COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES
SCHOOL OF EARTH SCIENCES**

**Groundwater potential and Recharge zone mapping by using GIS
and Remote sensing Techniques in the case of Middle Awash River
Basins, Ethiopia**

A thesis submitted to

*The school of graduate studies of Addis Ababa University in partial
fulfillment of the requirements for the degree of masters of sciences in
remote sensing and geo-informatics*

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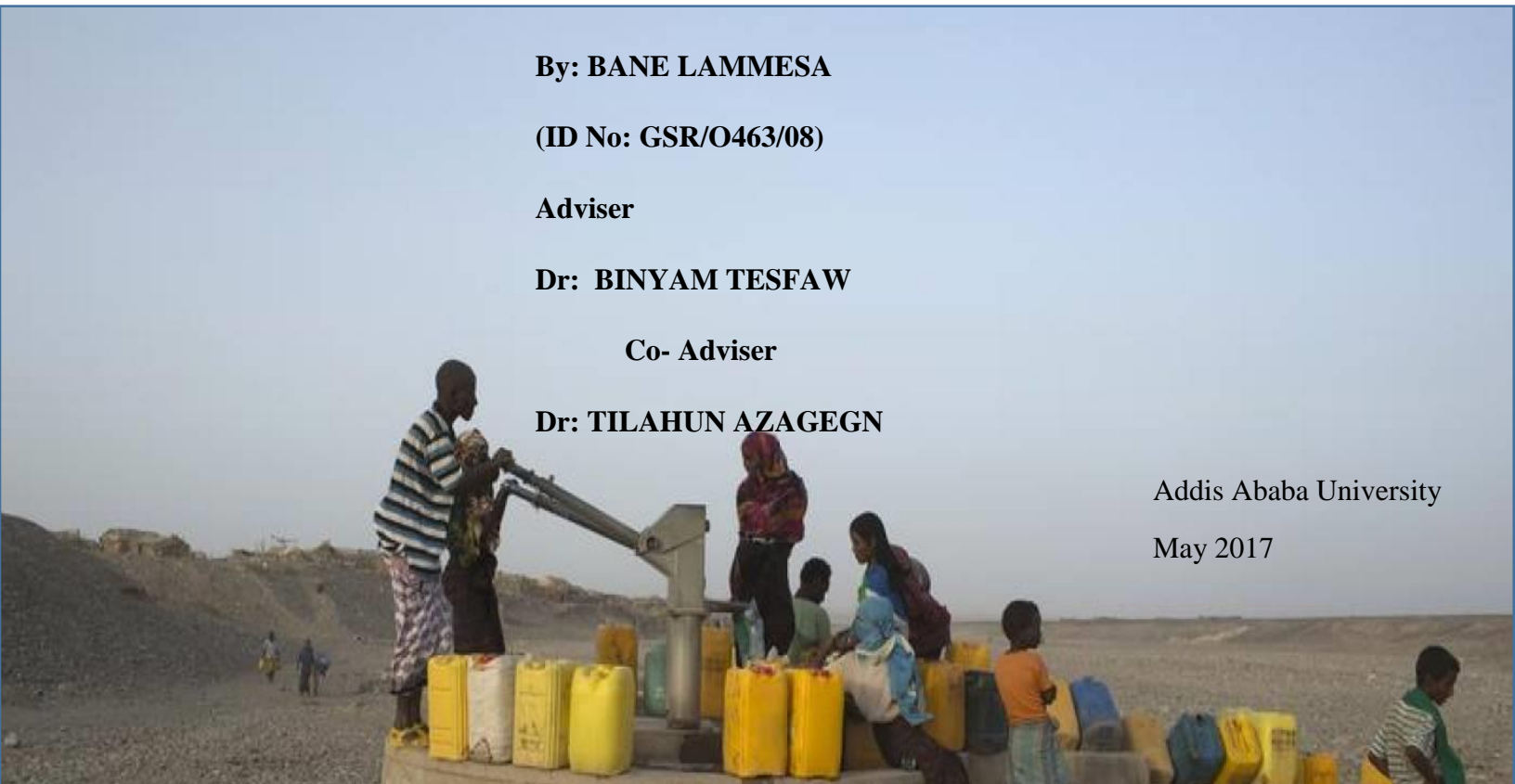
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SCIENCE IN REMOTE SENSING AND GEO-INFORMATICS**

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This is to certify the thesis prepared by BANE LAMMESA ENTITLED as “**Groundwater potential and Recharge zone mapping by using GIS and Remote sensing Techniques in the case of Middle Awash River Basins, Ethiopia**” is submitted in partial fulfillment of the requirements for the degree of masters of science in remote sensing and geo-informatics complies with the regulations of the university and meets the accepted standards with the respect to originality and quality.

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ACRONYMS

AHP	Analytical hierarchy process
CN	Curve Number
CSA	Central Statistical Agency
ERDAS	Earth Resource Data Analyze System
DEM	Digital Elevation Model
FAO	Food and Agricultural Organization
GIS	Geographical Information System
GWP	Groundwater Potential
GWR	Groundwater Recharge
HSG	Hydrological Soil Group
ITCZ	Inter Tropical Convergence Zone
LU/LC	Land use Land Cover
MCDM	Multi criteria Decision Making
MER	Main Ethiopia Rift
MoWR	Ministry of Water Resource
OLI	Operational Land Imager
RS	Remote Sensing
USDA	United States Department of Agricultures
USGS	United State of Geological Survey
WIOA	Weight Index Overlay Analysis
WWDE	Water Work Design Enterprise

ABSTRACT

Groundwater is a valuable and important natural resource in the world and it is the most fundamental for the growth and development of one country. However estimating the potential of groundwater potential and its recharge zone has still uncertainty due to the nature of groundwater. Therefore, this study aims to use the timely and cost effective remote sensing and geographical information system (GIS) methods for delineating, classify groundwater potential, and recharge zone in the Middle Awash River basin. Nine factors as a thematic map derived from Landsat 8 Operational Land Imager (OLI) Satellite image of the year 2016, Digital Elevation Models (DEM) with 30 m and 1km spatial resolution and secondary sources were utilized in this research. These were rainfall, slope, geomorphology, geology, lineament density, drainage density, surface runoff, and Land-use/land-cover and soil texture. The methods to assess the potential and recharge zone was using weight overlay analysis and Analytical Hierarchy Process (AHP) algorithm. All thematic layers were reclassified based knowledge based analysis that was reviewed from different kinds of literature. Then the weight for each factor was assigned according to their relative importance as per suitable based on Saatty's scale of AHP. The important factors result show that rainfall and slope have a higher weight and lithology has the lowest weight for identifying the potential of groundwater potential and recharge zone in the study area respectively. The resulting map of groundwater potential and recharge shows that 34 % and 32% of the area has very high potential, respectively. The produced map of groundwater recharge zone reveals that the northwestern and southeastern highlands of the study area are the most suitable areas. The result also exhibits very high groundwater potential areas have a very low slope, alluvial plains, with high lineament density and sandy loam soil textures. On the other hand, very low groundwater potential corresponding to barrier landforms, structural hills, and high slope areas. High recharge areas characterized by high rainfall, dense forest, and high drainage density. This result of groundwater potential and recharge was validated and shows 0.88 correlations of high and very high areas with that of existing water source and spring data. Therefore, this research demonstrates a robust method of using GIS and remote sensing techniques, which is efficient and useful in delineating and mapping groundwater potential and recharge zone.

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

CHAPTER ONE

INTRODUCTION

1.1 Background

Groundwater is defined as beneath surface water that fills all the pore space of soils and geologic formations below the water table. It flows in the aquifer layer towards the point of discharge, which includes wells, springs, rivers, lakes, and the ocean. Water is the valuable and important thing used for domestic use, livestock and industries in the world; it is the fundamental condition for the growth and development of one country. Ethiopia is definitely the progressive fulfillment of its urgent water needs as past and recent studies describe (Tamiru, 2006). According to Foster (1998), groundwater makes up about 60% of the world's freshwater supply, which is about 0.6% of the entire world's water.

The availability, accessibility, movement and occurrence of ground water depends on geology, slope aspect, lineaments, drainage density, land- use/land-cover, Rainfall, surface runoff and geomorphology of the area (Shaban *et al.*, 2005). Evaluation, exploitation, exploration, site selection/delineation and maps of groundwater need a serious caution, as it is cost and time effective. Because it is out of our site and improper evaluation of ground water and site selection is mostly expected to pose the problem (Tesfaye, 2012).

Geographical information system (GIS) and remote sensing (RS) is the optional methods to provide all parameters which influence groundwater potential and recharge zone of one area and it can access, manipulate and analysis the spatial and temporal data from satellite image (Kamal, 2017). Besides to this, (Gupta and Srivastava, 2010) Explain the several decision analysis approaches such us Multicriteria Decision Making (MCDM), Analytical Hierarchy process (AHP) and Fuzzy Logic to fill the gap of water scarcity and decision-making on ground water potential and recharge zone evaluation and mapping. Analytical Hierarchy Process is useful methods for complex decision-making. A serious pairwise comparison matrix used for checking consistency ratio (Saraf and Choudhury, 1998). These decision makers use to reduce the bias in decision making (Saaty,1980).This study was focused on the evaluation of groundwater potential zone in Middle Awash river basin by the integrated approach of remote sensing and GIS techniques using AHP modeling approach.

1.2 Statement of Problem

To investigate the groundwater potential of middle awash basins, a multi-disciplinary study involving hydrogeology and geophysics have been undertaken by the Ministry of Water Resources through the Water Well Design and Supervision Enterprise (Wakgari, 2010; WWSDE, 2015; Tilahun *et al.*, 2015) by using Geophysical, hydrogeological methods that consume time and cost. Besides to this, the groundwater potential and recharge zone are not delineated in previous studies by using GIS and RS techniques separately. Since there is a limitation of previously working done in the area of the potentials and recharge zone in details, the present study fills the gap by applying GIS and remote sensing technique. These techniques are very easy to access, identify groundwater potential, and recharge zone of large and inaccessible areas.

1.3 Objective

1.3.1 General Objective

The general objective of the study is to evaluate groundwater potential and recharge zone of the Middle Awash River basin by the integrated approach of GIS and remote sensing techniques.

1.3.2 Specific Objective

- ❖ To prepare the thematic maps of the study area such as Lithology, Land use/cover, slope, lineaments, soil texture, drainage density, and geomorphology and runoff depth.
- ❖ To identify the factors that more affects the groundwater potential and recharge zone.
- ❖ To Assess, evaluate and delineate groundwater potential and recharge zone of the area by using remote sensing and geospatial data analysis.

1.4 Research Question

- ❖ Can lithology, geology, geomorphology, drainage density, rainfall, slope, and lineaments be the main factors for an accurate result of the groundwater potential and recharge zone of the area?
- ❖ What are the further advantage of remote sensing and GIS from other methods groundwater potential and recharge zone identification?
- ❖ Are all the parameters have equal value to delineate groundwater potential and recharge zone of one area?
- ❖ Is there high potential and low potential of groundwater potential and recharge in the study area?

1.5 Significance of the study

Ethiopia is one of the countries in Africa known by abundant water resource but there is minimum utilization to ground water for irrigation, domestic life, and lively wood. The main part of Ethiopian rift valley are characterized by shortage rainfall especially lower and middle awash basin areas have a shortage of rainfall and water scarcity due to a fluctuation of climate.

The population of Middle Awash River basins is used waters for drinking and other livestock consumptions from ponds, surface waters and the others by going long travel to fetch the waters from rivers. The decrease rainfall trend of dry zone and the increase of population size and demands of water for irrigation and other livelihood requirement's calls sustainable exploitation of the groundwater resources in the region. By considering the problem and the gap from the other studies in terms of cost and time, increasing number of population density and fluctuation of climate on water scarcity in Middle Awash River basins. This research analyzes, design and map the spatial and temporal distribution of, groundwater availability, identify recharge areas and factors for ground water formation for the study area.

1.6 Limitation of the study

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

1.7 Thesis organization

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

as remote sensing images, digital elevation models. Chapter four contains results and discussion of groundwater potential and recharge zone. Chapter five contains conclusion and recommendation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Definition Of groundwater potential and Recharge zone

There are different definitions given to groundwater potential and recharge zone by different authors in different time. According to Rashman (2016), groundwater is the most important natural resources found beneath the earth surface stored in void space of geological stratum used in economic development, domestic life, and any ecological diversity. Also, he concludes the occurrence and flows system of groundwater is depends on geological characteristics of its porosity and permeability and the formation of landforms such us high mountains, rift valley's and flat areas and the role of landform on surface runoff and infiltration to the ground. Besides, (Rajaveni *et al.*,2015) define Groundwater recharge; it is the percolation/ infiltration of water from unsaturated zone to saturated zone through porosity and permeability of the earth materials above the water table and finalizes precipitation, infiltration/ percolation of the surface water to the subsurface influenced by geology and geomorphology.

2.2 Groundwater in Ethiopia

Awash River basin located within the main Ethiopian rift valley (MER). Concerning this area, numerous reports were done in previous. For instance, previously hydrogeological and related studies conducted in the Middle Awash River basin and its surrounding. Reys (2016) conducted on groundwater potential evaluation and use trends in the upper awash basin. This study partly discussed on the quantitative understanding of aquifer system and ground water conditions, how to manage ground water potential and use of trends in order to increase its contribution.

In addition to the above authors, Pavelic *et al.* (2012) conducted on groundwater availability and use in the sub-Sahara African country review of fifteen countries. He summarizes that the hydrological conditions of sub-Sahara Africa are the major controller of under groundwater more than other country and categorizes the hydrological aquifers parameters of sub-Saharan into crystalline basement complex rock, consolidated sedimentary rock, unconsolidated sedimentary rock, and volcanic rocks.

(Tamiru, 2006) done on the Groundwater occurrence in Ethiopia and describe the most important factors governing the groundwater flow and storage in volcanic rocks. In addition, he summarizes that the variation in mineralogy, texture, and structure of volcanic rocks cause the variation of

water bearing capacity of the area. (Seifu, 2010) conduct on the Groundwater occurrence in Ethiopia, partly divide the source of groundwater recharge in Ethiopia under flood recharge, wadi flood recharge, rainfall recharge and mountain block recharge, runoff from graben and summarize the water isotope is the evidence. (Yitbarek *et al.*, 2012). Describe type and distribution of lithology in Ethiopia and they categorize sedimentary and Mesozoic sandstone to the southern, karstic rocks to eastern and southeastern, quaternary volcanic rocks and unconsolidated sediments in rift valley and low land depression area, fractured intrusive rocks, old Precambrian rocks and metamorphic rocks to western part of Ethiopia and their aquifer characteristics.

Although, (Adetunji *et al.*, 2011) conducted Water balance of upper Awash River basins based on the satellite derived data /Remote sensing data on his MSc thesis, understanding the spatial variations of water balance components of upper Awash River basins will provide full information for the management surface and groundwater. The geology of main Ethiopia rift valley (MER) is very complex, which are difficult to describe the hydrology of the area because of variability and lateral discontinuity of volcanic rocks (Ernesto *et al.*, 2015).

2.3 Factors Affecting Groundwater Potential and Recharge

Groundwater potential and recharge zone affected by different factors that control/facilitate this process according to different previous works. As discussed by (Prasad, 2008) on deciphering of the ground potential zone in hard rock water through the application of GIS. Partly he discussed on the Lithology, geomorphology, lineament, slope soil, drainage pattern, land use and rainfall. Finally, he summarizes, as those above parameters are very important factors in ground water potential and recharge zone mapping. (Annesh and Pares, 2015). Study origin of occurrence and movement location of groundwater by using remote sensing data based on indirect analysis of directly observable terrain features like geological structures, geomorphology, Land-use/land-cover, Slope, Rainfall, drainage density, and lineaments.

2.4 Role of GIS and Remote Sensing in Groundwater Potential and Recharge

According to (Mukherje, 2008) GIS and remote sensing techniques, groundwater potential, and recharge zone easily characterized. For example, conducted on Role of Satellite Sensors in Groundwater Exploration, satellite sensors have the ability to emphasize the opened new systematic and efficient exploration of ground water, landform mapping, geological mapping, mineral exploration and geohazard studies. In addition, it helps to understand varies landforms, which are not easily observed.

According to Semere (2003) Geographical information system and remote sensing is the most advanced technology for much scientific application such as monitoring natural disasters, landslide, earthquake, volcanoes and agricultural management, mineral and groundwater exploration and can access large data at same time which are impossible to reach such as cliff, mountains, and gorges.

