

ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

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ASSESEMENT OF GROUNDWATER POTENTIAL ZONES USING REMOTE SENSING AND GIS TECHNIQUE; A CASE STUDY IN LAKE AWASSA CATCHMENT

A Thesis submitted to the School of Graduate Studies of Addis Ababa University In Partial Fulfillment of the Requirements for the Degree of Master of Science in Remote Sensing and Geographical Information Systems (GIS)

Eyerusalem Baye Tarekegn

June, 2015

ADDIS ABABA UNIVERSITY

COLLEGE OF NATURAL SCIENCES
SCHOOL OF EARTH SCIENCES
REMOTE SENSING AND GIS STREAM

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This is to certify that the thesis prepared by EYERUSALEM BAYE TARKEGEN, entitled ASSESEMENT OF GROUNDWATER POTENTIAL ZONES USING REMOTE SENSING AND GIS TECHNIQUE; A CASE STUDY IN LAKE AWASSA CATCHMENT and submitted in partial fulfillment of the requirement for the Degree of Master of Science in Remote Sensing and GIS complies with the regulations of the university and meets the accepted standards with respect to the originality and quality.

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DECLARATION

I hereby declare that the dissertation entitled "Assessment of Groundwater potential zones using remote sensing and GIS techniques; A case study in Lake Awassa catchment" has been carried out by me under the supervision of Dr. K.V. Suryabhagavan and Dr. Desse Nadew , School of Earth Science, Addis Abeba University during the year 2013-2015 as a part of Master of Science program in Remote sensing and GIS. I further declare that this work has been submitted to any other university or institution for the award of any degree or diploma.

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Abstract

Groundwater is an important source of potable water. It represents the largest available source of fresh water which lay beneath the ground therefore it has become crucial targeting on identifying groundwater potential zone. Thus an integrated approach was implemented using Geographic Information System (GIS) and Remote Sensing technique for locating promising areas. For groundwater exploration in Lake Awassa catchment, Southern Ethiopia; Satellite image and Toposheets together with field traverses and secondary data have been used as the data source. The thematic layers considered in this study are geology, geomorphology/landform, drainage density, lineament density, rainfall, soil, slope and land-use/land-cover were prepared ;As a result, a ground water potential map (GPM) was generated by modeling these parameters. A multi-criteria analysis following probability weighted approach has been applied for overlay analysis that allows a linear combination of weights of each thematic map with individual capability value. Groundwater potential map results were classified into four classes that describe the potentiality of each cell in the study area for groundwater exploration. These classes are; high, moderate, low and poor groundwater potential area. The high potential zones correspond to lacustrine sediment overlain by alluvium deposit and ignimbrite, and flat to undulating surface which coincide with the low slope and high lineaments density areas. The central part of the study area falls under moderate ground water potential zone while the eastern and southeastern part falls in low to poor ground water potential zone. The resulted groundwater potential zone map validated based on existing water sources well location which were plotted in the Ground water potential zone model and it was clearly shown that the well coordinates were exactly seated with classified zones.

Key words: GIS, Ground water potential, Lake Awassa catchment, Landsat, Remote Sensing.

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CHAPTER ONE

1 Introduction

1.1 Background

Groundwater is an important source of potable water. More than 98 % of the available fresh water is groundwater (Fetter, 1994). Therefore, it has become crucial not only targeting on groundwater potential zones, but also monitoring and conserving this important resource. Groundwater resources are dynamic in nature as they are affected by various human activities including the expansion of cultivated and irrigated lands, industrialization, urbanization and others. Thus in order to ensure wise use of ground water a systematic evaluation is required which include the use of integrated remote sensing and GIS techniques.

Increasing population and modern industrial and agricultural activities are not only creating more demand for groundwater resources due to the inadequate availability of surface water resources, but are also polluting groundwater resources by releasing untreated wastes. Consequently, these activities have resulted in an increase of research, not only with regard to groundwater resources, but also with an emphasis on locating groundwater of good quality for human consumption. Remote sensing and GIS can be a powerful tool for developing solutions for water resource problem and for assessing water quality.

GIS and remote sensing tools are widely used for the management of various natural resources (Dar et al., 2010; 2011 Magesh et al., 2011). Delineating the potential groundwater zones using remote sensing and GIS is an effective tool. In recent years, extensive use of satellite data along with conventional maps and rectified ground truth data, has made it easier to establish the base line information for groundwater potential zones (Tiwari and Rai, 1996; Das et al., 1994; Thomas et al., 1999; Harinarayana et al., 2000; Muralidhar et al., 2000; Chowdhury et al., 2010). Remote sensing not only provides a wide range scale of the space-time distribution of observations, but also saves time and money (Murthy, 2000; Leblanc et al., 2003; Tweed et al., 2007). In addition it is widely used to characterize the earth surface (such as lineaments, drainage patterns and lithology) as well as to examine the groundwater recharge zones (Sener et al., 2005). Remote sensing with its advantage of spatial, spectral and temporal avalability of data covering large and inaccessible areas with in a short time become a very handy tool in

assessing, moinitoring and conserving groundwater resource (Chowdhuryet al., 2010). Satellite data provides quick and useful baseline informtion on the parameters controlling the occurence and movements of ground water such as geology, geomorphology, lineament, soil and land use/cover (Das, 1990, 1994; Meijerink, 2000). Hence a systematic study of these factors lead to a better delination of groundwater prospective zones in an area; the various thematic layers generated using remote sensing data can be integrated with slope, drainage density and other collateral data in a Geographic Information System (GIS) framework and analyzed using a model developed with logical conditions associated with groundwater zones (Gossel et al., 2004).A GIS model was implemented using weighted overlay technique to derive the groundwater promising areas that are suitable for exploration.

The present study focused to delineate both groundwater potential zones and zones of groundwater quality suitable for domestic purposes in the Lake Awassa catchment, using remote sensing techniques and the application of GIS technology. The catchment is found in $6^{o}48'48"$ to $7^{o}13'47"$ N and $38^{o}16'15"$ to $38^{o}43'36"$ E; within Main Ethiopian Rift valley(MER) containing lake Awassa. It is characterized by a flat-lying topography with scattered small hills.

1.2 Statement of the problem

In many parts of Ethiopia, groundwater is the important source of potable water. However, the occurrence of groundwater is not uniform because it depends on various environmental and geological factors (Tamiru Alemayehu, 2006). With the population of the region increasing at an alarming rate, water requirements for drinking and other purposes is also increasing at high proportion. To meet the growing demand for drinking, domestic, agricultural and industrial sector and to address various issues related to ground water, Complete understanding of the limiting factors is very important.

Groundwater quality is also a crtical issue in the region which is high in floride. The lack of information in water quality makes it difficult to determine approprate strategies in a particular locality.

Despite the importance of ground water in the lives of millions of peoples; lack of adequate potable and agricultural water supplies inhibits the progress of the region and is the cause of considerable hardship to human life.Thus, as a part of filling this gap, GIS

and remote sensing techniques is usedto systematically assess the importance of each input parameters in the evaluation of groundwater occurrence and potential zone in the area.

1.3 Objectives

The main objective of the study is to evaluate and delineate groundwater potential zones in Awassa lake catchment using integrated geographic Information system (GIS) and Remote sensing techniques.

The specific objectives of the study are:

- To evaluate the ability of currently used GIS and remote sensing techniques to delineate groundwater potential zone.
- To identify and map parameters controlling groundwater occurrence and movement.
- To identify the degree of role of groundwater occurrence and distribution controlling parameters in the study area and their relationship to each other.
- To undertstand water quality of the study area.
- To evaluate the result of groundwater potential zone using perivious data.

1.4 Significance of the study

The study is expected to give further tool to local government and otherorganizations for planning the use and management of water resources by delineating the areas with better groundwater storage of usable quality that can help developers plan their development strategies, to change the life standard of the communities using groundwater resource as one input and to improve production and productivity in the respective areas.

CHAPTER TWO

2 Literature review

Using of Remote sensing and GIS in hydrogeology is only at its begining but there have been successsful application that started to develop (Gossel *et al*., 2004). With the advent of new high spatial and spectral resolution satellite and aircraft imagery new application for large scale monitoring have been possible. Many researchers are now using digital technique to derive the geological, structural and geomorphological details to understand the aquifer system (Jenson,1986). The various thematic layers generated using remote sensing data like lithology, geomorhology, Lu/Lc, and lineament can be integrated with slope, derainage density and other colletral data in a GIS frame work and analayzed using a model developed with logical conditions associated with ground water zones as well as artifical recharge sites (Das,1990; Gossel *et al.,* 2004).