(Salwa, 2015) explain the application of GIS and remote sensing; compares GIS and remote sensing applications on groundwater delineation with other methods such as geospatial, numerical modeling and geophysical methods. He concluded that the above methods are very expensive, laborious, time-consuming and destructive. In contrast to the above methods, according to Tesfaye, (2012) groundwater cannot be observed directly by our eyes because it is found beneath ground there are many techniques which give information about groundwater and recharge potential zones such as hydrological investigation, geophysical and geoelectrical or geophysical seismic refraction methods which are very expensive and time consuming. GIS and remote sensing are the latest, time and cost effective technology for groundwater exploration by acquiring full information and access all parameters of factors which control groundwater potentials and recharge zone areas by using different softwares easily.

A number of works have been done on the role of GIS and remote sensing on the groundwater potential and recharge zone. From those, Chowdhury *et al.* (2009) conducted an integrated remote sensing and GIS based study for assessing groundwater potential in West Medinipur district, India. Define when GIS and remote sensing techniques have increased for using groundwater potential and recharge zone mapping. (Agrawal and Grag, 2016) conducted a study on groundwater potential and recharge zone based on GIS and remote sensing and they identify different thematic maps for delineating groundwater potential and recharge zones like drainage density map, lineament map, land-use/land-cover map, hydrogeology map and soil map, slope map.

Additionally, Lazarus (2014) conducted an evaluation of groundwater potentiality using the integrated approach of remote sensing, geophysics, and GIS of Ojhala Sub-watershed, Mirzapur district, India. In general, different thematic layers like lineaments, slope, drainage and overburden thickness were used to integrate without considering aquifer thickness. This provides a broad idea about the groundwater prospect of the area and the result of groundwater potential zones map generated

through this model verified with the borehole yield data to find out the validity of the model developed which made the agreement with the result.

2.5 Analytical Hierarchy Process Methods

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

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Study Area

Middle Awash River basins are found in main Ethiopia rift between Latitude of 8°39'51"N–10°50'0.13" N and Longitude of 39°52'27" E–41°14'38" E with the total Area coverage of 30,464 km² as shown in Figure 3.1.

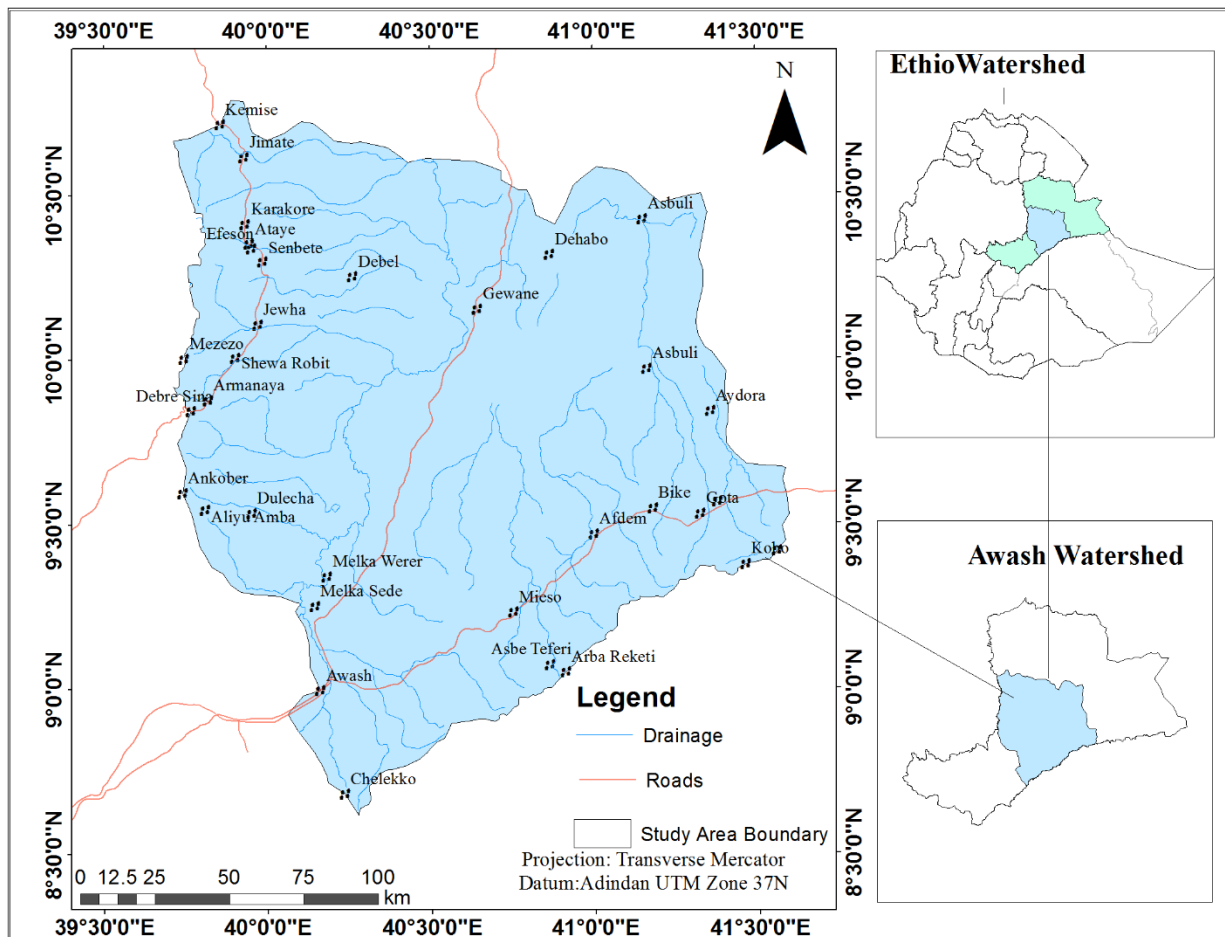


Figure 3. 1 Location Map of the Study Area

3.2 Population and Economic Activity

Middle Awash River basins dominated by various ethnic groups; Afar, Amhara, Oromo, Argoba and Ethio- somale peoples. The most inhabitants of populations are afar population. Major of them are Muslim followers and the others are Christian followers. Their economic activity are depend on agriculture, pastoralists and nomadic life. Amhara, Oromo and Argoba peoples are

depend on agricultural practice. The Afar people are nomadic and pastoralists and recently they start agriculture practice by irrigations along the rivers and low-lying riverine areas. According to the central statistical agency of Ethiopia CSA (1998), the total number of male and female in the study area are 465,492.

3.3 Rainfall and Temperature

The attitude variation of the study area causes temporal and spatial variability of rainfall. The mean annual rainfall varies between 250 mm and 1200 mm. However high land areas to the southeast and northwest of the study area have annual rainfall more than 1200 mm due to altitude effect. The rainfall pattern in the area generally displays a bimodal type which is divide into two distinct rainy periods in July and august as shown in Figure 3.2. As elevation increase the rainfall also increase as shown in Figure 3.3, the northern and southern high lands get high rainfall and the rift floor have low rainfall. Temperature also shows slight variation spatially in the study area. Rainfall and Elevations have a direct relationship. Southeast high lands to the lowland and northwest to the lowland from 23°C to 34°C and the maximum temperature are reaching more than 40°C in the study area. In general, temperature values are maximum for months of April, May, June and July in the Study area..

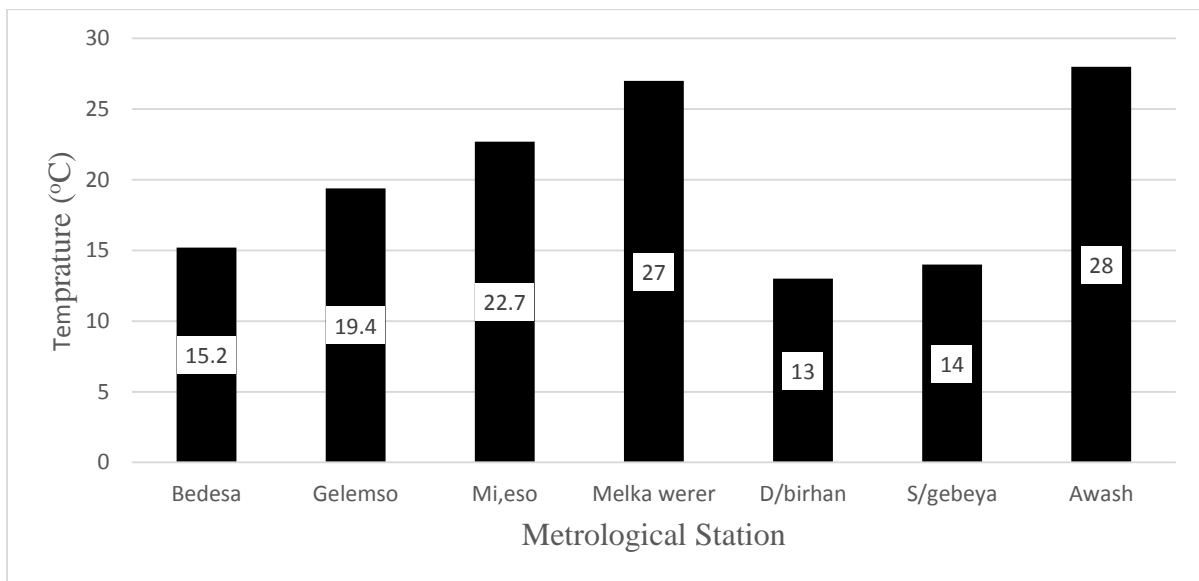


Figure 3. 2 : Annual Mean Temperature of the Study Area

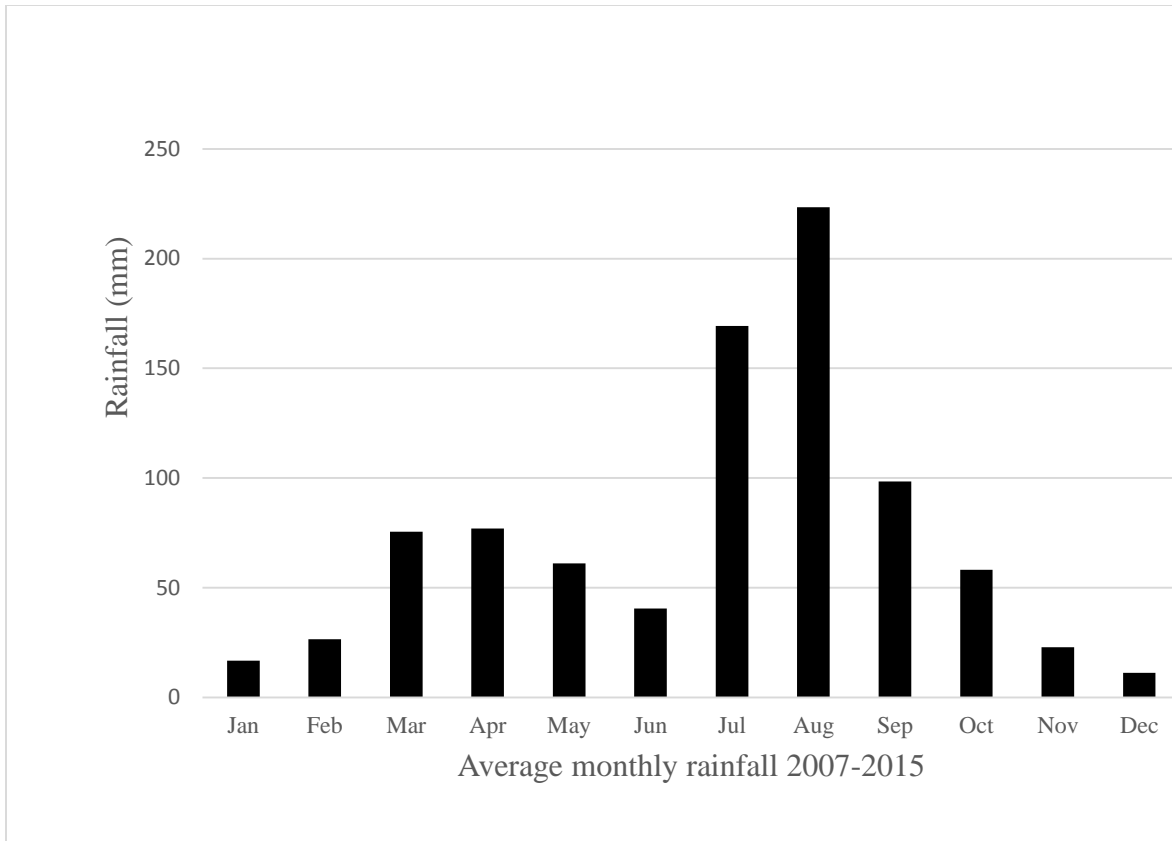


Figure 3. 3: Average Monthly Rainfall of the Study Area

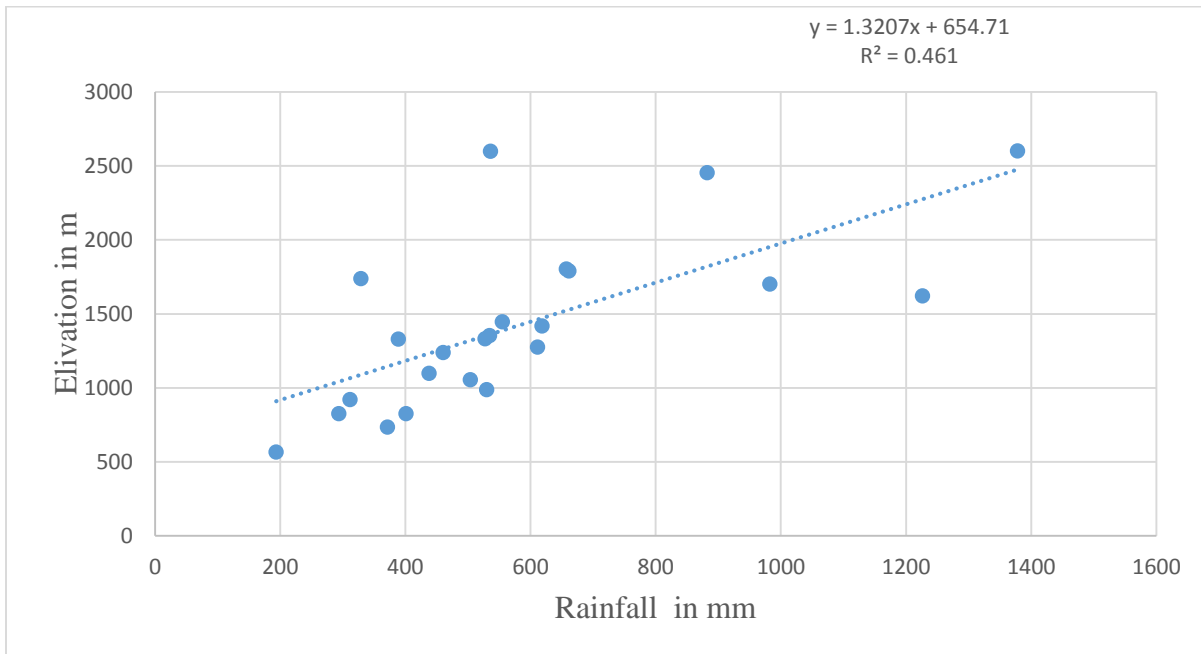


Figure 3. 4: Correlation of Rainfall with Altitude

The general positive correlations between rainfall and altitude shows not very much high as shown in Figure 3.4. Because of topographic effects on rainfall the southeastern plateau on the windward side (Wakgari, 2010)

3.4 Wind speed and Relative Humidity

The seasonal variation of inter-tropical convergence zone (ITCZ) are influence the wind Flow direction. The predominant wind direction during June to September is southerly to southwesterly. The mean monthly wind speed in Awash and Amibara areas range from minimum value of 0.85 meter/sec or 28.4 miles/day in Dec. to max values of 2.4 meter/sec or 80.4 miles/day in July with a mean annual value of 1.36 met/sec or 45.6 miles/day. From relative humidity, data available for Amibara area the mean annual relative humidity in the area is around 61.3 %.

3.5 Physiography and Drainage

The Miocene massive geological process of the Ethiopia rift was cause to serious three distinct slices of geomorphic series of plateau, escarpment and rift flooring. The physiographic configuration of the area creates three distinctive river basins of abbey, awash and Wabishebelle basins. The abbey basin located northwestern of the study area drains westward from northern highlands, Wabeshebelle basins located southeast wards of the study area drained from eastwards. The intermittent volcanic tectonic process of the rift form causes the landform deformation into successive pieces of stratum land masses stacked one after the other. The land mass of middle Awash River basin is categorized into three in Figure 3.5 which causes the physical and climate variation, plateau covers about small part of the study area to the north and south of the study area, escarpment covers small part of the area with moist climate of 16^oc to 24^oc and rift floor (Tewdros, 2011). These areas shares large amount of the study area with highest temperature of above 24^oc rain fall below 900 mm. The landforms of the rift floor area are flat plain with patch of volcanic dome and caldera, alluvial landform, flat/flood plain, residual landform and structural landform.

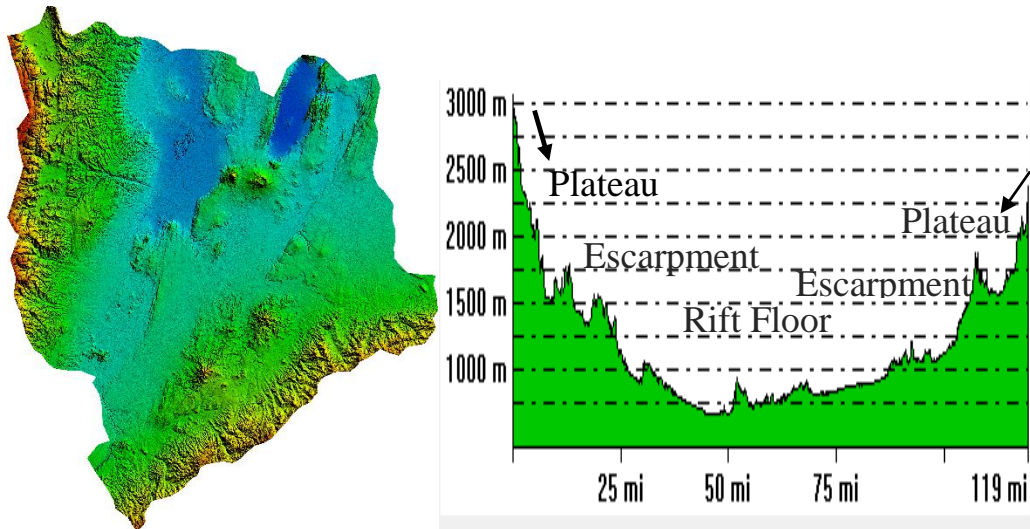


Figure 3. 5: Physiographic classes of the Study Area

3.6 Soil Type and Vegetation

Soils are highly affects the movement and infiltration of ground water (Hornsby, 1986, Maurice and Courteny, 1990). There are several major soil groups in the study area such as eutric cambisol, eutric fluvisol, chromic cambisol, chromic vertisol and vertic cambisol. The most dominant of the study areas are cambisols and leptosols According to FAO (1998) soil classification. Depositional places and soil composition, thickness and soil textures can have a significant role on hydrological process. Besides soil types, its texture and soil index properties play great role on the runoff and infiltration rates of waters to the ground. The degree of permeability and porosity are the principal factor in hydrogeology that indicates ground water potential and recharge zone. The relative proportion of sand, silt and clay of the soil determines soil textures, which categorized in to fine medium and coarse. The common types of vegetation's of the study area are *julifora*, *Acacia*, shrubs, thorny bushes, grassland and riverine woodland trees are also found along the middle Awash River of floor plains. The crop production under irrigated and rainfall farms among others are teff, Cotton, Maize and Vegetables like Tomatoes, Green and Red Pepper and Onions.

3.1.6 Hydrogeology of the Study Area

Geological structure of fractures, joints, faults, folds and lineaments and physiography affects hydrological process of an area (Wakgari, 2010). Crustal thickening and land disconnection are takes place which is response to tensional force at the central rift produce various fissures size

aligned NNE-SSW as the main geological structures (Abebe *et al.*, 2007). The presence of fissures and volcanic activities in the several of the rift floor makes a partial change of the fissures in the hydrological flow system, ground water and surface water interaction.

3.1.7 Aquifer Characterization of the Study Area

There are three types of aquifers data in the middle Awash River basins according to Ministry of Water Irrigation and Energy report (MOWR) including; alluvial and lacustrine deposits, Quaternary Pleistocene tuff, Miocene and welded tuff, Tertiary Pliocene, and basalt that associate to shallow aquifer system and deep aquifer systems in the area. The above statement suggest that, there is an understanding of hydrogeological patterns and lithological makeup of the area from this data. Besides, from different shallow wells and open dug wells drilled on the riverbanks of Awash (i.e. The shallow wells observed at Bilen, Sheleko, Melka worer and Melka Sedi) where a shallow sand and gravel aquifer system are encountered at a depth of around 30 meters and below in a semi confined nature. The water level in these well rises to a depth 10 – 15 meters. The shallow wells of Melka Worer, Sheleko, Ambush, Melkasedi and Bilen indicate that the depth of around 50 meters.

3.1.8 Groundwater Recharge

Ground water recharge process is the percolation /the infiltration of water to the ground that, occurs when any surface water flow to the groundwater table and infiltrate to the saturated zone. The sources can be Precipitation, surface waters and irrigation losses through diffuse (direct) or preferential (localized/indirect) and also Groundwater can be recharged from rainfall, surface water storage, adjoining of watershed, infiltration through streams and rivers and artificial recharge from ponds and reservoirs by direct and indirect mechanism (Lerner, 1997; Seifu, 2010). The area characterized by deep non-expansive soil formation; rainfall events can give the significant groundwater recharge. Specially, arid and semi-arid areas get natural recharge indirectly from neighbor areas influenced by slope; recharge is less in high slope and very high in areas where the discontinuities of rocks (fractures, joints and cracks) high and low slope. Mountain blocks, heavy rainfall, floods from highlands, rivers and small streams are the major source of groundwater recharge in the middle Awash River basins (Seifu, 2012). They influenced by several factors like slope, land use land cover, lineament, soil properties and runoff. Those entire parameters map are prepared and reclassified as suitable for the groundwater recharge zone according to the map of the middle Awash River basins presented in Figure 3.15. Diffuse recharge mechanism refers to the

water added to the groundwater reservoir in excess soil-moisture deficits and evapotranspiration by direct vertical percolation of precipitation through the unsaturated zone (Bisrat, 2015)

3.1.9 Groundwater Flow Direction

Both topography and geology plays a major role for the groundwater flow in the area. There is a regional groundwater flow from the eastern mountain range towards North West /topographic flows in the valley floor as observed from the Potentiometric head map constructed. This regional flow most possibly controlled by the regional tectonics, which trend northwards following the main rift trend. Local tectonics like the Wonji faults play major roles controlling the local flow pattern where most hot springs emerges at the base of these local fault lines at Bilen and Meteka areas.

From the conceptual flow, based on topographic setting three types of flow system observed in the area of topographically undulation of the catchment creates local and intermitted flow system in the area and that part with shallower and short flow paths known with local flow system. Small permanent lakes in the upland portions of watersheds are usually discharge areas for local and intermediate systems (Tenalem, 2008). Therefore, from this logical point of view, the presence of small Permanent River indicates that, the local and intermediate flow systems in the eastern part of the area. The groundwater flow system around Afdem and gewane area highly dominated by intermediate flow system.

3.2 Methods

GIS and remote sensing techniques were applied to delineate groundwater potential and recharge of the middle Awash River basins through analytical hierarchy process. The methods for this research work includes the following stages: i) identification and evaluation of criteria; ii) data collection; iii) preprocessing; iv) input dataset; vi) reclassified input layers; vii) Pair wise comparison of criteria and give weight with Analytical Hierarchy Process(AHP); x)overlay analysis with Weight sum overlay analysis in ArcGIS tools, Ranking the final value. The overall methods are illustrated as shown in (Figure 3.6).

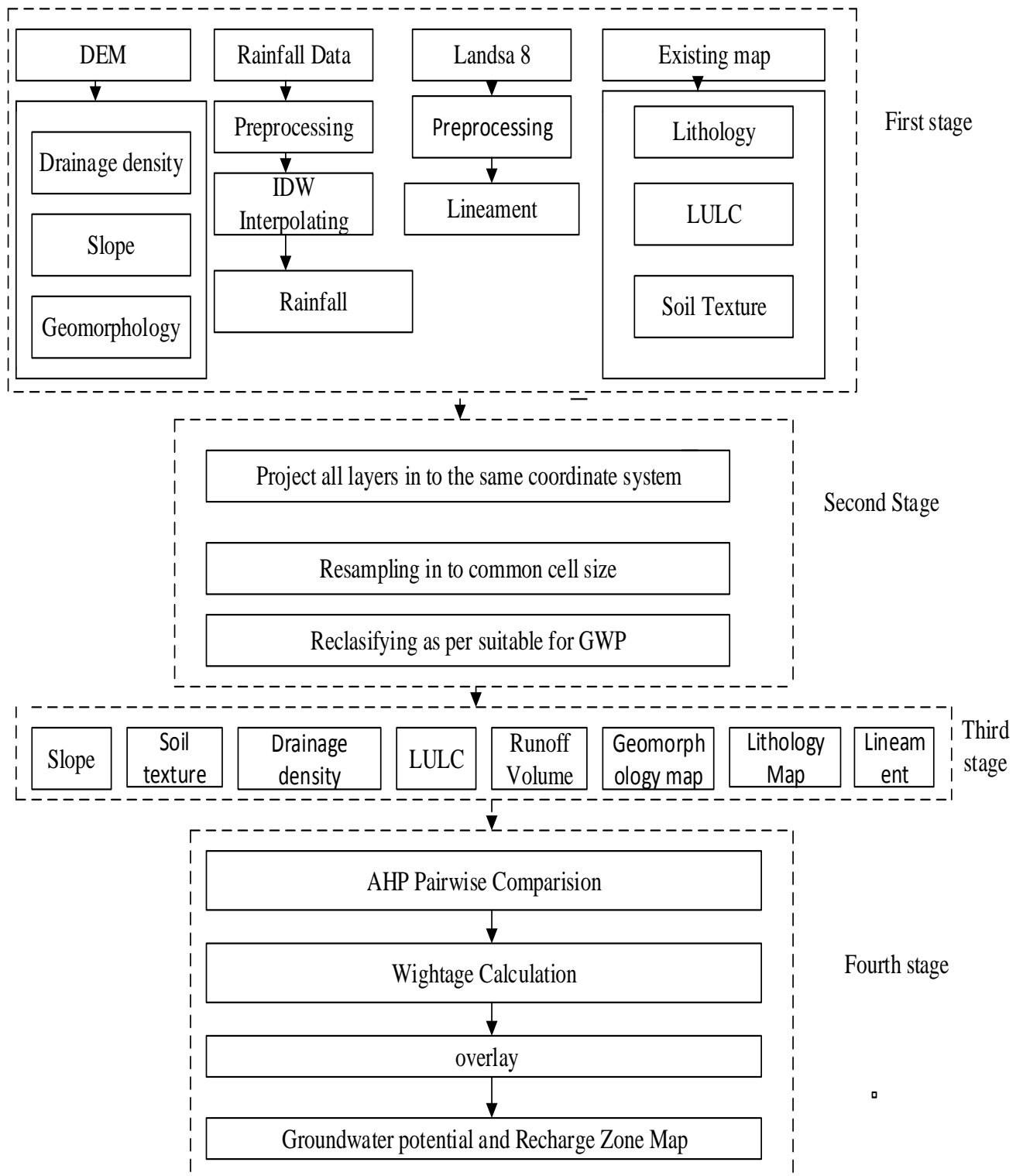


Figure 3. 6 : Flow chart of Methodology

3.3 Data Description and Software

3.3.1 Software

Table 3. 1: types of software used

No.	Software used	Version	Description
1	ArcGIS	10.2 and 10.5	For image preprocessing and thematic map generating
2	ERDAS	15	For image preprocessing, such us layer stacking and for other uses
3	PCI Geomatica	17	For lineament generation
4	Surfer	14.3	For 3-D visualization of land surface

3.3.2 Data Description

Hydrogeological data used for ground water potential and recharge zone of the study area and the summery of data descriptions are as follows.

- Metrology data obtained from Ethiopia Metrological Agency and Ministry of Water Resources bureau for rainfall descriptions.
- Downloading Soil and rainfall Map from food and agricultural organization (FAO, 1998) data website for land-use/land-cover mapping.
- Water sources inventory data from Afar regional state, Oromia and Amhara. Water Resource Development Bureau and zonal water offices for validations of groundwater potentials result.s
- Geological Maps prepared by Geological Survey of Ethiopia 1:250,000 Scale for lithological mapping.
- Landsat8 (with path and row of 053/168, 054/167 and 054/168 scenes) from the year for lineament map January 2016 image of 30 m Resolution.

- Digital Elevation Model of 1 km Resolution for generation of slope, drainage density and geomorphology.

Table 3. 2: Data Used their Source

Data type	source	Output layer	Resolution
Rainfall	Metrological agency of Ethiopia	Rainfall, Runoff Depth	
Soil map	Food and agricultural organization	Soil texture	
Geological Map	Geological survey of Ethiopia	Geology map	
DEM	http://igskmncngs506.cr.usgs.gov/gmtd	Drainage, slope	1 km
Landsat8	USGS	Lineament	30 m

3.4 Input Dataset

The input layers were prepared for multiple variables such as thematic maps of Slope, drainage density and geomorphology map generated from DEM data of 1km resolution. Lineament map of 30 m resolution from Landsat 8 and manually digitized from geological map of Ethiopia. Land-use land-cover map from Food and Agricultural Organization, runoff joining of land-use land-cover and soil texture and rainfall by simple empirical formula.

Lithology was prepared from geological survey of Ethiopia maps sheets of Wara Ilu, Ayelu Terara, Debribhan, Diredawa, Nathreth and Bedesa sheet by mosaicking and digitizing from 1:250,000 scale.

Rainfall map was interpolated in ArcGIS 10.5 from available Metrological data of ten years two thousand six to two thousand fifteen from of twenty six stations of Abayater, Afdem, AliyuAmba, Ankober, Arbabordade, Argoba, Asabae, Teferi ,Asebot, Ataye,Awashb Arba ,Awash sebat Kilo, Bedesa, Kora, Kuni, Koreberte, Meteha Bila, Mieso, Mezezo, Shewa Robit, Shola Gebeya and Gelemso. Rainfall data of 1km resolution from FAO (1998) used for preparation of layers as parameters. Each factor map was prepared in a manner that can support to the overall goal of groundwater potential and recharge zone mapping, the digitized vector layers and prepared input layers were changed and resampled to raster layers of 1km cell size in order to make appropriate for the overlay analysis.

To evaluate groundwater potential and recharge zone the necessary parameters were prepared for each layer and resampling to a common spatial resolution as per suitable for overlaying, weighting as per suitable for groundwater potential and recharge controlling capacity and each of thematic maps was computed by AHP pairwise comparisons.

3.5 Identification Criteria for Groundwater Potential and Recharge Zone Mapping

Parameters influencing groundwater potential and recharge and their relative importance are taken from previous literature. The exactly the same factors were combined and only representative parameters were selected. The others uses lithology, geomorphology, land use land cover, lineaments, slope, soil, drainage density, rainfall and runoff which affects groundwater potential and recharge as the major parameters (Sajikumar and Gigo, 2013; Mahswaran *et al.*, 2016).

Geology

The types geology that exposed to the surface are highly affect groundwater recharge by controlling the percolation and flow of water to the ground Shaban *et al.* (2005) and geology plays a great role in the occurrence and distribution of groundwater potentials zone. Each lithological unit and their aquifer characteristics described in Table 3.3

Table 3. 3 : Lithology and its aquifer characteristics

Factors	Lithological unit	Aquifer characteristics
Lithology	Sedimentary rocks	Very high
	Igneous rocks	Moderate
	Metamorphic rocks	Low

Source: (Mwega, 2013)

Geomorphology

Geomorphology describes the landform and structural features including; hills, plateaus, pediment/Pedi plain and rift floor that helps to understand the characteristics of the hydrological formations of one area. The value of geomorphology vary in terms of their characteristics and spatial distribution for groundwater potential and recharge processes as presented in (Table 3.4).

Table 3. 4 : Reviewed Geomorphology effect on groundwater potentials

Factors	Class	Rank	Groundwater potential
Factors	hill	1	Very Poor
	plateau	2	Poor
	Pediment/Pedi plain	3	Moderate
	Valley/flat	4	Good

Source: (Nagaraju, 2016)

Lineament density

Mogaji *et al.* (2011) Lineaments are the structural discontinuity of the earth surface such as faults, foliations, joints, and bedding planes. also a mappable linear features present on the surfaces indicates the zone of weakness and structural discontinuities it may be curve, linear and slightly curve which is the most essential for the infiltration and movement of water to the ground as described in (Table 3.5)

Table 3. 5 : Lineament Density

Factors	Criteria Value in km/km²	Classification
Lineament density	0 – 0.34	Very low
	0.34 – 0.99	low
	0.99 – 1.57	Moderate
	1.57 – 2.11	High
	2.11–2.69	Very high

Source: (Waikar and Aditya, 2014)

Slope

HsinFuYeh (2016). Slope is one of the factors controlling infiltration of water to the ground and the indicator of groundwater potential suitability. A high sloping region causes more runoff and less infiltration and have poor groundwater prospects compared to the low slope region. Low sloping regions causes less runoff and high infiltration rate and have good ground water prospect as shown in (Table 3.6).