Applications of remote sensing and GIS for the exploration of groundwater potential zones are carried out by a number of researchers around the world, and it was found that the involved factors in determining the groundwater potential zones were different, and hence the results vary accordingly. Teeuw (1995) relied only on the lineaments for groundwater exploration and others merged different factors apart from lineaments like drainage density, geomorphology, geology, slope, land-use, rainfall intensity and soil texture (Sander et al., 1996; Das, 2000; Sener et al., 2005; Ganapuram et al., 2008). The derived results are found to be satisfactory based on field survey and it varies from one region to another because of varied geo-environmental conditions.

Abhay et al.,(2011), showed the advantage of integrated remote sensing and GIS technique in assessing ground water situation in parts of Chandrapurand Gadchiroli districts of Maharashtra.In the process of assessment of ground water in the area, on lithology, lineaments, geomorphology and land use/land cover are used and assigned with differential weightage values as per their groundwater recharge and storagecharacteristics. The ground water potential map has been derived using GIS enviroment by integrating all tematic maps and consedering their respective weightage values . The ground water potential map generated was verfied with the yield data to ascertain the validity of the model developed and found that it exhibits a good correlation with the actual ground

water scenario in the area. The study significantly demonstratesthat theintegration of thematic maps derived by using remote sensing technique in conjunctionwith collateral data in GIS environment is immensely helpful in delineating the groundwaterpotential zones at a micro-level.

Murugesan et al., (2012) have carried out groundwater study in the Dindigul district of kodaikanal hill, which is a mountainous terrain in the Western Ghats of Tamilnadu. Ground water potential zones have been demarcated with the help of remote sensing and Geographical information (GIS) techniques. All thematic maps are generated using the resource sat (IRS P6 LISS IV MX) data and Inverse distance weight (IDW) model is used in GIS data to identify the groundwater potential of the study area. For the various geomorphic units, weight factors were assigned based on their capability to store groundwater.

Jobin et al., (2011) determined groundwater potential zone in tropical river basin (Kerala, India) using remote sensing and GIS techniques. The information on geology, geomorphology, lineaments, slope and land use/land cover was gathered from Landsat ETM^{+} data and Survey of India (SOI) toposheets of scale 1:50,000 in addition, GIS platform was used for the integration of various themes. The composite map generated was further classified according to the spatial variation of the groundwater potential. The spatial variation of the potential indicates that groundwater occurrence is controlled by geology, structures, slope and landforms.

Deepesh et al., (2010) proposed a standard methodology to delineate groundwater potential zones using integrated RS, GIS and multi-criteria decision making (MCDM) techniques. The methodology is demonstrated by a case study in Udaipur district of Rajasthan, western India. Initially, ten thematic layers have been considered. Weights of the thematic layers and their features then normalized by using AHP (analytic hierarchy process) MCDM technique and eigenvector method. Finally, the selected thematic maps were integrated by weighted linear combination method in a GIS environment to generate a groundwater potential map.

Prabir et al., (2012) made an attempt to determine the groundwater potential zones within an arid region of Kachchh district, Gujarat. Thematic layers have been generated by using ancillary data and digital satellite image. The potential zones have been obtained by

weighted overlay analysis, the ranking given for each individual parameter of each thematic map and weights were assigned according to their influence.

Anju et al.,(2003) have carried out a research in Lucknow, India. Delineation of groundwater potential zone and zones of ground water quality suitable for domestic purposes using remote sensing and GIS. Different thematic maps were prepared using Satellite image and ancillary data and also groundwater maps of total dissolved solvent (TDS), total hardness (TH), incrustation problem and magnesium concentration have been prepared and classified for spatial analysis. Different classes in each thematic map have been assigned a knowledge based hierarchy of weights. According to the study, all the thematic maps related to ground water potential zone have been integrated and classified depending on the added weight factors determined in the analysis. In the same way all thematic maps of ground water quality have been also integrated and classified. Finally, the study integrates groundwater potential classes with groundwater quality and suitability classes**.**

ChengHaw et al., (2008) proposed that assessing the potential zone of groundwater recharge is extremely important for the protection of water quality and the management of groundwater systems. Further groundwater potential study was carried out in Taiwan with the help of remote sensing and the geographical information system (GIS) by integrating the five contributing factors: lithology, land cover/land use, lineaments, drainage, and slope. The weights of factors contributing to the groundwater recharge are derived using aerial photos, geology maps, a land use database, and field verification.

In Awassa and its surrounding the majority of water used for domestic purposes comes from groundwater sources.

Tadesse, and Zenaw (2003) Conducted a research in overall Hydrogeology and engineering geology of Lake Awassa catchment. In these study the hydrology, geology, hydrogeology and engineering geology of the area have been studied. The study was conducted by collecting and analyzing water samples, measuring field parameters such as Temperature, electric conductivity, PH, water level, stream discharge rates and taking representative soil samples for determination of porosity, permeability and grain size distribution. The study aimed to elucidate the cause for awassa lake rise and forward possible remedial measures and to assess the water resource of awassa lake catchment. According to the study the methodology used includes major ion chemistry, isotopes, and

water balance approach. The study classifies ground water potential zones in to five classes based on recharge, permeability, aquifer thickness, yield of spring and topography. According to the study east of Wondogenet escarpment in the Awassa caldera is classified as very high potential aquifer where considerable amount of recharge to ground water is taking place from overland flow and direct precipitation. Low potential groundwater area was characterized by hilly topography that favors high runoff and low discharge to groundwater. The hydro chemistry of the catchment have been also studied using borehole, dug well, springs, river, lake Awassa and rainwater. The study includes different physical parameters, major ions and cations; based on the study the dominant water type is sodium bicarbonate.

CHAPTER THREE

3 Materials and Method

3.1 Study area

3.1.1 Location and Accessibility

The study area is located 275 km south of Addis Ababa in the Main Ethiopian rift (MER). Geographically it lies between $6^{o}48'48"-7^{o}13'47"$N latitude and $38^{o}16'15"-38^{o}43'36"$ E longitude, the catement total extent area of 1455 $km^2$of which 93.6 $km^2$is the lake surface area (Fig 3.1).The area is accessed through Addis Ababa−Moyale main road and to different parts of the catchment through the network of dry wethered roads.

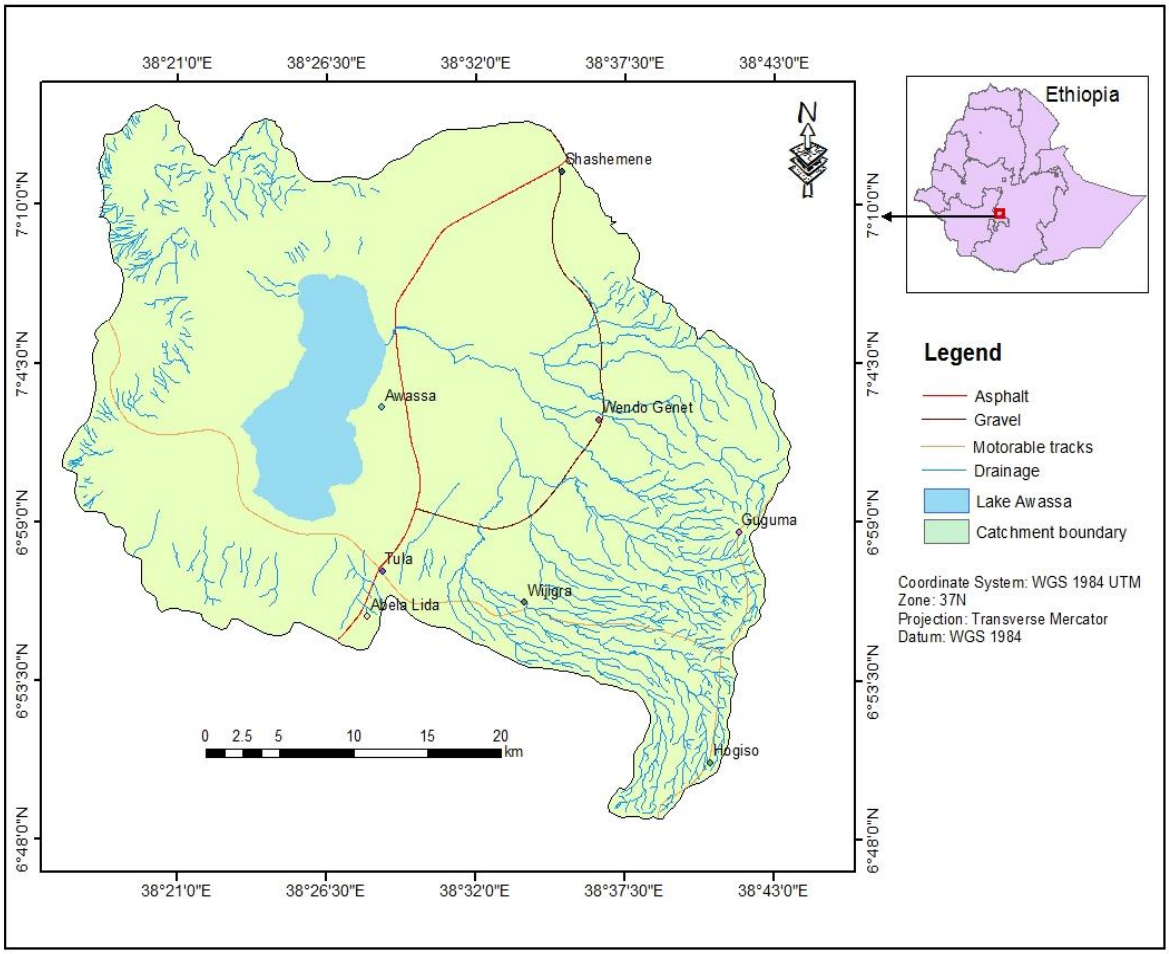


Figure 3.1 Location map of the study area

3.1.2 Physiography and Drainage

The lake watershed mainly is characterized by a flat-lying topography with scattered small hills. Elevation of the rift escarpments and ridges in the east and west of the watershed range from 2000 to the maximum of 2940m asl. It is known that the uplands on either side of the flat lowlands are deforested and denudated. The steeply sloping and deforested uplands are likely to produce high runoff to the lowlands shortly after individual storms. The continuous erosion process on the eastern highlands have resulted on filling Cheleleka Lake with sediment load and transformed it to a swamp (Yemane, 2004).

The highly eroded and most deforested western part of the catchment has relatively flat topography and is massive in nature made of coarse un-welded pumicious pyroclastic rocks has no significant drainage system. The absence of significant river channels crossing the low laying plains is another indication of less importance of surface runoff from the northern and western side on the lake level rise. Thus water input to the lake from this sub-catchment is mainly through groundwater inflow provided that the hydrogeologic condition of the subsurface is conducive. It is different from the Eastern side which is covered with fracture ignimbrites and tuffs. The Eastern and South eastern portion, which is characterized by dense drainage system, has streams flowing separately and in a radial pattern, which is the common feature of volcanic area. Some of the rivers like Wedesa, Gomesho, Wetera ,Werka, Wesha, are perennial feeding the catchment floor and all ends up in the Cheleleka swamp, where TikurWuha river gets its water.The fact that most of the runoff produced from the South-Western and North-Western highlands ends up on the closed sub catchments of Muleti, 91.6 km^2 and Wondokosha, 114km^2 and due to flatness of the plain agricultural land west of the Lake no significant surface runoff can be expected to enter the lake. In addition to that there should not be a sedimentation problem on the lake due to land use change on the closed sub catchment.

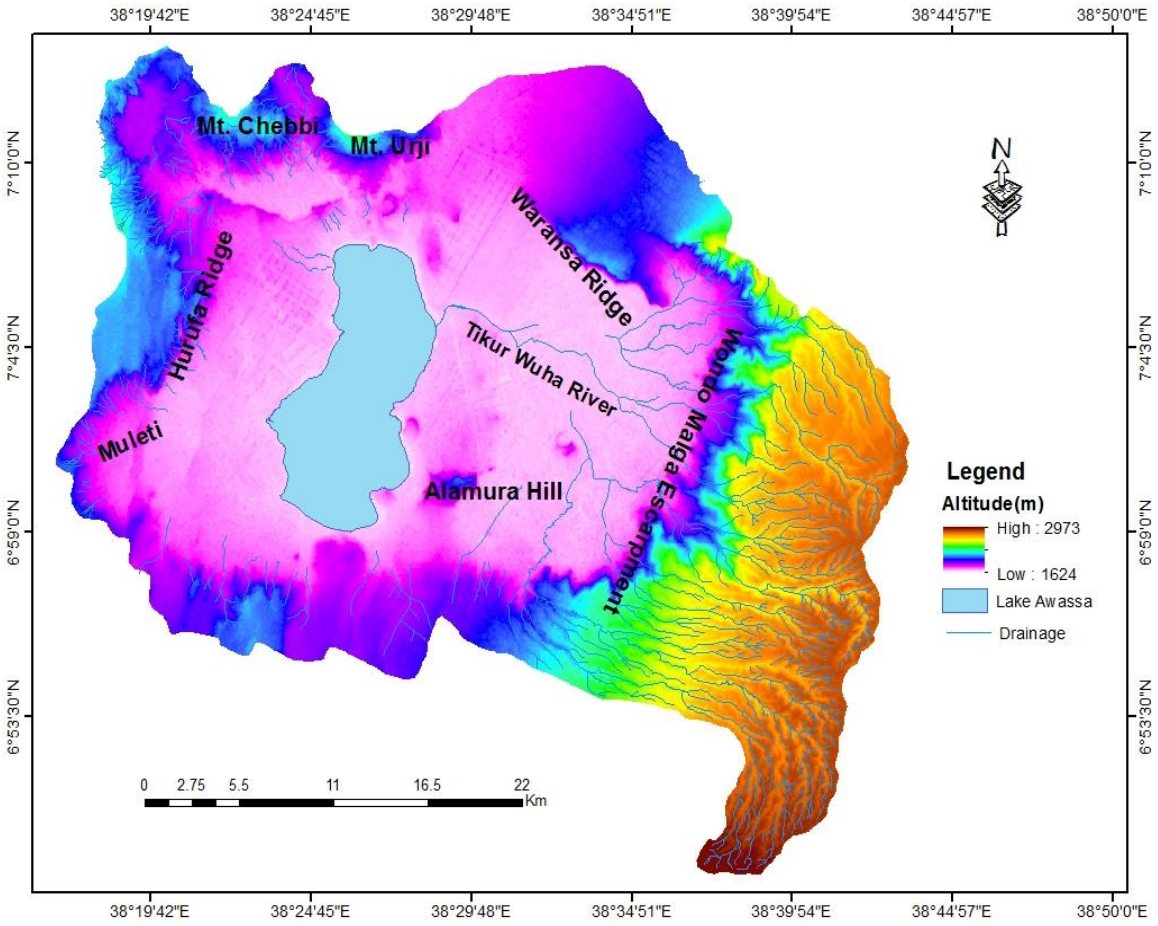


Figure 3.2 Physiographic and Drainage of the study area

3.1.3 Climate

According to Legesse et al., (2003), the watershed is characterized by three main seasons. The long rainy season in the summer from June-September is known locally as Kiremt and is primarily controlled by the seasonal migration of the inter-tropical convergence zone (ITCZ), which lies to the north of Ethiopia at this period. The wet period represents 50-70% of the mean annual total rainfall. The dry period (locally named as Bega) extends between October and February when the ITCZ lies to the south of Ethiopia (Legesse et al., 2004). During March and May, The "small rain" season (locally named as Belg) occurs when about 20-30% of the annual rainfall falls. The climate in the area varies from dry to sub-humid according to the Thornthwaite's system of defining climate or moisture regions (Dessie, 1995).

The rainfall data collected from 1981 to 2014 at five meteorological stations that contribute to the catchment. The mean annual rainfall in the catchment ranges between 821−1129mm with that for Awassa town being 959mm, the northern part if the catchment

receives the lowest rainfall, rising to the rest of the catchment. Both the amount and seasonality of the rainfall shows some variability. The wettest months are April, May and September.

At Awassa Station the mean annual temperature is 20.05^{o}C with the minimum average ranging from 10^{o}C during December to 14.3^{o}C during July; and maximum temperature varying from 24.3^{o}C during July to 29.7^{o}C during March.

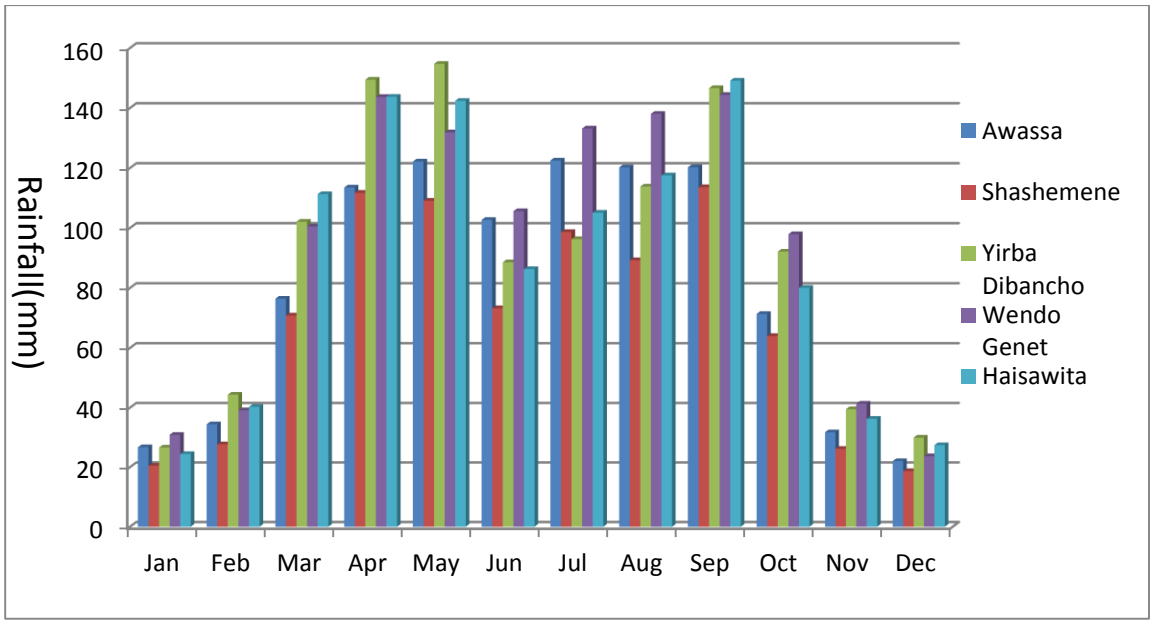


Figure 3.3 mean monthly precipitation (1981−2014)