Table 3. 6: Role of Slope for groundwater potential and recharge

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

Source: (Maheswaran *et al.*, 1999)

Drainage density

Drainage basin is the natural draining of water runoff to lowland or to a common point. Drainage density and type of drainage indicate the information of rock and soil permeability, infiltration of water and surface runoff (Horton, 1945). There are several types of drainage network, dendritic drainage, rectangular, parallel drainage and coarse drainage.

Table 3. 7: Drainage Density for groundwater potential and recharge

Drainage density(km/km ²)	description	Ranking in words	Ranking in words
0 – 0.5	Low density	Good	1
0.5 – 1.0	Moderate density	Moderate	2
1.0 – 1.5	High density	Poor	3
1.5	Very high density	Poor	3

Source: (Salwa, 2014).

3. 6 Reclassified Thematic Map of the Study Area

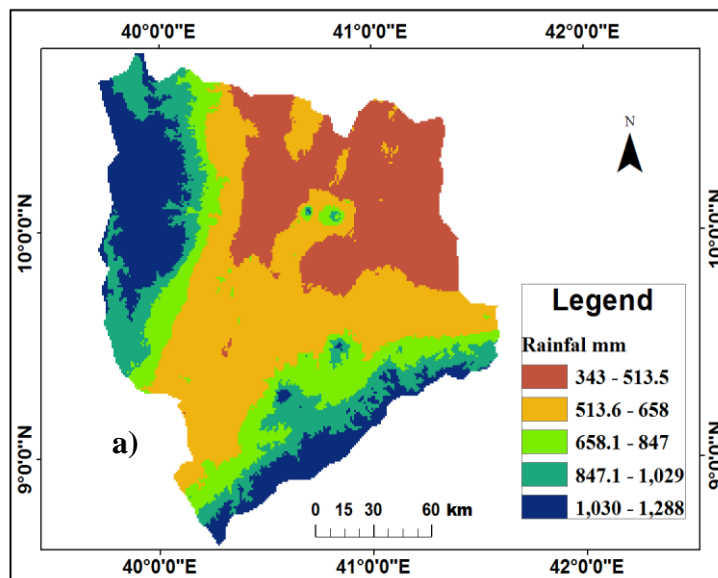
Parameters influencing groundwater potential and recharge and their relative importance were reviewed from previous literature and from hydrological experts. These study uses lithology, geomorphology, land use land cover, lineaments, slope, soil, drainage density, rainfall for groundwater potential and rainfall, runoff depth, slope, geomorphology, soil texture, drainage density, geomorphology and lithology for groundwater recharge which affects groundwater potential and recharge. In determining the value given to each parameters and in establishing the level of desirability of each attribute, different measurements and ranges was used where most applicable to existing national norms and standards.

3.6.1 Rainfall

Rainfall is the most factors for the formation of ground water potential and recharge. The rainfall map of the study area is shown in (Figure 3. 7). The northwestern and southeastern part of the study area receives very high rainfall of around 1030 – 1288 mm/year; the southeastern and northwestern part receives high rainfall of around 847 – 1029 mm/year. The northwestern and southeastern highland foot receives moderate rainfall 658 – 847 mm/year. The central rift floor receives low rainfall 513.5 – 658 mm/year. The eastern rift floor part receives very low rainfalls (343 – 513.5 mm/year as presented in Table 3.8. The high rainfall distribution along high slope gradient in the northwest and southeast highland parts directly affects the infiltration rate groundwater potential zones in the downstream central rift floor of the study area.

Table 3. 8: Rainfall and its rank as per suitable for groundwater potential and recharge

factors	Value in mm	Rank in word	Rank in number
Rainfall	343 – 513.5	Very low	1
	513.5 – 658	low	2
	658 – 847	moderate	3
	847 – 1029	high	4
	1030 – 1288	Very high	5



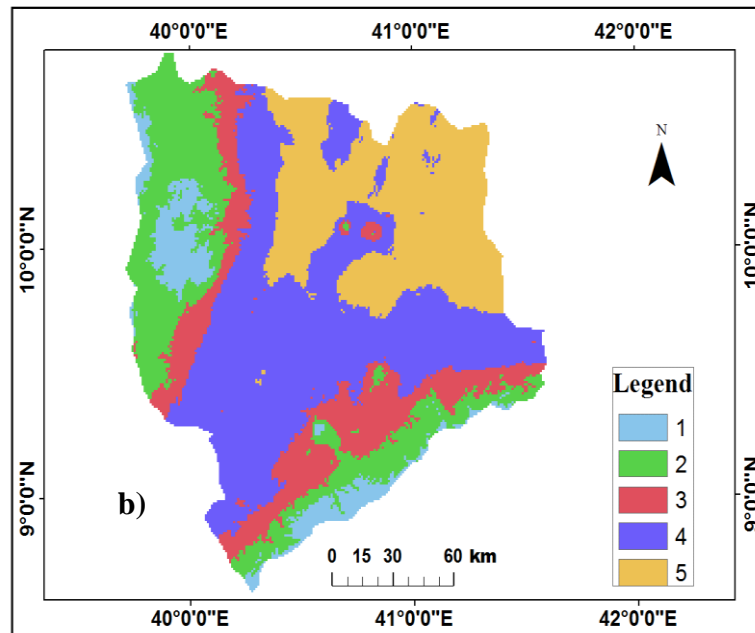


Figure 3. 7: a) Rainfall map and b) Reclassified Rainfall map of the study area

3.6.2 Drainage Density

Drainage density is the natural flowing of water runoff to lowland/ common point. It indicates behavior of surface and subsurface formation, the information of rock, soil permeability, infiltration of water and surface runoff (Mishra, 2013). The structural Drainage network used to explain the characteristics of groundwater potential and recharge zone as shown in Table 3.9. The area where High drainage density values have high runoff and indicates low possibility of groundwater availability and hence higher weights are assigning to the low drainage density area and vice versa. (Domingos *et al.*, 2015, Agrwal and Grag, 2015).

Drainage density preparing from Digital Elevation Model (DEM) by line density tool ArcGIS 10.5 and reclassified into five categories as shown in Figure 3.8 (a and b). Very high drainage density recorded at the volcanic mountains and near the mountain foots and very low drainage density recorded at the central rift floor area and some part of the high lands.

Table 3. 9: Drainage Density and its rank as per suitable for groundwater potential and recharge

Factors	Km/km ²	Rank	Rank in words
Drainage Density	≤ 0.146 – 0.48	1	Very high
	0.48– 0.63	2	High
	0.630743 – 0.73	3	Moderate
	0.73 – 0.84	4	Low
	≥ 0.84	5	Very low

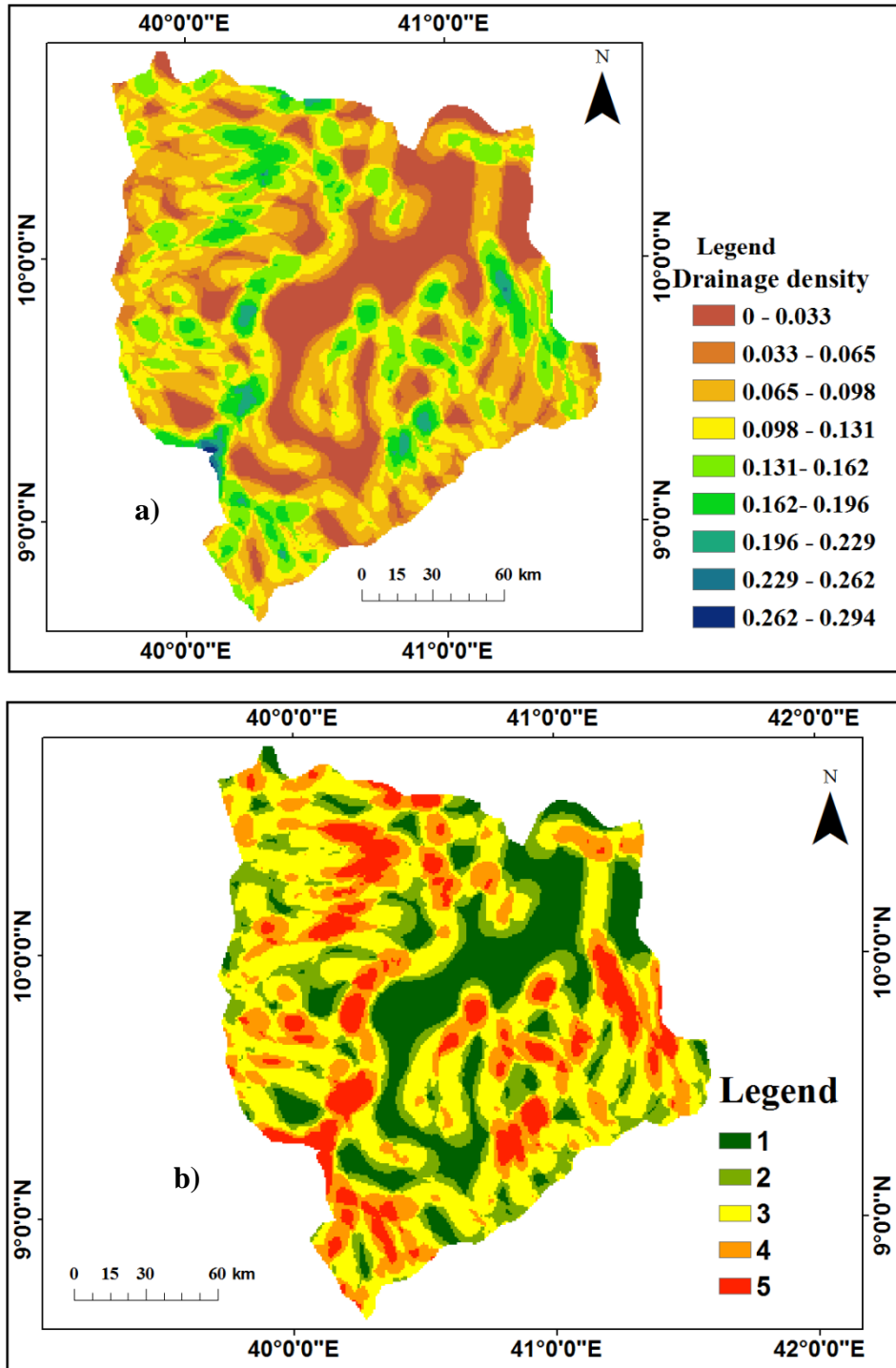


Figure 3. 8 : a) Drainage density map and b) Reclassified drainage density map

3.6.3 Slope

Slope is the steepness or the change of elevation between two locations and it has a direct influence on ground water recharge (Chowdhury, 2009). High slope regions have high runoff and low

infiltration rate that are not suitable for groundwater recharge, because of water cannot get enough time to infiltrate to the ground (Chenini *et al.*, 2010). The slope map of the study area was prepared based on the Digital elevation model data using the spatial analysis tool in ArcGIS 10.5. Based on these result, the slope of study area was divided in to five classes namely; flat, gentle, moderate, high and steep slope. The generated map was reclassified and ranking depend on their groundwater potential and recharge influence as shown in Figure 3.9. The highest rank was given to flat slope because, flat area have ability to hold water which are very easy for infiltration of water to the ground and the lowest rank was assigned for steep slope because they result to high runoff and low infiltration which cause low groundwater recharge as shown in Table 3.10. About 88 percent of the study area are categorized under very low slope/flat, 10 percent are medium slope, 1 percent are under very steep slope.

Table 3. 10: slope value of and its rank as per suitable for ground water potential and recharge

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

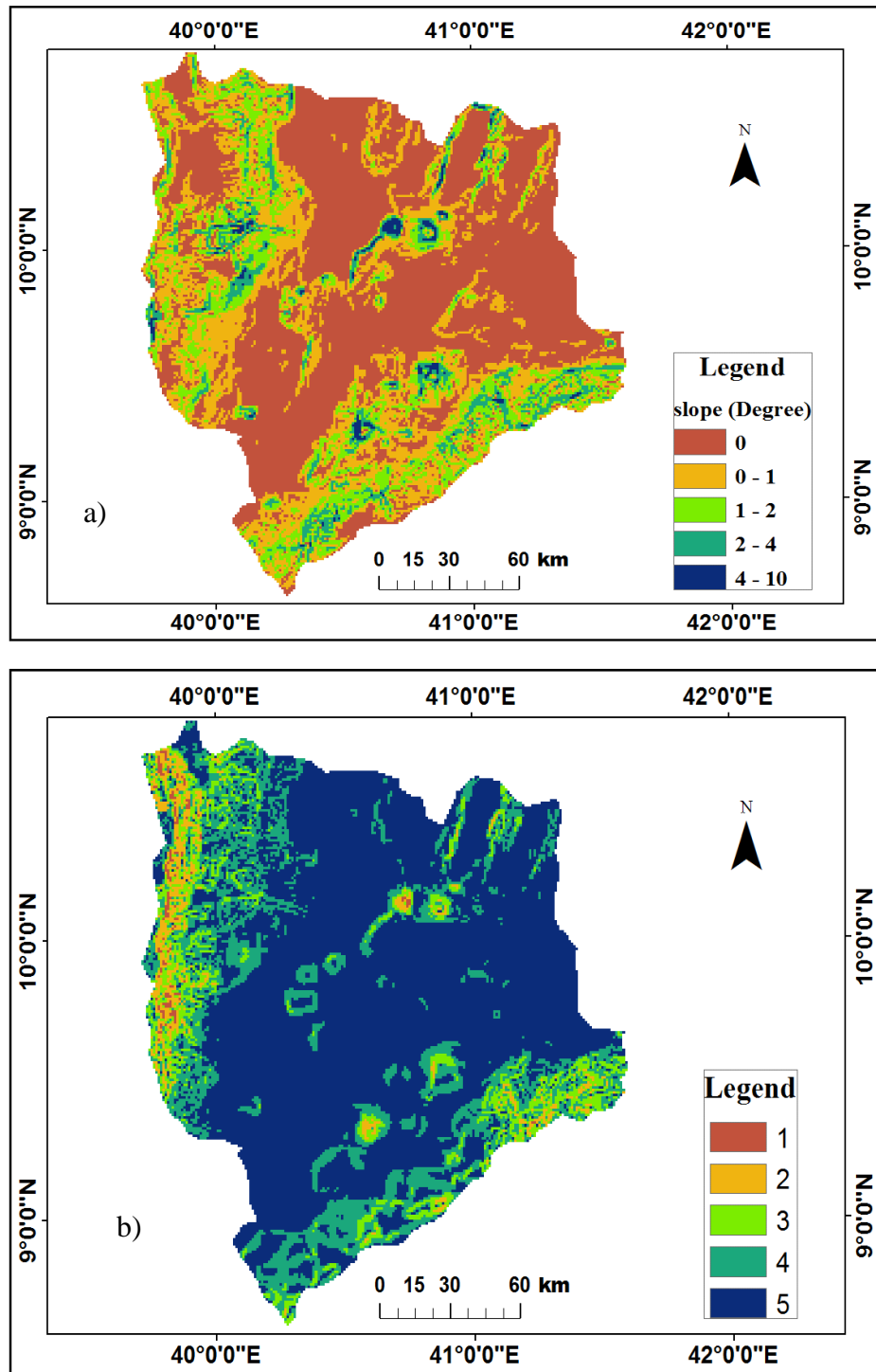


Figure 3. 9: a) Slope map and b) Reclassified slope map of the study area

3.6.4 Lineament Density

Lineaments are the structural discontinuity of the earth surface such as faults, foliations, joints, bedding planes and mappable linear features present on the surfaces. It may be curve, linear and

slightly curve which is the most essential for the infiltration and movement of water to the ground (Morelli and Piana, 2006). High lineament density area are good for ground water recharge and low lineament density are less suitable for groundwater recharge and discharges. The lineaments for this research are extracted from geological map of the study area aligned to south east to north western which are understood from Figure 3.10 . The direction of lineaments of the study area are towards the direction of the tributaries and wetlands, which suggests that the direction of aquifers mostly tends to be aligned with the surface water bodies. The runoff from the points of lineaments is towards the direction of the valleys cause for the high productive of groundwater recharge (Abdullahi *et al.*, 2013). The lineament density done by the line density in ArcGIS tools and classified in to five categories 0 – 0.1, 0.11– 0.23, 0.23– 0.40, 0.40 – 0.46 and 0.46 – 0.54 km/km² as presented in Table 3.11. The lineament density was relatively high in west and east of the study area when compared with the other areas and very less at the west northern, north eastern, central south eastern of the study area. The place having very high lineament density, the infiltration rate of the ground water will be more and the place were low lineament density, the infiltration rate of the groundwater will be less.

Table 3. 11 : Lineament density and its rank as per suitable for groundwater potential and recharge

Factors	Km/km²	Rank	suitability
Lineament Density	0 – 0.0728	1	Very low
	0.0728 – 0.1455	2	Low
	0.1455 – 0.2183	3	moderate
	0.2183 – 0.3639	4	High
	0.3639 – 0.655	5	Very high

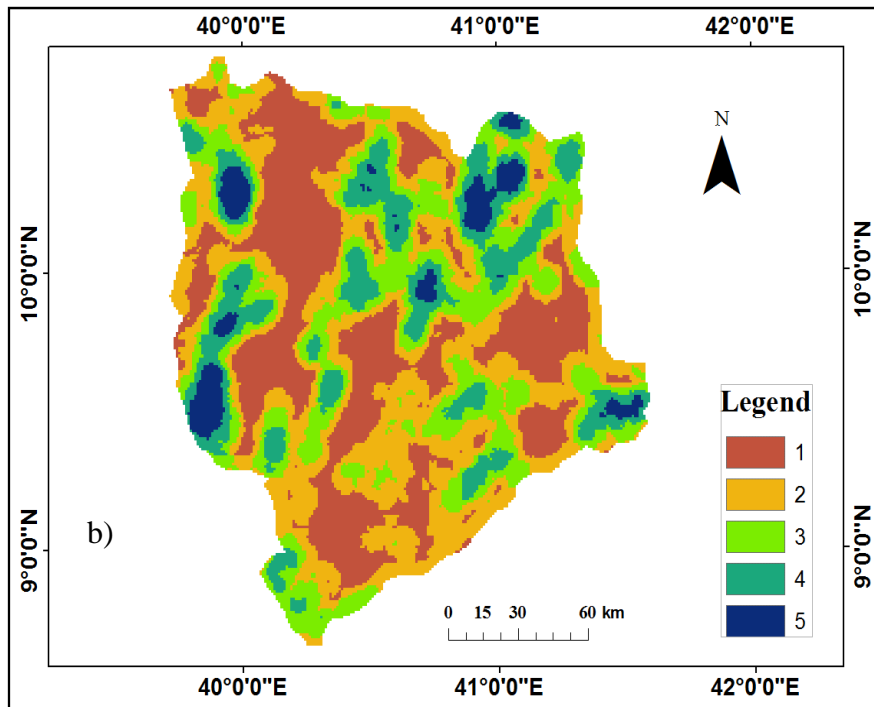
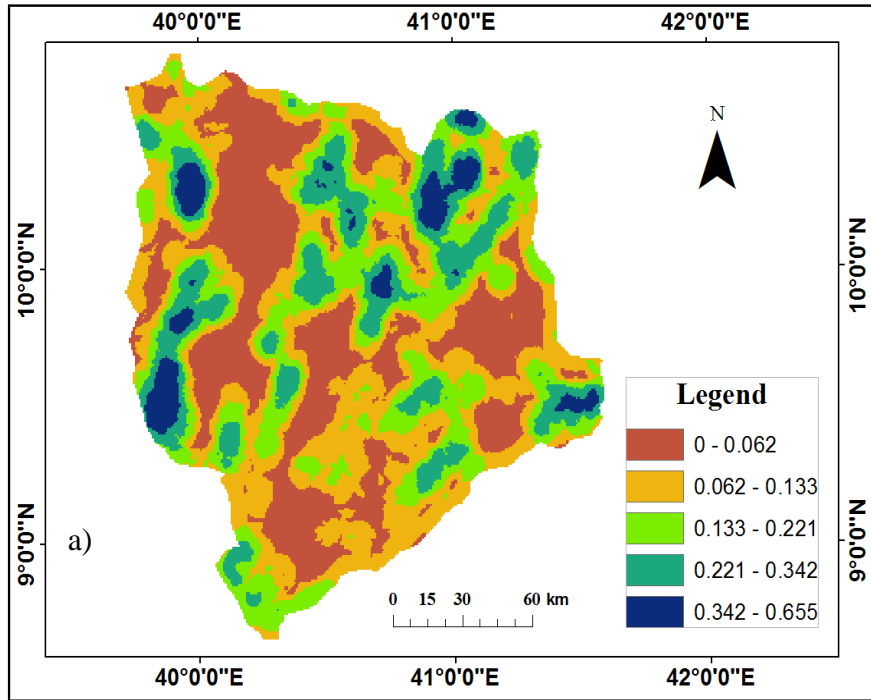


Figure 3. 10: a) lineament density map and b) reclassified lineament density map of the study area

3.6.5 Soil Texture

Soils are the most important factors for ground water recharge and its quality. The percolation or infiltration rate of water to the water tables influenced by soil permeability. Soil texture of the study area reclassified into five classes based on (FAO, 1998) shown in Figure 3.11 and their hydrological soil group (HSG) properties are described by Universal Soil Data Analysis (USDA) Class – 1 (clay, Soil group D): It covers small amount of highland of northern and eastern of basins have hydrological properties of Highest runoff potential and very low infiltration rates have mainly clay soil as described in Table 3.12.

Class – 2 (Sandy Clay, Loam, soil group C): cover the western, eastern southern and central part of the study area in small amount and have hydrological properties of low infiltration rates and consists of chiefly of soils with moderate fine to fine textures.

Class – 3 (Sandy Loam, soil group A) Covers large part of southern, western and northern of the study area have hydrological properties of low runoff and high infiltration rates consists mainly of deep well excessively drained sand or gravels. Class – 4 (Loam, soil group B) covers small part of the study area to the eastern and have hydrological properties of moderate infiltration rates of consists moderately fine to moderately coarse textures and Class – 5 wetlands (soil group A)

Table 3. 12 : Soil texture and their rank as per suitable for groundwater potential and recharge.

Factors	Classification	Rank in words	Rank in numbers
Soil texture	Clay	Very poor	1
	Clay loam	Poor	2
	Sandy clay loam	Moderate	3
	Sandy loam	High	4
	Sandy and wetland	Very high	5

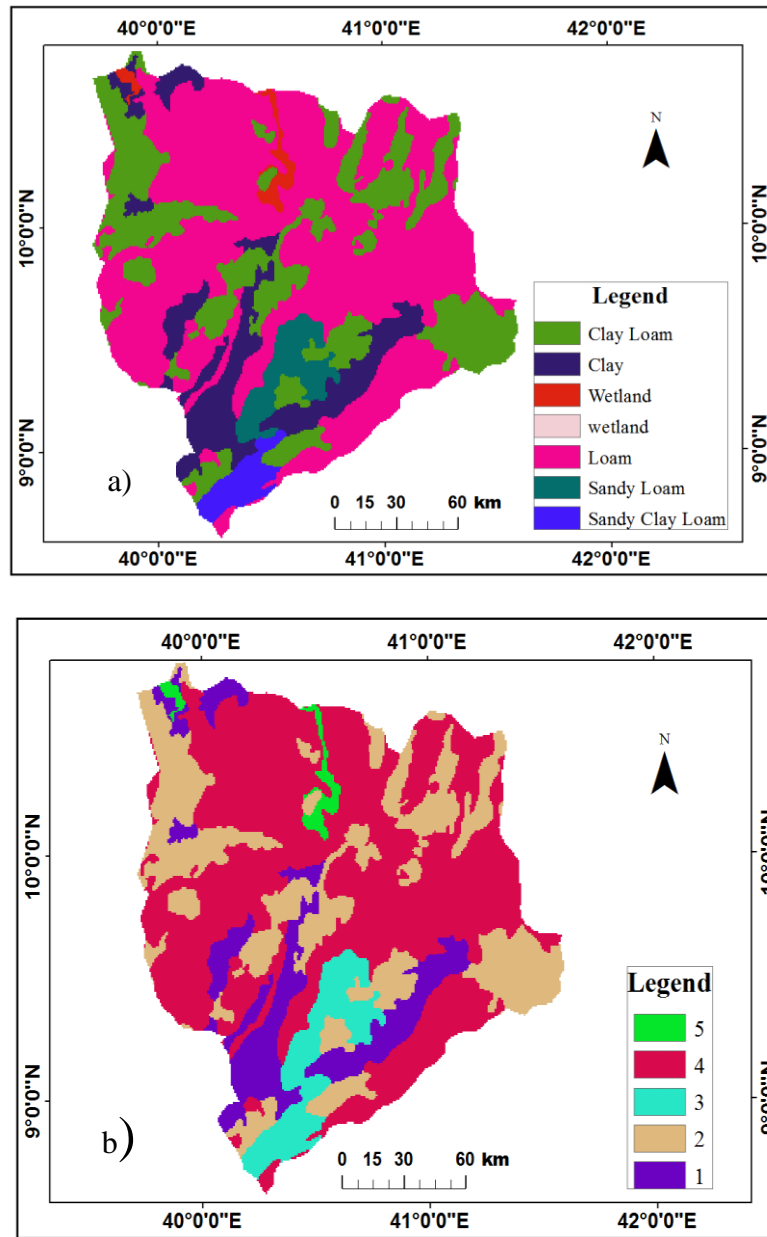


Figure 3. 11: a) soil texture map and b) reclassified soil texture map of the study area.

3.6.6 Land-use/Land-cover

Land-use/land-cover have a direct effect on the hydrological process of surface runoff, evapotranspiration and groundwater recharge. Water body, agriculture land and the waterlogged area are excellent sources of groundwater recharge, while the bare lands and exposed rock surface areas are less important for groundwater recharge as shown in Table 3.13. The Land-use/land-covers of the study area were taken from FAO (1998) data and the area highly covered by shrubs and exposed rocks, bare land, built up area, forest, dense forest, grass land and cultivated lands. The rift valley were covered by bare lands, exposed volcanic rocks and sandy soil sparse vegetation. While still to some extent the riparian vegetation occur along considerable stretches of mainstream Awash river. The northeastern and southeastern escarpments are predominately shrublands, croplands. Shrubs and grasses mainly cover the pediment slopes along escarpment margins as presented in Figure 3.12.

Table 3. 13 : land-use/land-cover and its rank as per suitable for groundwater potential and recharge.

Factors	Classification	Rankin numbers	Rankin words
Land-use/land-cover	Bare land, rock outcrops, settlement and lava flow	1	Very poor
	Annual crop land	2	Poor
	Sparse forest, open grassland and wood land, open shrub land, closed shrub land and closed grass land	3	Moderate
	Dense forest and open grass land,	4	High
	Wetland and water body	5	Very high

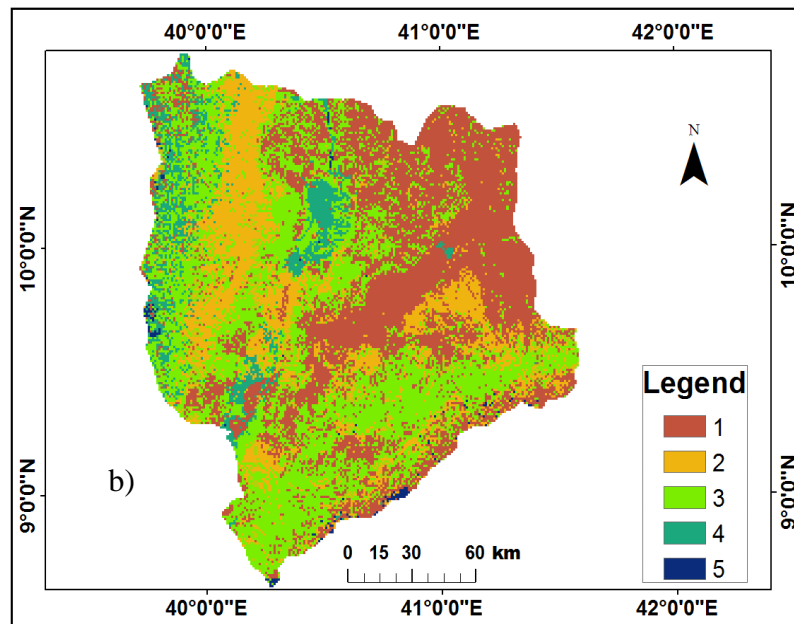
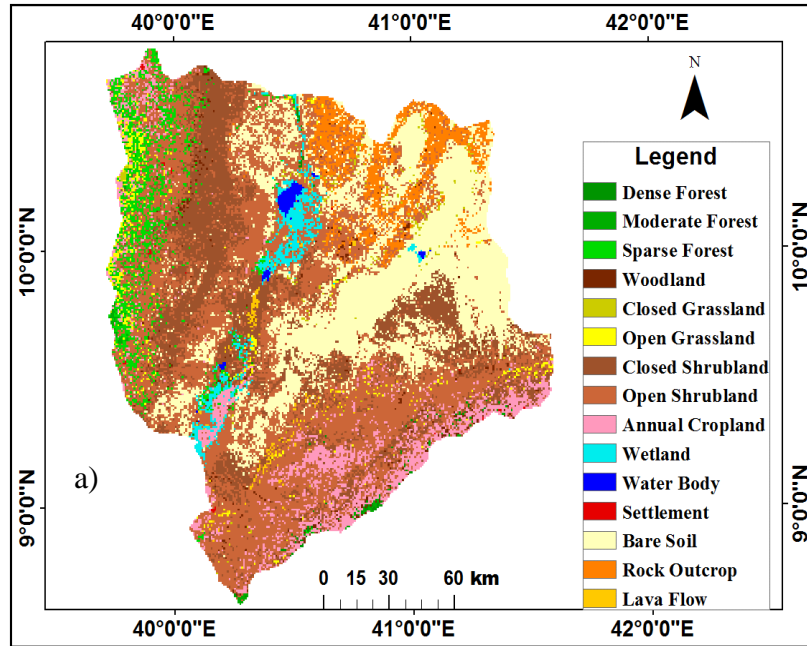


Figure 3. 12: a) Land-use/Land-cover map and b) Reclassified Land-use/Land-cover Map of the Study Area.