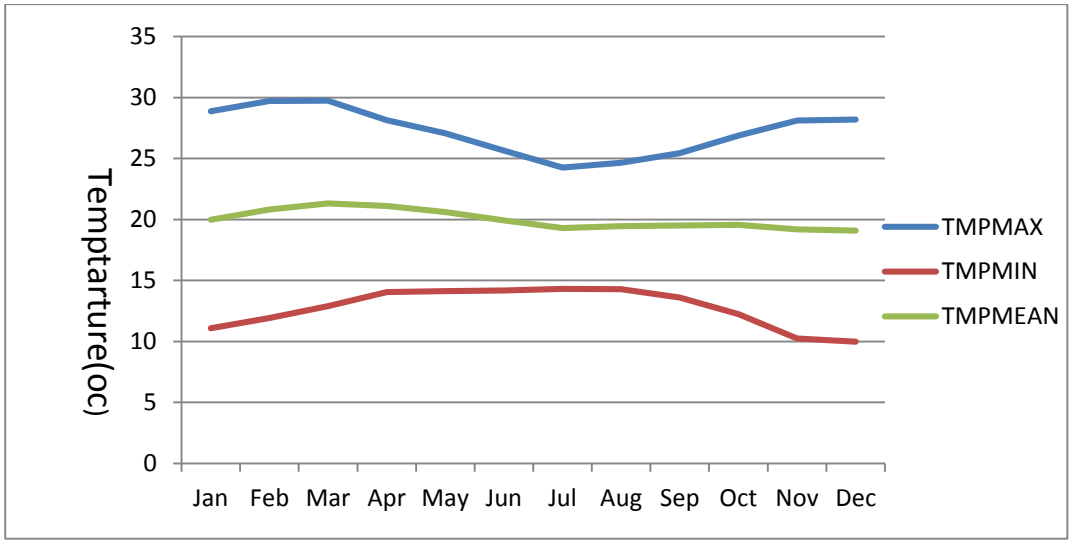


Figure 3.4 Long-term mean monthly Min, Max and Average temperature

3.1.4 Soil

Soil formation is a factor of climate, parent rock material, the nature of the landform, soil organisms and time. Due to geology and time the soils of the basin are relatively young. These are derived from the late tertiary to quaternary volcanic rocks. Water Works Design and Supervision Enterprise have classified the soil based on the physical and chemical characteristics. Depth, color, structural development, texture and evidence of profile development such as presence of diagnostic horizons, reaction to 10% HCl and PH value are some of the classification criteria based on which soil map has been produced.

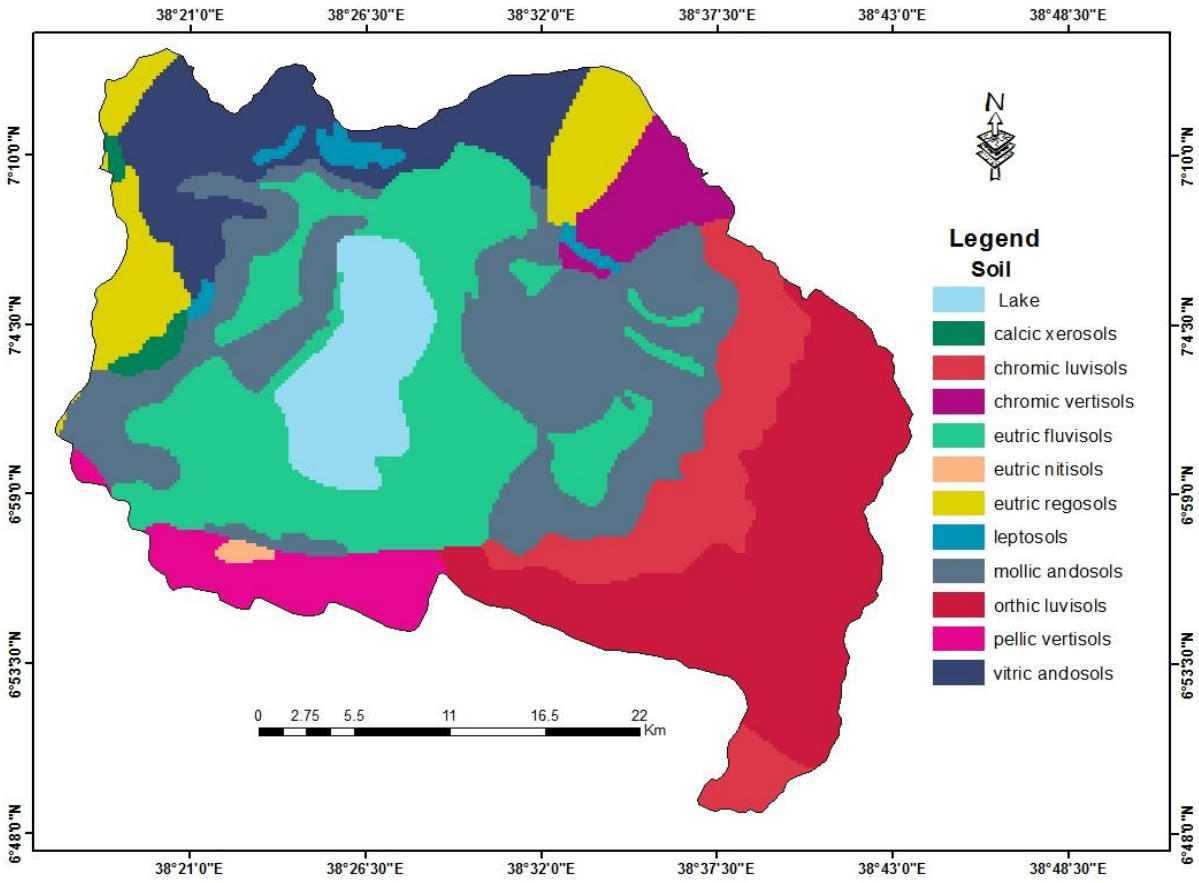


Figure 3.5 Soil map

3.1.5 Land use and vegitation

The land use of Lake Awassa catchment has been changed progressively due to extreme deforestation as a result of increase in population, which results in replacement of vegetation cover by cultivation land. Agriculture is the main land use practice in the catchment and occupies most of the floor of the catchment. Woody vegtation with cultivated land found on the floor and southern part of the area; Intensively Cultivated

land with exposed bare rock and soil found westren part of the area; Open grassland covering the eastern escarpment and western caldera rims are landuse/landcover condition of the area. As the deforestation of the natural vegetation cover continues soil loss due to erosion will result and it is aggravated where the slope is higher especially on theescarpments. This erosion could be one of the reasons for the rise of Lake Awassa water level and disappearance of Lake Cheleleka.