3.6.7 Geomorphology

The identification and characterization of various landforms and structural features in the study area are very important from geomorphological study point of view. Which are mandatory for groundwater potential and recharge zone (Shifaji and Nitin, 2014). The geomorphology reclassified in terms of groundwater recharge and potential the geomorphology of the study area classified in to five units: Structural hills, flood plains, residual landform, evaporate and volcanic land form. Locationally, structural hills to the eastern and southern part of the study area, flood plain or flat land to the central and northwestern of the area, volcanic landforms to the central and small part to the eastern of the area, residual landforms to the southern and western part, evaporate small part to the northeastern of the Study area. There is a maximum runoff associate with Landforms which characterized by hills slope. This shows poor Potentiality for groundwater potential and recharge possibility. However, there is a small portion of land, which has high elevation compared to local surrounding land. By extraction of various classes of geomorphology, a thematic map for geomorphology generated as shown in Figure 3.13. The rank assigned to the individual landform classification according to its respective influence of groundwater occurrence, holding and recharge, as presented in Table 3.14

Table 3. 14 : Geomorphology and its rank as per suitable for groundwater potential and recharge

Factors	Geomorphic units	Ranking in word	Ranking
Geomorphology	Volcanic landform	Very poor	1
	Residual landform	Moderate	3
	Structural landform	Poor	2
	Alluvial landform	Good	4
	Flat or flood plain	Very good	5

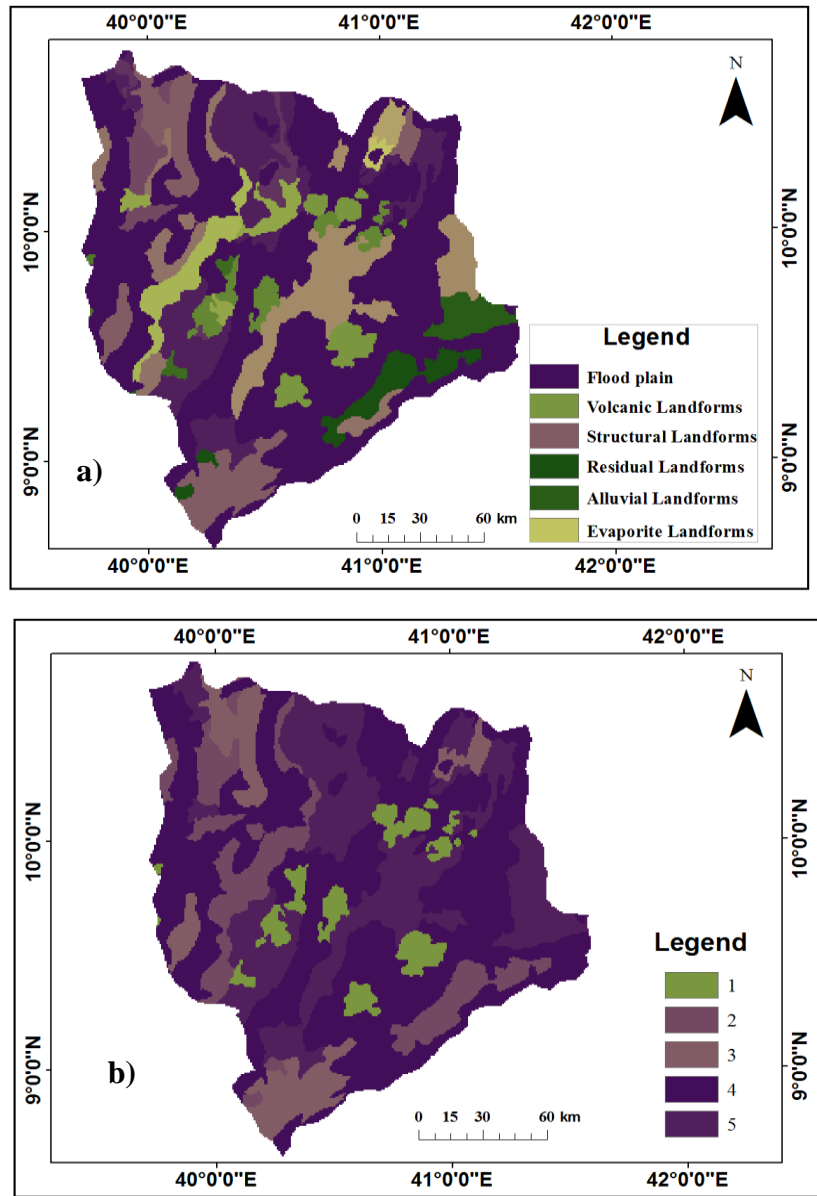


Figure 3. 13: a) Geomorphology map and b) Reclassified Geomorphology map of the study area

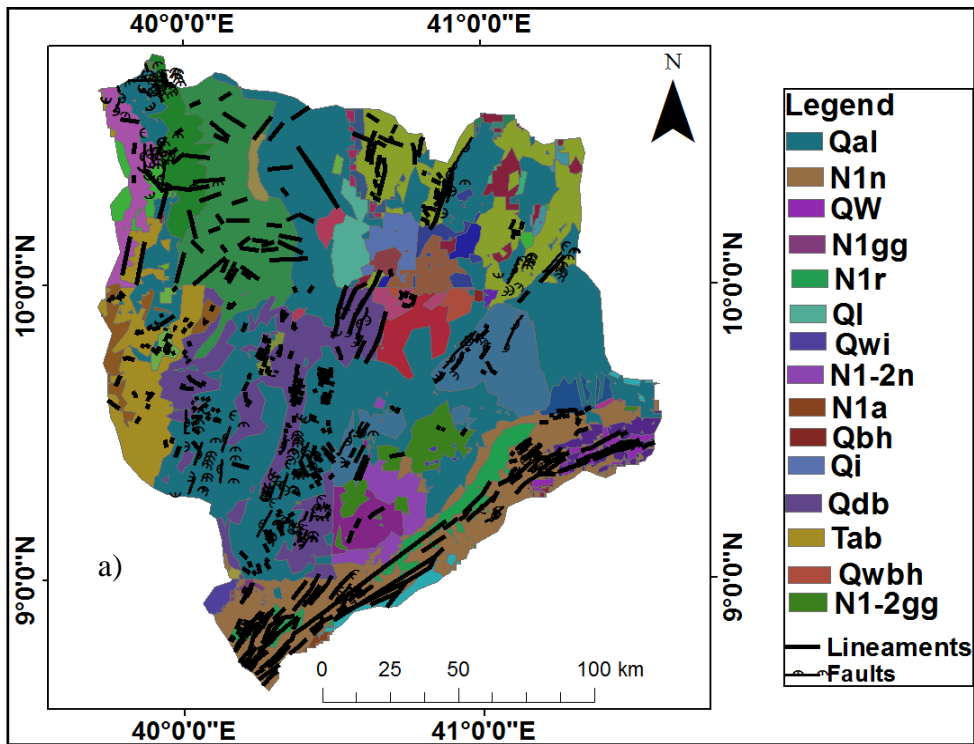
3.6.8 Geology

The way of Geologic formation and genetic type is essential condition for ground water flow, transport and mineral composition. Types of rocks determine peculiarities of hydrological cross-section structure, type of porosity values, the nature of permeability, geological structure geomorphology and character of spatial heterogeneity of flow and transport parameters. Lithological stratigraphy of the middle Awash River basins investigated by the Ethiopian Geological survey in different times as presented in (Figure 3.14). This area consists volcanic and

sedimentary rock units and the stratigraphic summary of the area described from the oldest to the youngest as follows:

Table 3. 15 : Geology and its rank as per suitable for groundwater potential and recharge

Factors	Classification	Rank in word	Rank in numbers
Geology	N1-2n and Qwi	Very low	1
	Qdb	Low	2
	N1gg and N1a	Moderate	3
	N1n,Tab,N1-gg,	High	4
	Qal, Ql and Qwbh, Qbh, Tab	Very high	5



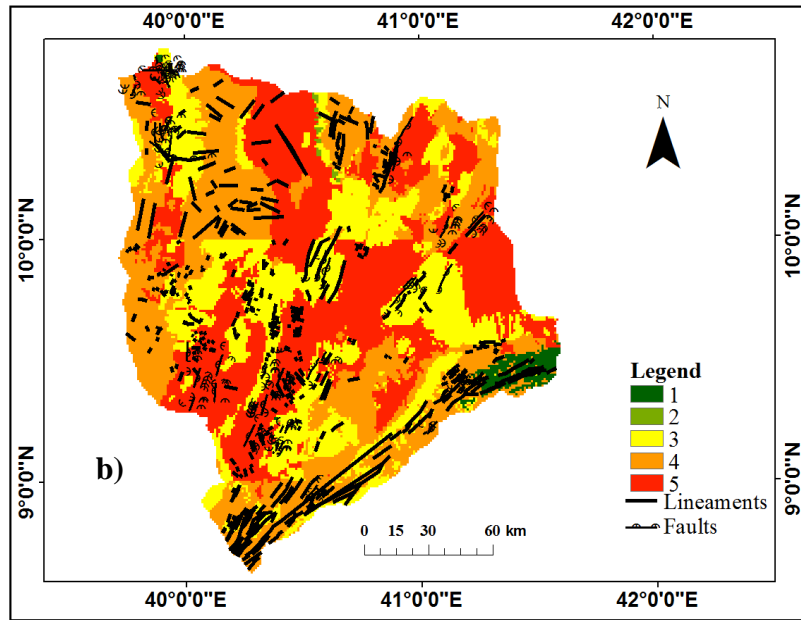


Figure 3. 14: a) Geological map and b) Reclassified geological map of the study area

Pre-rift basaltic succession (Qwbp); they are dominated by minor silica members (Jima volcanic –Tertiary volcanic) that, well exposed on the low land areas of middle awash basin with unbroken Succession and covers very small area. They also intensely jointed, hydrothermally altered and spheroidally weathered basalt outcrops in the western escarps of the Lake Abaya graben (Mengesha *et.al*, 1996).

Nazereth-Group (N1n, Nrn, N1gg, N1-2a) the name Nazeret Series was given to a thick succession of welded ignimbrites with flame, pumice, ash and rhyolite flows and domes with rare intercalations of basalt flows which occur in the Main Ethiopia Rift, rift margins and adjacent plateaus (Meyer *et al.*1978 as cited Mangesha *et al.*, 1996). In composition, the ignimbrites are sub-alkaline rhyolites and trachyte with rare peralkaline varieties. The Nazereth formation widely covered southern and western part of the study area.

Dino Formation (Qw, Qdp, Qw) these units are coarse unwedded pumiceous Pyroclastic mainly of light tuff and ignimbrite outcropped in most part of low land of the southwest, west and north of the study area. The ignimbrite outcropped contains coarse quartz grains with joints displayed categorized under this formation

Quaternary ignimbrites (Qwi): This formation consist of Quaternary bimodal transitional basalt/peralkaline felsic volcanic products of Wonji Group. The volcanic products of Wonji Group

are intimately associated with lacustrine sediments related to ancestral lakes in the rift floor (in the fluvial periods of Pleistocene) covers small low land part of the study area.

Rhyolites (Qwa): The units mainly covers small part of study area; composed of ash and pumice deposits, Trachytic lava flows from the volcanic centers near gewane area and exposed rocks of light greenish gray, porphyritic trachyte which show cooling joints and more weathering near the flanks of the shield.

Lower quaternary Basalts (Qwbh): It is basaltic eruptions with lines of scoria cones making fault traces and the interstratified with the earlier succession of lake sediments exposed in the low land of the study area.

Volcanic Lacustrine –Sediments (Ql): covers mainly the floor of the depression near rivers and essentially lacustrine sediments of mainly volcanic origin and were related to the existence of large lakes during Pleistocene times (Mohr, 1968). They are generally yellowish-gray colored, horizontally bedded and poorly sorted with fragments of rhyolite, obsidian and basalt in a matrix of ash and silt clay.

Alluvium and Fluvial deposits (Qal): fluvial deposits, lacustrine deltas and Colluvial outwash debris found widespread in the study area particularly along the foothills of the major fault scarps and low land areas. Recent deposits in the area include soils and alluvial sand deposits. The soils are mainly residual weathering deposits, whose composition controlled more by the physical condition of formations than by the type of rock from that they derived.

3.6.9 Runoff

Runoff is the over land flow of water that occurs when the excess storm water or other source are flow on the surface. to calculate the runoff there is formula that requires some inputs Curve Number (CN) which represents land-use /land-cover and soil textures and rainfall data.

3.6.10 Curve Number

The curve number of hydrological parameter used to describe the storm water runoff potential for drainage areas and function of land use, soil type and soil moisture (Shereif *et al.*, 2014) as well as the empirical parameters used in hydrology for predicting direct runoff infiltration from excess rainfall. The amount of infiltration of surface water or rainfall is determined by soil type and land use land cover. Generation of curve number requires Hydrological soil group (HSG) map, land use land cove map and drainage boundaries (Preston *et al.*, 1998). The hydrological soil group and soil relationship described in Table 3.15. Besides it is a dimensionless number and limited range 1-100

Table 3. 16 : Hydrological soil group and its hydrological properties

HSG	Soil content	Property
A	Sand, Loamy Sand	Low runoff potential and high infiltration rate
B	Silt Loam, Loam or Silt	Moderate infiltration rate
C	Sandy Clay Loam	Low infiltration rate
D	Clay Loam, Silt Clay Loam, Sandy Clay, Silt Clay or Clay Water Bodies.	Highest runoff potential and very low infiltration rates

Source: (Hong *et al.*, 2008)

Runoff depth is preparing the land-use /land-cover map and converting raster to polygon. Then after joining the land- use land- cover with soil texture map Table 3.1

Table 3. 17 : Curve numbers for selected land use land cover and hydrological soil group

LULC	HSG			
	A	B	C	D
Dense Forest	100	100	100	100
Moderate Forest	36	60	73	79
Sparse Forest	45	66	77	83
Wood Land	45	66	77	83
Closed Grass Land	68	79	86	89
Open Grass Land	68	79	86	89
Closed Shrub Land	45	65	75	80
Open Shrub Land	49	69	79	84
Annual Crop Land	67	78	85	89
Wet Land	49	69	79	84
Water Body	100	100	100	100
Settlements	80	85	90	95
Bare Soil	77	86	91	94
Rock Out Crop	90	93	95	96
Lava Flow	90	93	95	96

Source: (United States Department of Agriculture, 1986; Soulis and Valiantzas, 2012)

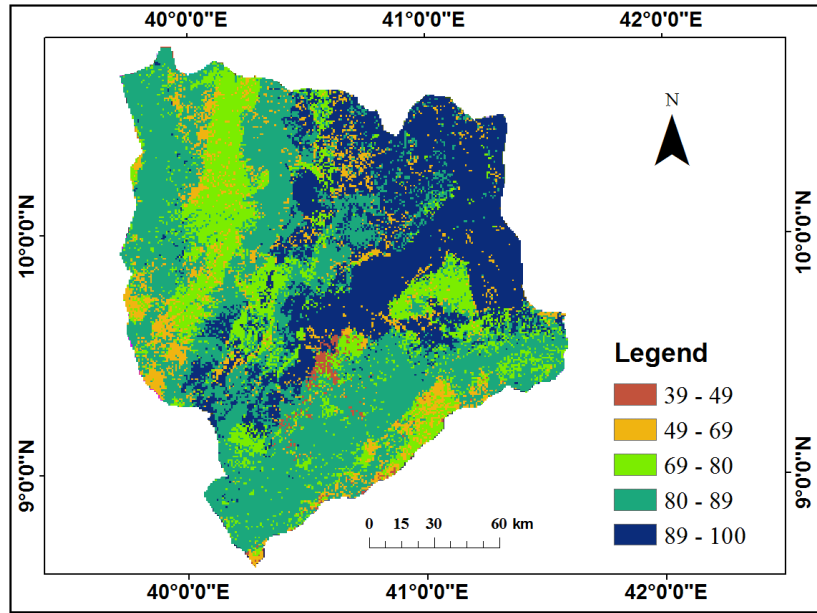


Figure 3. 15: Curve Number map of the study area

$$CN_{aw} = \frac{\sum_{i=1}^n (CN_i \times A_i)}{\sum_i A_i} \quad \text{Eq. (1)}$$

Where CN_{aw} = the area weighted CN for the drain age basins

CN_i and A_i = CN area for each land use land cover and soil group polygon respectively.

n = number of polygon in each drainage basins

$$Q = \frac{(P - I_a)^2}{(P - I_a)} + S \quad \text{Eq. (2)}$$

Q = runoff (mm) P = rainfall (mm)

S = Potential maximum retention after runoff begins

I_a = initial abstracts (mm)

$I_a = 0.2s$

Substitute the value of I_a in equation 2 for equation 3 results to calculate Q

$$Q = \frac{(P - 0.2s)^2}{(P - 0.2s)} + S \quad \text{Eq. (3)}$$

$$S = 254 \left(\frac{25400}{CN - 10} \right) \quad \text{Eq. (4)}$$

Where, CN is curve number for the time.