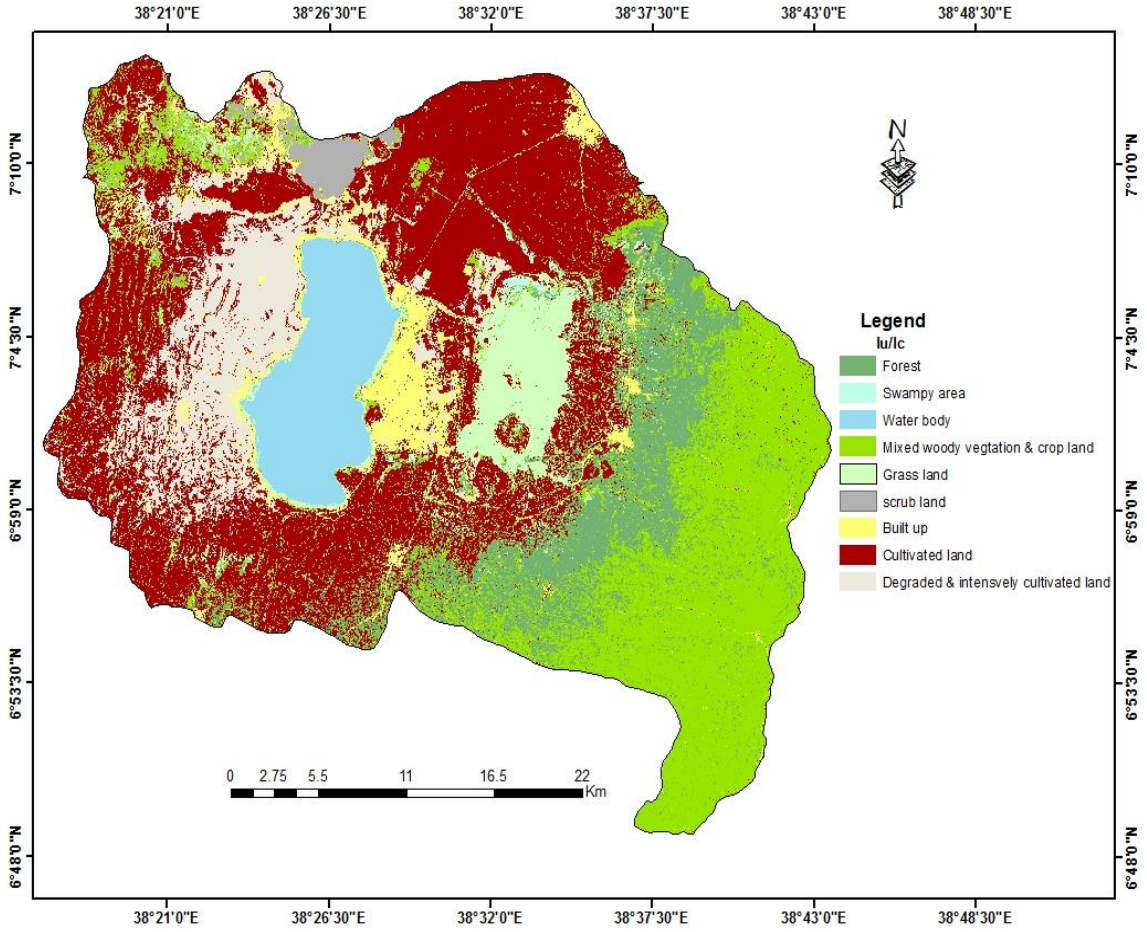


Figure 3.6 Landuse/landcover map of 2015

3.1.6 Geological setting

The main Ethiopian rift valley is divided based on structural feature in to three geographic areas; represented by the north (Fentale−Nazerate), Central (Nazerat−Awassa) and Southern(Awassa−Konso) part. The central part, where the Awassa lake basin belongs to is a symmetric rift basin where both sides of the rift margins are fully defined except in the region between Guraghe and Soddo of the western escarpment and the Shashemene area of the eastern margin,(Tadesse and Zenaw, 2003). The closed basin of the nested

Awassa−Korbetti caldera complex is a giant elliptical depression 30−40 km wide. According to Dessie (1995) the main formation in the area subdivided in to four lithologic units as follows;

1. Volcano lacustrine deposit, which covers most part of the floor of depression, composed mostly of volcanic origin.

2. Recent acidic volcanic which covers large part of the north and north-western part of the catchment were glassy ryholitic rock superimposed and form massive domes and thick obsidian flows.

3. Basaltic lava flows, scoria and hydroclastic which are observed sprinkled on the flat catchment floor forming conical shapes.

4.Ignimbrite of the rift floor and the rift scarp, which is common rock type for the region and cover the east, southwest and the southern part of the catchment where the top few meter of the rock is weathered and fractured in place with columnar joints.

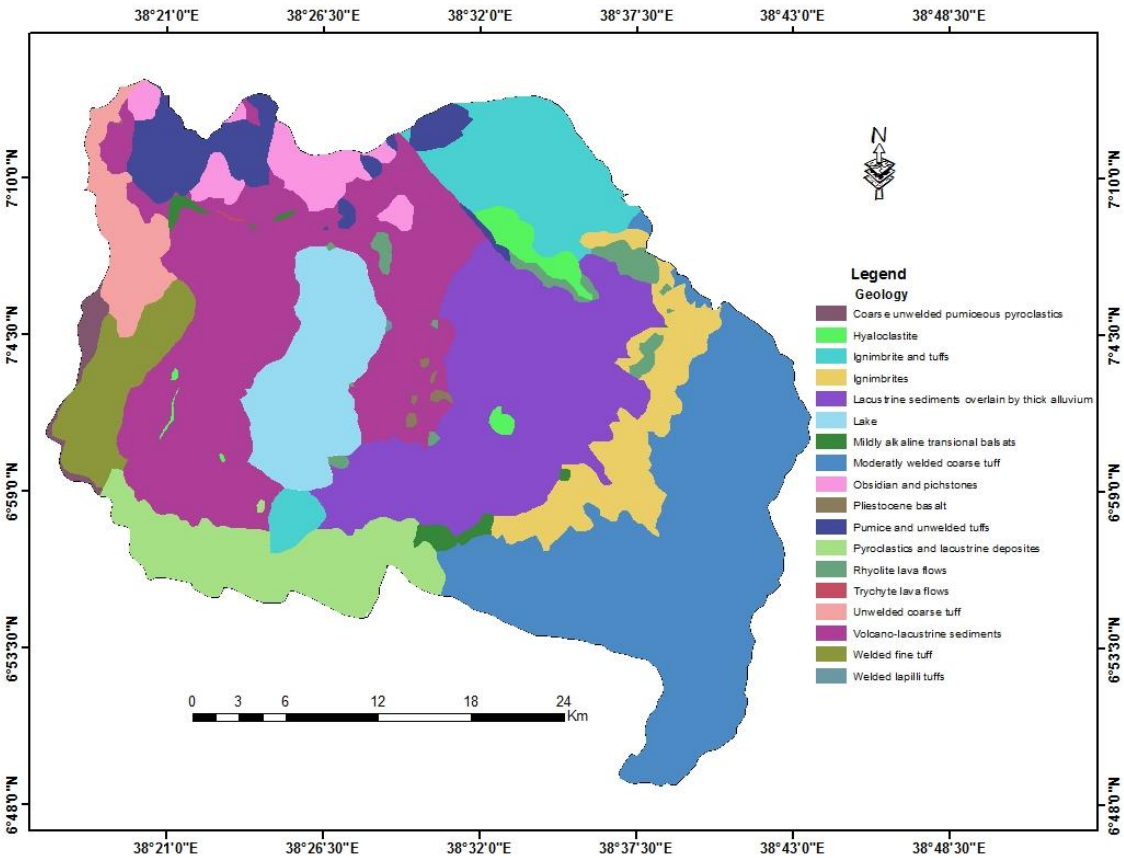


Figure 3.7 Geological map of the study area

3.1.7 Geological Structures

There are a number of rift system faults with north and northeast trend along which the length of Lake Awassa is oriented. These faults are expansion (normal faults) forming step faults. They are mainly dominant to the south and south west of the lake. The volcanic collapse structure (caldera) forms nearly circular structure around Lake Awassa basin. This collapse shifts some of the MER fault systems showing that the collapse has taken place subsequent to the rifting. In the Awassa caldera a line of young faults affect the rift floor. These faults, the Wonji fault Belt shattered the rift floor into several relatively small horst and graben. Lakes or swamps occupy the more depressed areas.(Tadesse and Zenaw, 2003).

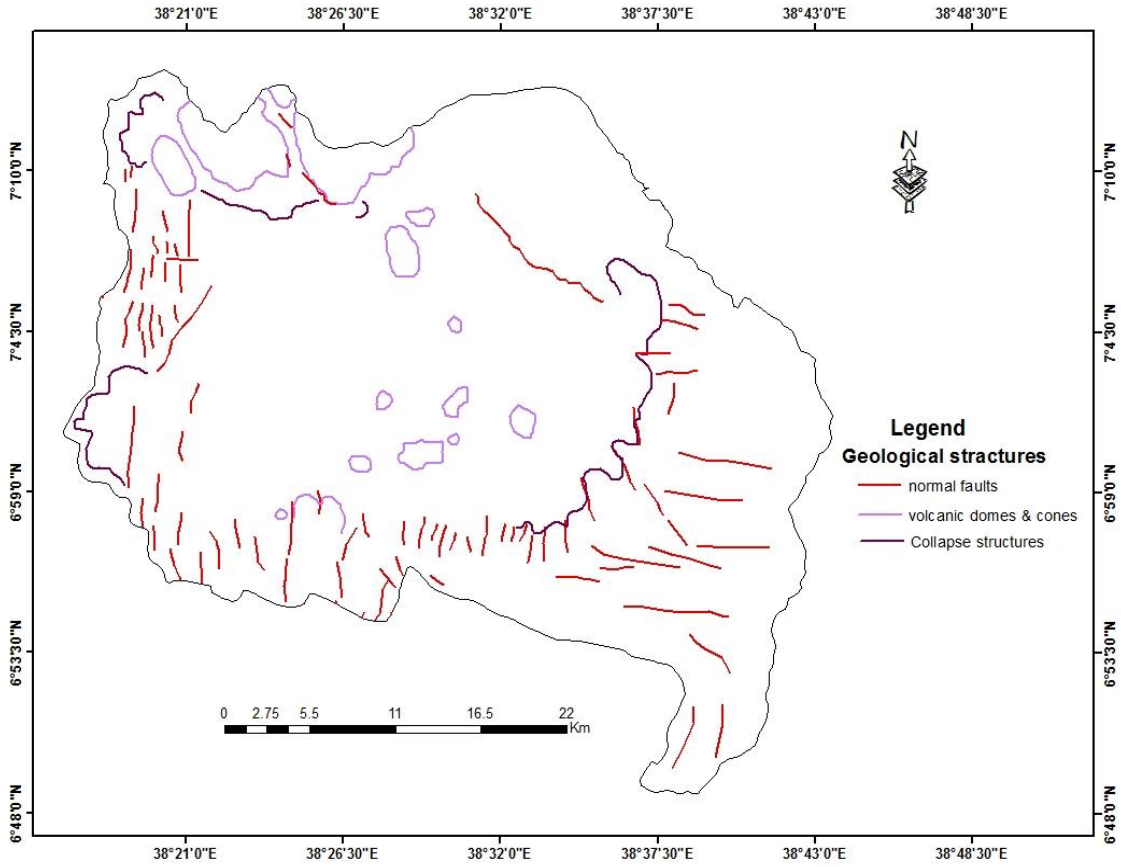


Figure 3.8 Structural map

3.1.8 Hydrogeology

hydrological studyconducted by Tessfaye chrenet, pointed out that Awassa lake cathcment is covered by highly permeable lacustrine sedments, moderatly premeable acidic volcanic(rhyolites, tuffs, pumice and obsidian) and low permeability iginiberite and tuffs. acidic volcanics are highly preamble when sorted and ignimbrites are hihgly permeable when they are jointed. Based on borehole data and field observation the lacustrine sediments have medium to high transmisivity values ranging from 100 to over 1000 m^2/day. The ground water is generally unconfined. Avarage thickness of the lake sediment is estimated to be about 40 to 50 meters. The temprature of groundwater varies from 21 to 32 ^oC and conductivity from 230 to 1900 μS/cm,(W.W.D.S.E, 2001).

3.2 Materials and Data used

The following data have been collected and used in this study for the assessment of ground water potential zone and water quality using remote sensing and GIS.

i) Satellite data

- Landsat ETM + image from the year 2003 image were used.The ETM+ imagery data which were used in this study included the visible (1, 2 and 3), the shortwave infrared (SWIR), the middle infrared (MIR) and the pan- chromatic bands. The spatial resolutions for these bands were 30 m for the visible to infrared and 15 m for the panchromatic.
- Landsat 8 Operational Land Imager (OLI) image acquired in 2015 G. C was mostly used.
- SRTM (Shuttle Radar Topographic Mission) data of 30m resolution was used to produce 3D map of the catchment.

ii) Topographical map

Four toposheets of 1:50,000 scale of the study area were used to delineate the catchment area and drainage pattern.

iii) Secondary data

- The Geology and Soil map of the area prepared by (W.W.D.S.E., 2001) were used as to show the geological and soil map of the study area.
- Monthly and annual precipitation data of 5 stations for 25−30 years
- River flow data and Water sources inventory data, Borehole data and
- Water chemistry data were used.

iv) GPS data

The points collected from GPS were used to cross check in the field.

3.3 Software used

ERDAS Imagine 10 used for georeferencing, coordinates transformation of all the data used in to UTM 37N Zone, Adindan Datum and image analysis.

ArcGIS10.1used for catchments delineation and GIS analysis.

Global mapper used for analysis of landforms/Geomorphology.

IDRISI software used for weight calculation.

DNRGARMIN which is extension of ArcGIS going to be used for transferring GPS data in to computer.

Aquachem used to test water chemistry.

3.4 Methodology

3.4.1 Remote sensing applications

The interpretation of satellite data in conjunction with sufficient ground truth make it possible to identify and outline various ground features that serve as direct or indirect indicators of the occurrence of groundwater. From Remote sensing data processing and interpretation preliminary geological, structural and geomorphological attributes were deduced. In order to enhance the raw data, image processing such as band rationing, principal component analysis, filtering, Linear contrast stretching, supervised classification etc. were also applied.

3.4.2 GIS application

GIS analyses such as distance from geologic structures, density of drainage, interpolation of rainfall point data, derivation of slope from digitized contours and overlay analysis for producing the groundwater potential area were done; moreover weights and multi-criteria evaluation were done for analysis of the different parameters that control groundwater occurrences. The controlling parameters are geology, geomorphology, geological structure/Lineament density, drainage density, slop, soil, landuse/ landcover and annual rainfall.

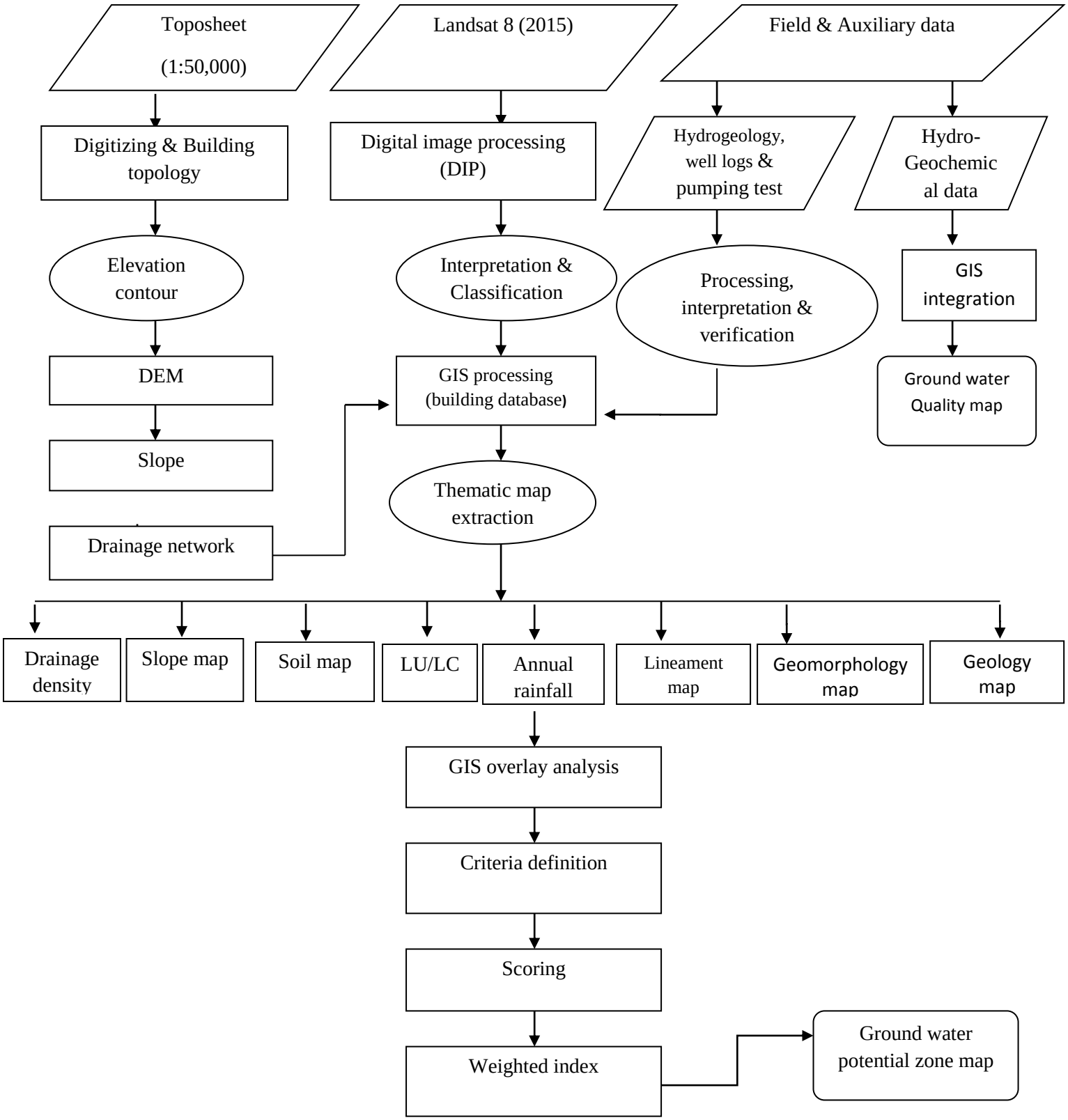


Figure 3.9 Flow chart of the study area

3.5 Preparation of Thematic maps using GIS and Remote sensing technique

Groundwater potential zones are demarcated with the help of remote sensing and GIS techniques. One of the advantages of using the advantage of remote sensing data in hydrological investigation and monitoring is its ability to generate information in spatial and temporal domain; which are very crucial for successful analysis, prediction and validation. The various layers generated using remote sensing data are integrated in a GIS framework and analyzed with reference to the ground water zone.