Table 3. 18 : Runoff and its rank as per suitable for groundwater potential and recharge zone

Factors	Value in mm	Rank in word	Rank in numbers
Runoff	116 - 431	Very low	1
	431- 537	Low	2
	537- 657	Moderate	3
	657 - 833	High	4
	833 - 1295	Very high	5

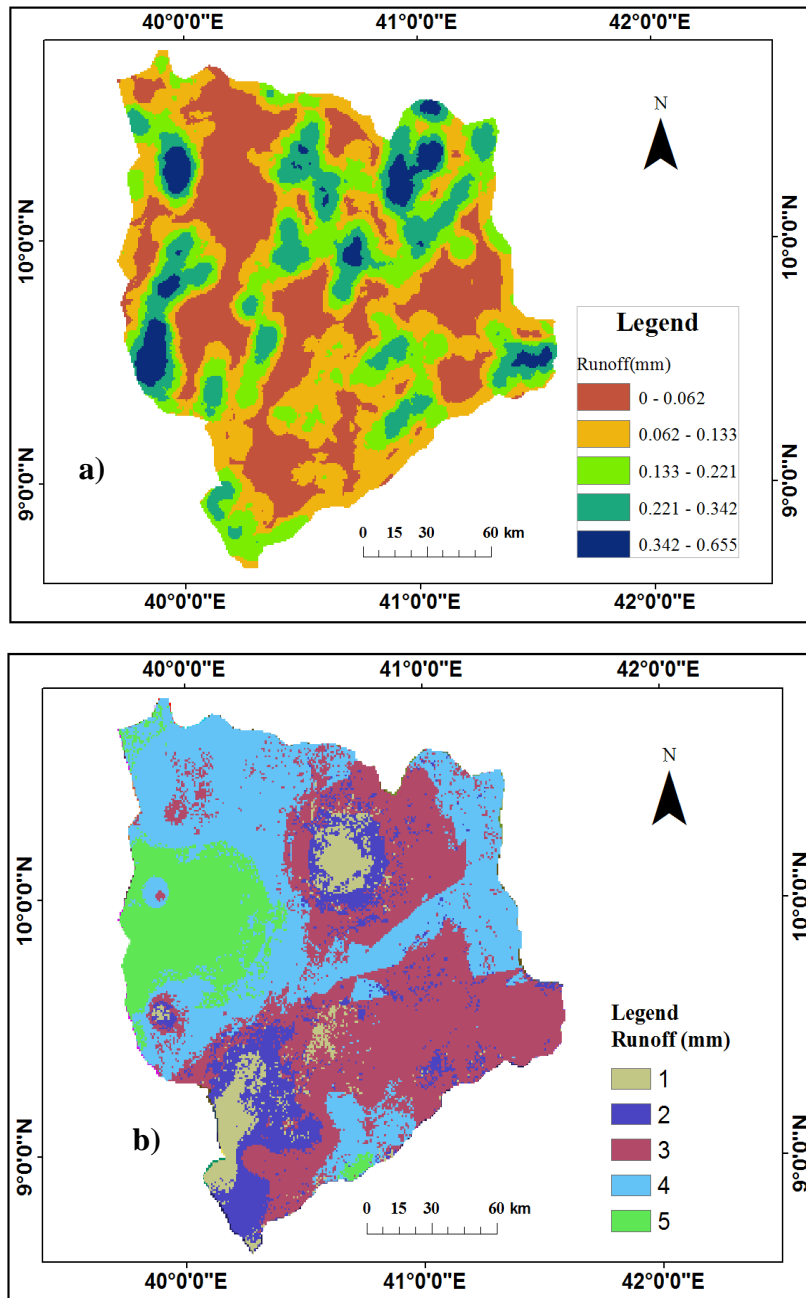


Figure 3. 16: a) curve number map and b) Reclassified Curve Number of the Study Area

3.7 Analytical Hierarchy Process

The analytical hierarchy process (AHP) is a theory of measurement by pairwise comparison and depend on the decision of experts to derive priority scales. The comparison was made on a scale of numbers 1–9 which shows how many times a layer is important than the other (Saaty, 1980).

(Table 3.18) represents the scaling used in AHP. If the matrix formed is equal to b_{ij} , $a_{ij} = w_i/w_j$, where w is the weight of each parameters, $i, j=1 \dots n$ of every positive numbers entry to everywhere and satisfy the reciprocal properties, $b_{ij} = 1/b_{ji}$ which is called reciprocal matrices.

Table 3. 19 : Saatty’s, scale of intensity relative importance

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

Source: (Saatty’s, 1980)

3.8 Weight Assessment and Normalization

The pairwise comparison matrix was carried out by using AHP techniques. To compute the cumulative weight of the main criteria, the relative weight of their corresponding classes were considered. Map Categorization and weight Assignment for groundwater potential and recharge parameters selected for groundwater potential and nine parameters selected for groundwater recharge potential zone. Categorization and weight Assignment for both Groundwater potential and recharge zones. Normalization of Assign Weight using AHP, on the basis of Saaty’s scale, considering two themes and classes at a time on the basis of their relative importance to determine the Groundwater Potentials and recharge zone. Thereafter, pairwise comparison matrices of assigned weights to different thematic layers and their individual classes are constructed using (Saaty’s, 1980) AHP and weights normalized by eigenvector approach. Consistency Ratio (CR) calculated to examine the normalized weights of various thematic layers and their individual classes according to Saaty (1980). To compute CR of various thematic layers and their individual classes, the following steps were carried out.

$$A_1 \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ \vdots & \ddots & & \vdots \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix}, a_{ij} = \frac{a_{ij}}{\sum a_{ij}} \text{ for } i, j = 1, 2, \dots, n \quad \text{Eq.(5)}$$

The eigenvalue and the eigenvector calculated as:

$$W = \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \end{bmatrix} \text{ and } W_i = \frac{\sum_{j=1}^n a_{ij}}{n} \text{ for all } i=1, 2, \dots, n \text{ and } W' = \begin{bmatrix} W_1' \\ W_2' \\ \vdots \\ W_n' \end{bmatrix} \quad \text{Eq. (6)}$$

$$\lambda_{\max} = \frac{1}{n} \left(\frac{W_1'}{W_1} + \frac{W_2'}{W_2} + \dots + \frac{W_n'}{W_n} \right) \quad \text{Eq.(7)}$$

W: Eigenvector,

w_i :Eigenvalue of criterion i, and.

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

CR is a measurement of consistency, of pairwise comparison matrix and it is calculated using equation

Consistency ratio is the indication of acceptability of reciprocal matrix, which calculated as the following

$$CR = \frac{CI}{RI} \quad \text{Eq. (8)}$$

Where CI is consistency index and RI is random consistency index

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad \text{Eq. (9)}$$

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

Table 3. 20 : Random consistency index

Matrix size	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1,24	1.32	1.41	1.45	1.49

CHAPTER FOUR

RESULT AND DISCUSION

4.1 Groundwater potential

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

4.1.1 Weight Assessment

The Relative weight for thematic layers(Rainfall, Slope, Geomorphology, Lineament density ,Drainage density, Soil texture, Land-use/Land-cover and lithology) were assigned according to their relative importance for each analyzed based on the judgment of works carried out by researchers or knowledge of expert gained through similar work on groundwater potential zone mapping (Tesfaye, 2012). To compare the importance of two layer maps show that one of them has more influence to the groundwater occurrence than the other.

Table 4. 1 : Relative weight for selected thematic layers

parame ters	Rf	Sl	Gm	Ln	Dd	St	Lulc	Lith
Rf	1	2.00	3.00	5.00	6.00	4.00	6.00	7.00
Sl	0.50	1	2.00	3.00	5.00	5.00	6.00	7.00
Gm	0.33	0.50	1	0.50	2.00	4.00	2.00	3.00
Ln	0.20	0.33	2.00	1	2.00	2.00	2.00	3.00
Dd	0.17	0.20	0.50	0.50	1	2.00	3.00	4.00
St	0.25	0.20	0.25	0.50	0.50	1	3.00	4.00
Lulc	0.17	0.17	0.50	0.50	0.33	0.33	1	4.00
Lith	0.14	0.14	0.33	0.33	0.25	0.25	0.25	1
Total	2.76	4.54	9.58	11.33	17.08	18.58	23.25	33.00

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

4.1.2 Weight Normalization

The weights were normalized based on the equation five (5), which are calculated by averaging the values in each row to get the corresponding ranking, which gives the results of normalized weights of each parameter as presented in Table 4.1. From the result, observed rainfall has the highest value rather than other parameters. Because, It indicate high rainfall have the possibility of high groundwater recharge thus high groundwater potential zones, while low rainfall indicates low groundwater recharge thus low groundwater potential zones. The main source of groundwater in the area was the rainfall of the northwestern and southeastern highlands the study area due to mountain block and slope.

TABLE 4. 2 : Pairwise comparison matrix and normalized weight

	Rf	Sl	Gm	Ln	Dd	St	Lulc	Lith	Wt	Wt (%)
RF	0.363	0.441	0.313	0.441	0.351	0.215	0.258	0.212	0.32	32
SL	0.181	0.221	0.209	0.265	0.293	0.269	0.258	0.212	0.238	23.8
GM	0.120	0.111	0.104	0.044	0.117	0.215	0.086	0.091	0.111	11.1
LN	0.073	0.073	0.209	0.088	0.117	0.107	0.086	0.091	0.105	10.5
DD	0.060	0.044	0.052	0.044	0.059	0.107	0.129	0.121	0.077	7.7
ST	0.091	0.044	0.026	0.044	0.029	0.054	0.129	0.121	0.067	6.7
LULC	0.060	0.037	0.052	0.044	0.019	0.018	0.043	0.121	0.049	4.9
LITH	0.051	0.031	0.035	0.029	0.015	0.013	0.011	0.031	0.027	2.7
TOT	1	1	1	1	1	1	1	1	1	100

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

4.1.3 Principal Eigen Vector

In order to check the weight assigned to each parameter in Table 4.2, the normalized principal Eigen vector value (λ_{max}) was computed depending on equation 6 and 7 to drive the formula of consistency ratio (equation 8). This was done by multiplying the weight of the first criterion (for example, Rainfall = 32) as shown in Table 4.2 with the total value that was found in the pairwise comparison matrix (for example, Rainfall =2.76) table 4.1. This was applied for the rest of seven factors as per equation 8. Finally, the summation of these values gives the consistency vector (λ_{max} of = 8.84) as shown in Table 4.3 for calculating consistency index.

Table 4. 3 :Normalized Principal Eigen vectors

Parameters	Normalized principal Eigen vectors
Rf	0.894
Sl	1.082
Gm	1.064
Ld	1.196
Dd	1.317
St	1.250
Lulc	1.147
Lith	0.891
λ_{max}	8.843

The consistency index was computed to overcome for the formula of consistency ratio and this was done based on equation 9, which results $CI = 0.120$. Then, consistency ratio was computed as per equation 8 and the computed result of $CR = 0.085$ that is less than 0.1 and the given weights was valid for further analysis. Groundwater potential zone map (GWPZM) was computed after checking all criterion as follows:

$$\mathbf{GWPZM} = \mathbf{0.32} * \mathbf{RRf} + \mathbf{23.8} * \mathbf{RGm} + \mathbf{11.1} * \mathbf{RSI} + \mathbf{10.5} * \mathbf{RSt} + \mathbf{7.7} * \mathbf{RLd} + \mathbf{6.7} * \mathbf{RDd} + \mathbf{4.9} * \mathbf{RLulc} + \mathbf{2.7} * \mathbf{RLith}.$$

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

Rainfall, slope, lineament density and geomorphology holds the highest value relative to the other parameters. The weight assigned for Rainfall were greater than the weight of other, which influence the occurrence of groundwater potential and recharge zone than others parameters (Mwega, 2013; Kamal *et al.*, 2016). The result for groundwater potential zones was classified in to very high, high, moderate, low and very low Figure 4.1.

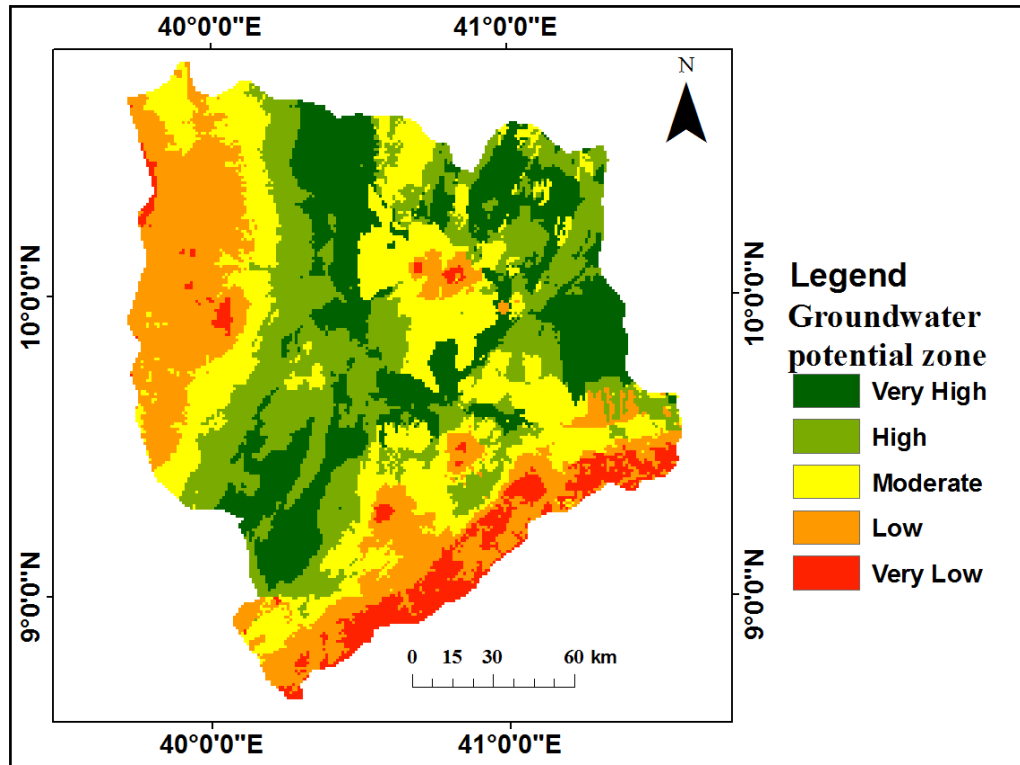


Figure 4. 1: Groundwater Potential Zone Map of the Study Area

The result of groundwater potential of the study area done by integration of all thematic maps to delineate groundwater potential zones. The results categorized in to five categories namely: very high, high, moderate, low and very low of groundwater potential zone Figure 4.1. Very low groundwater potentials cover 2688 km² of the study area, low groundwater potential covers 385 km² at the central rift floor of Gewane area around volcanic mountain of Afdem, southeastern and northwestern of the study area. Moderate groundwater potentials cover 6924 km² at the foot of northwestern and southeastern highlands and near horst and grabens. High to very high groundwater potentials are covers 9890 km² and 10575 km², respectively to the main rift floor lowland of the study area as shown in Figure 4.1.

Table 4. 4: Groundwater potential area and percentage of the study area.

No	Groundwater Potential zone	Area (km ²)	Area (%)
1	Very high	10575.6	34
2	High	9890.6	32
3	Moderate	6924.2	22
4	Low	2688.5	9
5	Very Low	385.3	1

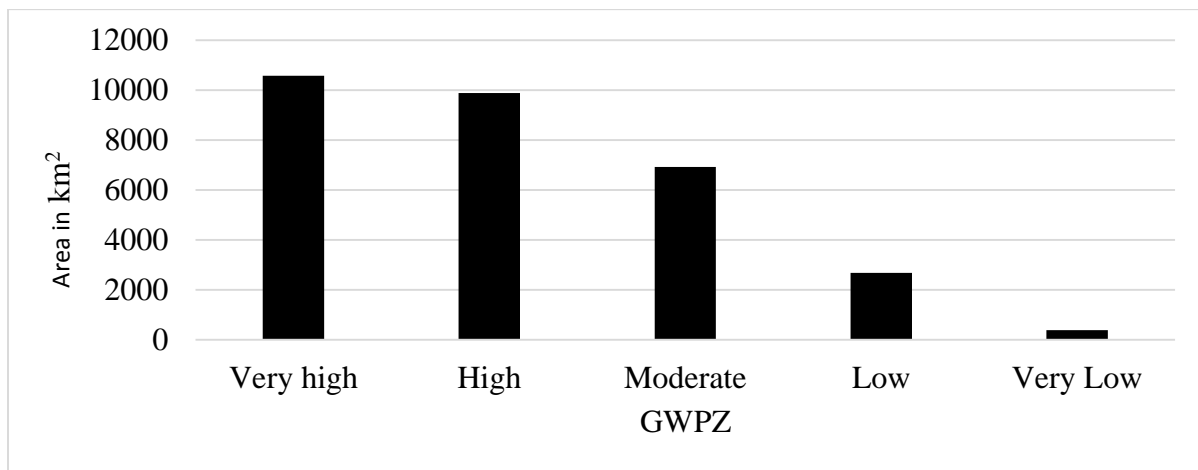


Figure 4. 2: Groundwater potential zone Area Coverage of the study area

Based on the normalized weighting of the individual features of the thematic layers, very high and high groundwater potentials was fallen in the alluvial plains in in the rift floors covers 34% and 32% percent respectively. Because of NE-SW, fault systems highly control the permeability of the rocks in the basin apart from other Parameters, in which most of the springs, marshlands and drainage lines following these weak zones that would support groundwater flow as shown in Figure 3.12.

Moderate groundwater potentials were found in foothills to the northwestern and southeastern highlands of the study area. Very low groundwater potential was found Northwestern, Southeastern and volcanic landforms between caldera and cones near Afdem and were mountains of gewane area, the northern and southern part of the study area.

4.2 Groundwater Recharge

The groundwater recharge zone investigation considers the analysis of thematic layers (rainfall, soil texture, slope, runoff depth, land- use/ land- cover, lineament, geomorphology, drainage density and lithology), which the same maps that were used for groundwater potential zone are mapping. The parameters values was given based on the saatty scale as shown in Table 4.5. As per the pairwise comparison matrix, the relative weight matrix and normalized Principal Eigen vector were calculated for getting the relative weights of the variables. The influence percentage of thematic layers and the rank for its parameters was assigned based on the judgment of works carried out by researchers or knowledge of expert gained through similar work on groundwater recharge mapping (Shifaji and Nitin, 2014).