In the present study, the ground water potentiality were derived from the drainage density, geology, geomorphology, slope, lineament density, soil, rainfall and land use/land cover using Satty's Analytic Hierarchy Process (AHP). In this method the relative importance of each individual class with in the same map were compared with each other by pair-wise and eight importance matrices were prepared for assigning weight to each class.

Table 3.1 The Continuous Rating Scale developed by Saaty (1977).

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

Less Important More Important

3.5.1 Factors Controlling Groundwater Occurrence in the Study Area

3.5.1.1 Drainage density

Drainage density is one of the important parameter to understand the Ground water potential of watershed. It (in terms of km/km^2) indicates closeness of spacing of channel as well as the nature of surface material, thus providing a quantitative measure of average length of stream channel for whole basin. The drainage density and pattern mainly depend on climate, rock and soil formations, topography, surface and sub-surface fracture intensities. It gives information related to runoff, infiltration, relief and permeability. The drainage map of the study area was prepared by digitization of Topographic map (1:50,000). In the study area radial drainage patterns are recognized which are manifestation of lithological and topographic homogeneity. Drainage density is calculated

using the stream length within grid area. It has been observed from drainage density measurement made over a wide range of geologic and climatic type that a low drainage density is more likely to occur in region of highly permeable subsoil material under and where relief is low. High drainage density is the resultant of impermeable subsurface land mountainous relief. The drainage density characterizes the runoff in an area or in other words, the quantum of relative rainwater that could have infiltrated. Hence the lesser the drainage density, the higher is the potential groundwater zone. The entire drainage density map (Fig. 3.10) is divided into five (5) categories. High drainage density was found in eastern and south eastern part of the study. Moderate and low drainage density concentrate in the Northern and central part of the study area. With respect to groundwater occurrences the higher drainage density is related to less infiltration of water to the ground, which in turn leads to higher run off and vice versa. The rating done based on this fact as described in (Table 3.2) has shown that for areas with low drainage density higher value was given and vice versa. Based on this classification the reclassified map of drainage density (Figure 3.11) was produced.

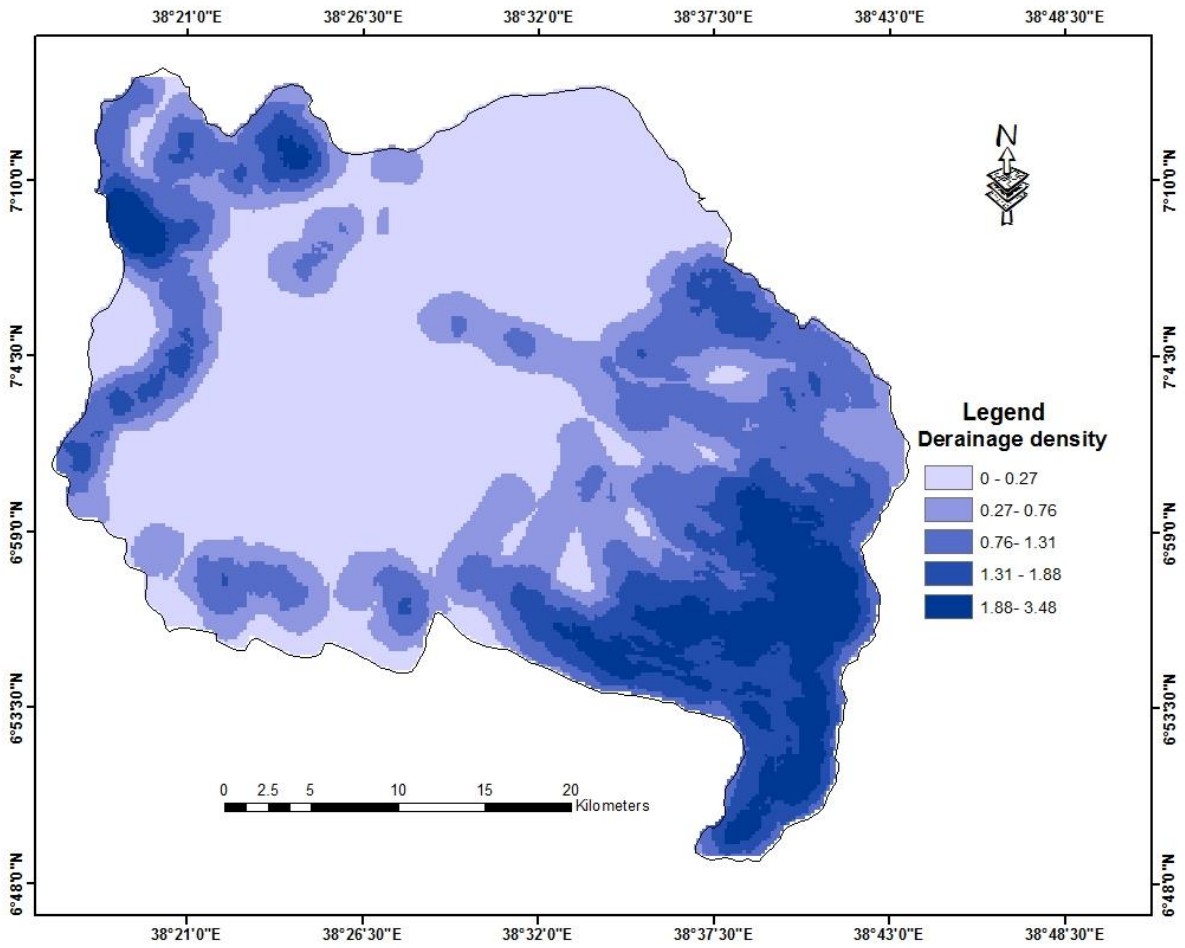


Figure 3.10 Drainage density map.

Table 3.2 weighted value for Drainage density

Drainage Density (km/sq.km)	Drainage density category	Weight
0–0.27	Very low	5
0.27–0.76	Low	4
0.76–1.31	Moderate	3
1.31–1.88	High	2
1.88–3.48	Very high	1