Determination of the relative importance and the weight of each thematic map with another paired-comparison matrix was done by saatty importance scale. In this pairwise comparison matrix, the weight of consistency ratio value of groundwater recharge was computed and the result is less than 0.1 for all experts. This indicates that all experts' weightings are consistent and suitable for the implementation.

4.2.1 Weight Analysis

The relative weight importance between criteria was assigned according to a numerical scale from 1 to 9, as shown in Table 4.6, and it is assumed that the selected parameters were equally important or more important than others selected parameters. In this research, the relative Weight were assigned for delineating and mapping of groundwater recharge of thematic layers(Rainfall, Runoff, Slope, Soil texture, Lineament density, Drainage density, Land-use/land-cover and Lithology).

Table 4.5 : Pairwise comparison matrix

	Rf	Sl	Ro	Dd	Ld	Gm	Lith	St	Lulc
Rf	1.00	2.00	3.00	4.00	5.00	5.50	6.00	6.50	7.00
Sl	0.50	1.00	1.50	2.00	3.00	3.50	4.50	5.00	4.50
Ro	0.33	0.67	1.00	1.50	2.00	2.50	3.00	4.00	4.50
Dd	0.25	0.50	0.67	1.00	1.50	1.50	3.00	3.50	4.00
Ld	0.20	0.33	0.50	0.67	1.00	0.50	1.50	1.50	2.00
Gm	0.18	0.29	0.40	0.67	2.00	1.00	0.50	1.50	2.00
Lith	0.17	0.22	0.33	0.33	0.67	2.00	1.00	1.00	1.50
St	0.15	0.20	0.25	0.29	0.67	0.67	1.00	1.00	1.50
Lulc	0.14	0.22	0.22	0.25	0.50	0.50	0.67	0.67	1.00
Tot	2.93	5.43	7.87	10.70	16.33	17.67	21.17	24.67	28.00

Where, **Rf** = Rainfall, **Ro** = Runoff, **Dd** = Drainage density, **Ld** = Lineament density, **Gm** = Geomorphology, **Lith** = Lithology, **St** = Soil texture, **Lulc**= Land-use/land-cover

4.2.2 Weight Normalization

Weight normalization was calculated by averaging the values in each row to get the corresponding ranking, which gives the results of normalized weights of each parameter as presented in Table 4.6. These calculated weights were considered the total weight. From result observed rainfall have highest value and lithology have the lowest value. From the selected parameters, the weight assigned for rainfall was higher than the rest parameters this happened because of

Table 4. 6 : pairwise comparison matrix and normalized weight

Parameters	Rf	Sl	Ro	Dd	Ld	Gm	Lith	St	Lulc	wt	Wt (%)
Rf	0.34	0.37	0.38	0.37	0.31	0.31	0.28	0.26	0.25	0.32	32.00
Sl	0.17	0.18	0.19	0.19	0.18	0.20	0.21	0.20	0.16	0.19	19.00
Ro	0.11	0.12	0.13	0.14	0.12	0.14	0.14	0.16	0.16	0.14	14.00
Dd	0.09	0.09	0.08	0.09	0.09	0.08	0.14	0.14	0.14	0.11	11.00
Ld	0.07	0.06	0.06	0.06	0.06	0.03	0.07	0.06	0.07	0.06	6.00
Gm	0.06	0.05	0.05	0.06	0.12	0.06	0.02	0.06	0.07	0.06	6.25
Lith	0.06	0.04	0.04	0.03	0.04	0.11	0.05	0.04	0.05	0.05	5.00
St	0.05	0.04	0.03	0.03	0.04	0.04	0.05	0.04	0.05	0.04	4.00
Lulc	0.05	0.04	0.03	0.02	0.03	0.03	0.03	0.03	0.04	0.03	3.00
Tot	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	100.00

4.2.3 Normalized Principal Eigen Vectors

In order to check the weight assigned to each parameter in Table 4.5, the normalized principal Eigen vector value (λ_{max}) was computed depending on equation 6 and 7 to drive the formula of consistency ratio (equation 8) . This was done by multiplying the weight of the first criterion (for example, Rainfall = 32.00.) as shown in Table 4.6 with the total value that was found in the pairwise comparison matrix (for example, Rainfall =2.93) table 4.4. This calculation was applied for the rest of eight factors as per equation 8. Finally, the summation of these values gives the consistency vector (λ_{max} of = 9.30) as shown in Table 4.3 for calculating consistency index.

Table 4. 7: Normalized Principal Eigenvector

Parameters	Normalized principal Eigen vectors
RF	0.94
SL	1.02
RO	1.08
DD	1.14
LD	0.99
GM	1.10
LULC	1.10
ST	1.01
Lith	0.92
λ_{max}	9.30

The consistency index was calculated based on the equation 8 and equation 9 to which results CI = 0.04. Then, consistency ratio was computed as per equation 8 and the computed result was CR = 0.03 that is less than 0.1 and the given weights was accepted for further analysis. Groundwater Recharge zone map (GWRZM) was computed after checking all criterion as follows:

$$\text{GWPRM} = 32 * \text{RRf} + 18.78 * \text{RSI} + 13.69 * \text{RRo} + 10.65 * \text{RDd} + 6.09 * \text{RLd} + 6.25 * \text{RGm} + 5.19 * \text{RLulc} + 4.09 * \text{RSt} + 3.27 * \text{RLith}$$

Where **RRf**: Reclassified Rainfall map, **RSI**: Reclassified Slope map, **RRo**: Reclassified Runoff, **RDd**: Reclassified Drainage density map, **RLd**: Reclassified Lineament density map, **RGm**: Reclassified Geomorphology map, **RLulc**: Reclassified Land -use/ land- cover, **RSt**: Reclassified Soil texture, **RLith**: Reclassified Lithology

This study used nine major factors, which influence groundwater recharge potential zone (Runoff, Rainfall, Slope, geomorphology, soil, land use land cover, drainage density, lineament density and lithology). The result groundwater recharge of the study area was categorized into five classes namely, very high, high, moderate, low and very low as shown in Figure 4.3. Very high groundwater recharge dominate a large part of the study area, in rift floor relatively high slope, northwestern and southeastern highlands and very low groundwater recharge cover small part to the lowland of the study area.

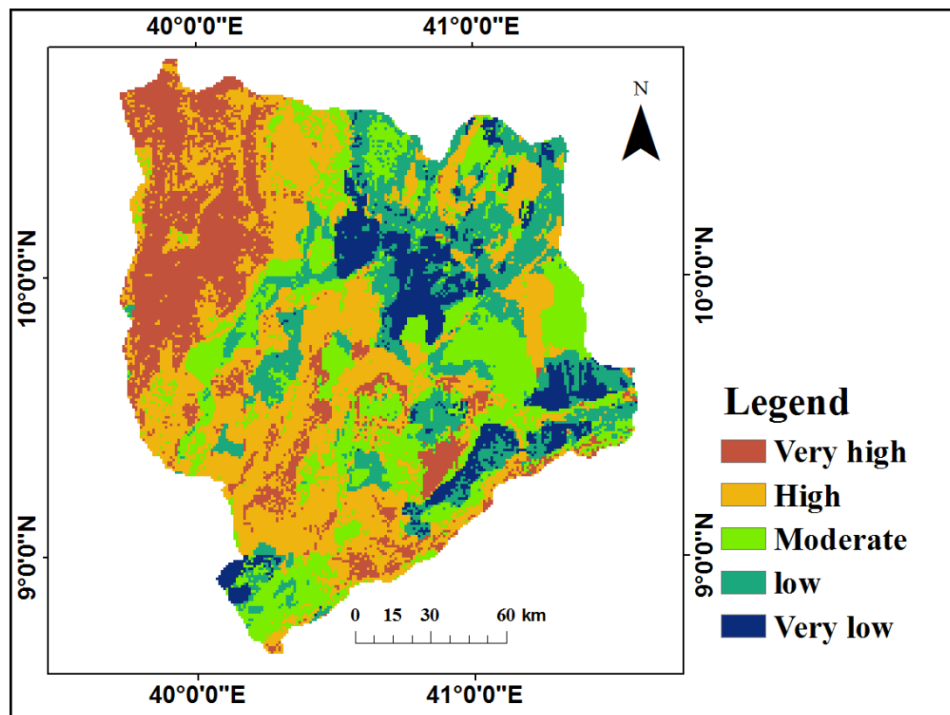


Figure 4. 3: Groundwater recharge zone map of the study area

Very high groundwater recharge was located to the northern and southern highlands of the study area and some parts of lowland in the rift floor. (Sumit *et al.*, 2014; Agrawl and Grag, 2015) follows the same methods and use similar parameters of (geology, drainage density, slope, and

soil) data's for groundwater potential zone, The result shows high groundwater potential in Highlands which is similar to the present study result. Very low groundwater recharge are located in the lowlands of rift floor of the study area. Very low and low groundwater potentials are falls in the area of volcanic landform, bare lands, and rock exposure. The low value was assigned for these parameters because of volcanic landform.

4.3. Validation of Groundwater Potential Zones

Delineation of groundwater potential and recharge zone by integrated GIS and remote sensing techniques have a close agreement with the available point source inventory data as shown in Figure 4.4. However, there is high yields of groundwater potentials in the some areas. This may happen when the rift faults in the area have caused variable degrees of displacement on rock formations coming to lateral contact to different rock types that have high permeability and as a result, the lacustrine deposits to that areas. The spring observed in the study area are located in the high groundwater potential following the same attitudes. In addition to this previous study, discuss the occurrence of permeable rocks and high recharge rates in some highlands adjacent to steep escarpments. For verification of resulted map Secondary field data collected in of 34 observation wells, from these four wells fall in the low groundwater potential zone. The value with the depth of 100-150ft and yields 2.4- 5.3 l/sec in low zone also three spring were used for validating, from this three spring data three of them are fall in the very high groundwater potential zone. From resulted map of groundwater potential zone 0.88 correlations shows high and very high areas with that of existing water source and spring data.

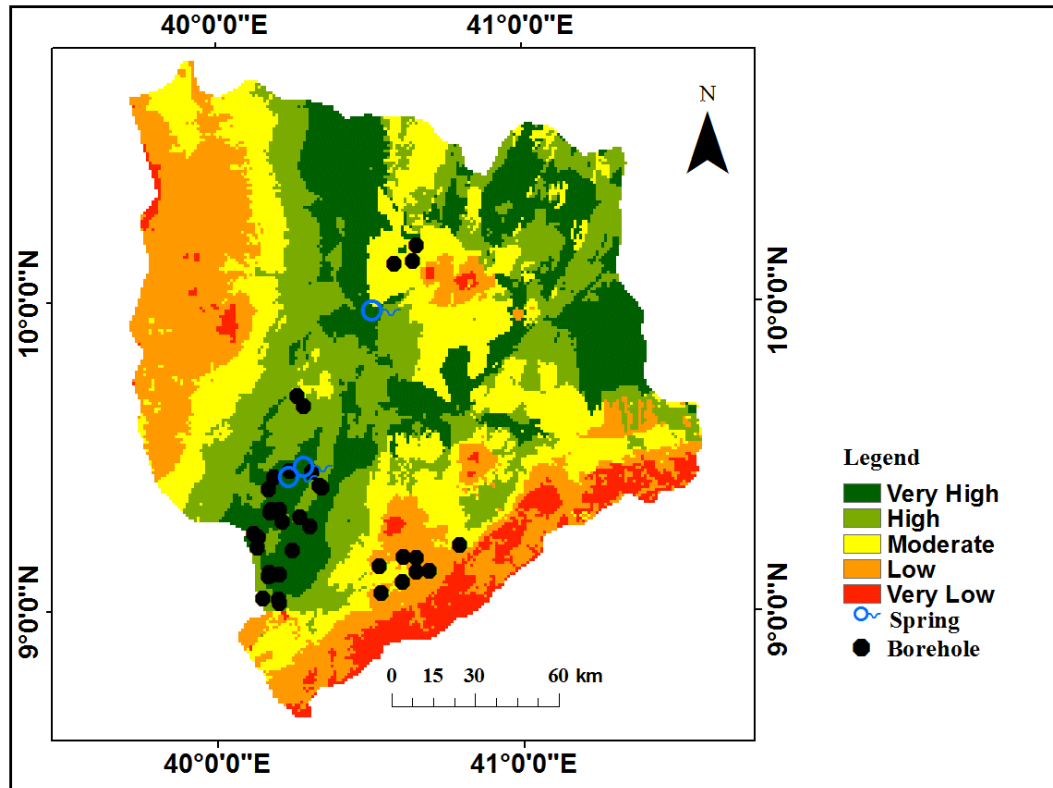


Figure 4. 4: Groundwater potential validation map of the study area

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

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

The results of consistency ratio in this study were 0.08 and 0.03 for groundwater potential and recharge respectively. If the result of consistency ratios are greater than 0.1, the value is unaccepted and it must be re-evaluated. In this case, the consistency ratio for both groundwater potential and recharge zone was less than 0.1 and the value was accepted for further analysis.

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

The delineated Groundwater recharge zone of the study area has been also classified into five classes; namely 'very high', 'high', 'moderate', 'low' and 'very low' for recharge zone. Very high groundwater recharge was identified to the northern and southern highlands of the study area in high rainfall, high drainage density, high lineament density and structural landforms.

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

Most of the area, around 34% zone under very high groundwater potential and the next very Moderate groundwater potential zone where 32.47% covers, the third coverage of the area are moderate groundwater potentials of 22.73% and the rest areas were categorized under high to very low groundwater potential zone of 8.83% and 1.27%, respectively.

5.2 Recommendation

High potential groundwater recharge area was Based on the findings obtained and conclusions reached the following recommendations were forward as follow:

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

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

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

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APPENDIX

Borehole data of the study area

site name	Code	x	y	Depth	yield
BurkaMisra	BH-35	696722	1018866	123	8
Tutuftu	BH-36	685854	1009743	196	5.6
Daga dhaba	BH-37	681409	1009313	151	5.6
Sabaka	BH-38	676209	1005803	150	
Ufe/Negib farm/	BH-39	681160	1014332	118	1.5
Kurfa Jarti	BH-40	676671	1014620	267	
Hayo	BH-41	668814	1001716	228	3
Fugnan Ajo	BH-42	668234	1011339	272	0.4
Awa. Dudub	BH-1	626351	999671	129	1.5
Kessem	BH-2	606466	1011563	100	5.3
Kebena	BH-3	611283	1022078	100	5.6
Awash	BH-4	618963	1023518	100	5
Kurkura	BH-5	632047	999422	91.08	4.6
Kurkura	BH-6	632412	998041	242	4
arba	BH-7	628900	1008000	80	
Gonita birk	BH-8	637070	1017019	85.72	3.5
Awa. Arba	BH-9	628683	1008918	126	2.1
Awa. Arba	BH-10	629018	1008158	52	
arba wonz	BH-11	628898	1007914	148	2.5
lalib.Cons.arba	BH-12	632471	1008252	194	5
Arba mil. Ca	BH-13	628311	1007852	117	6.2
Kerensa	BH-14	624548	1017845	81	2.95
odeelise	BH-15	639503	1028950	117	6.7
Elfora	BH-16	643277	1025555	120	2.6
Andedo	Deep Well	646560	1040111	120	5.6
Andedo	BH-18	647560	1039522	88	3.8

melka sedi	BH-19	623270	1023044	105	
melkas.agr	BH-20	624705	1021649	70	
serkemo	BH-21	632337	1031448	84	2
serkemo	BH-22	632988	1031094		6.5
berta well	BH-23	633197	1027266	82	5
Worer	BH-24	629485	1031634	41	0.6
Wore2	BH-25	629045	1030474	72	6.2
Ambash	BH-26	630511	1043228	48	7.9
Sheleko	BH-27	628562	1038760	50	5.6
gelsa	BH-28	638732	1072353	140	4.2
Halidebi	BH-29	641074	1068549	66	3.5
Belen	HSP-1	644235	1046853		
Hassoba	BH-30	635843	1045364	100	4.8
buremedaitu	BH-31	663409	1102863		
Ouref	BH-32	673286	1119646	120	6.7
gewan town	BH-33	681441	1126215	88	2.4
gewa.town	BH-34	680061	1120521	113	4.2
Berta	Deep Well	633107	1027266		
Undelisea	Deep Well	639500	1028942		
Buremedatu	Artesian well	668700	1102550		