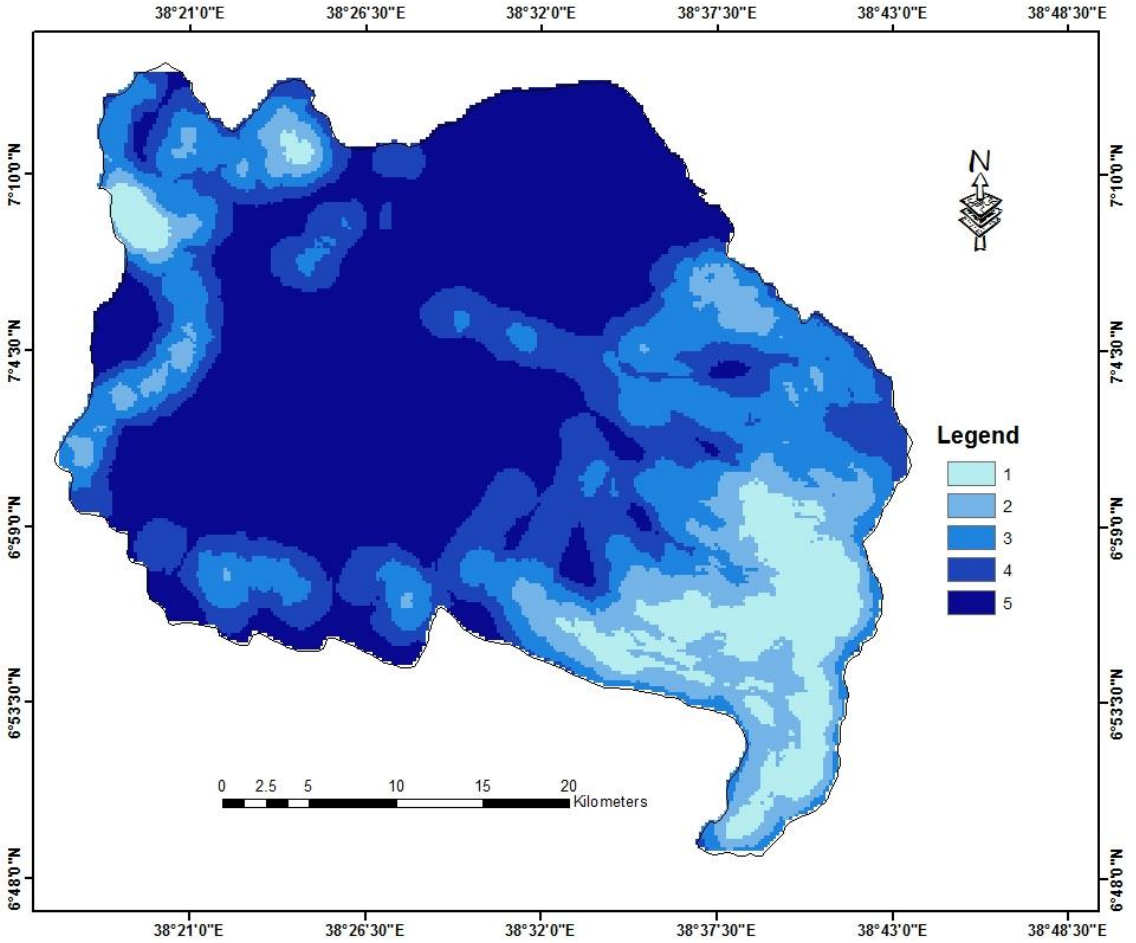


Figure 3.11 Reclassified drainage density map

3.5.1.2 Lineament density

Lineament is defined as large scale linear feature, which express itself in terms of topography of the underlying structural features. These are primarily a reflection of discontinuities on the Earth's surface caused by geological or geomorphic processes. Lineament provides the pathway for ground water movement and are hydro geologically very important. Lineament map of the study area have been generated following the standard visual interpretation technique on satellite image. In such imagery they are identified on the basis of break of slope, truncation of terraces knick points, abrupt change in stream course, lithology, vegetation, texture, drainage density etc. Lineaments were delineated by visual interpretation of the false color composite (FCC) 471(RGB) this band combinations were used after examining various band combinations. (Fig. 3.12) shows the hydro geologically significant lineament map. The map was prepared by removing all lineaments that fall on hills, ridges and those on streams and river channels which are presumed not to be structurally controlled in the study area.

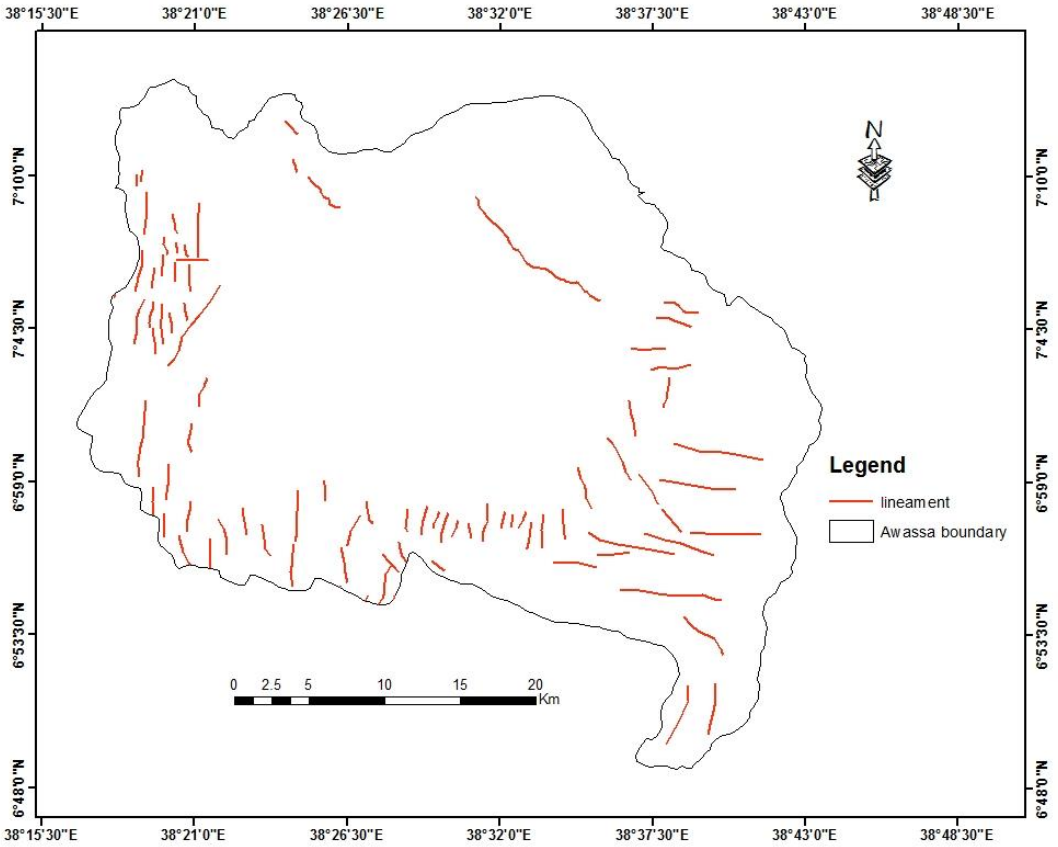


Figure 3.12 Lineament map

The lineament map is then converted into zones of different lineament density. Lineament density map (fig.3.13) is a measure of quantitative length of linear feature expressed in (km/km^2). Lineament density of an area can indirectly reveals the ground water potential, since the presence of lineament usually denotes a permeable zone. Areas with high lineament density are favorable for ground water developments. In present study area (table 3.3) with very high lineament density (3.5−5.1) have good groundwater potential where as area with very low lineament density (0-0.4) have poor groundwater potential. The entire map classified in five categories (fig.3.14).

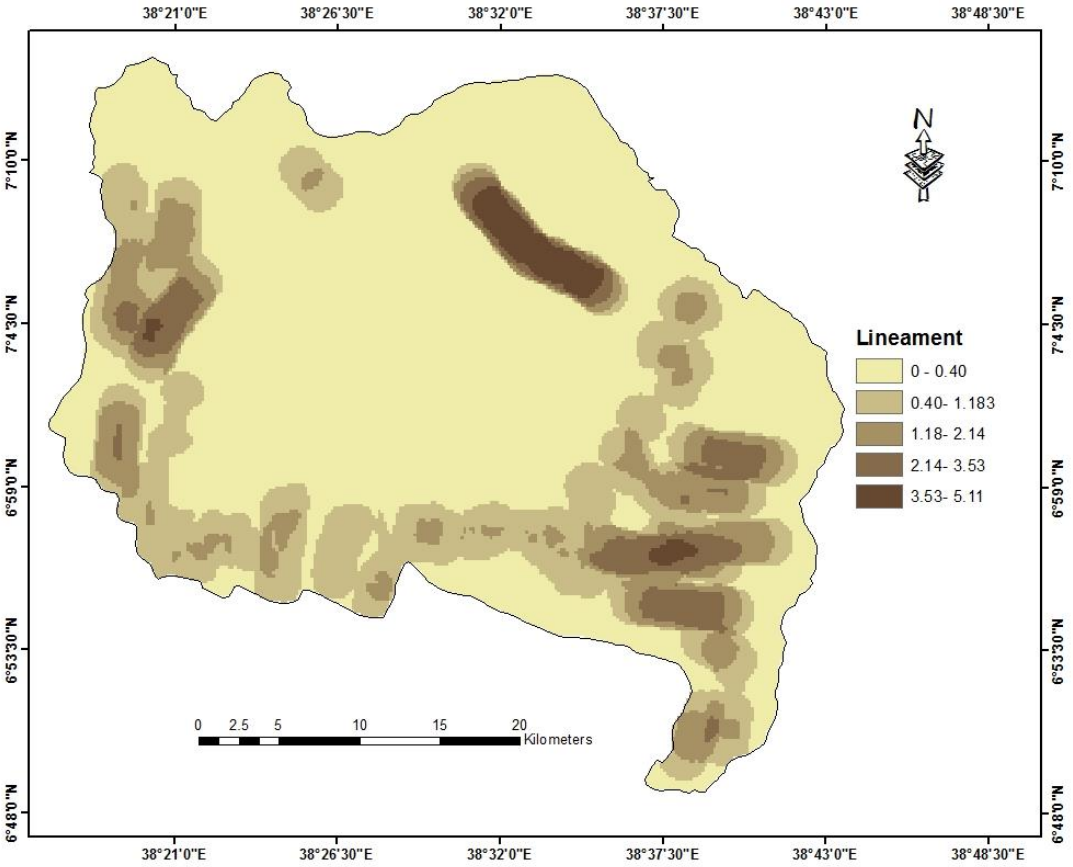


Figure 3.13 Lineament density map

Table 3.3 Weighted values for Lineament density

Km/Km^2	Lineament density category	Class
0−0.4	Very low	1
0.4−1.18	Low	2
1.18−2.14	Moderate	3
2.14−3.53	High	4
3.53−5.11	Very high	5

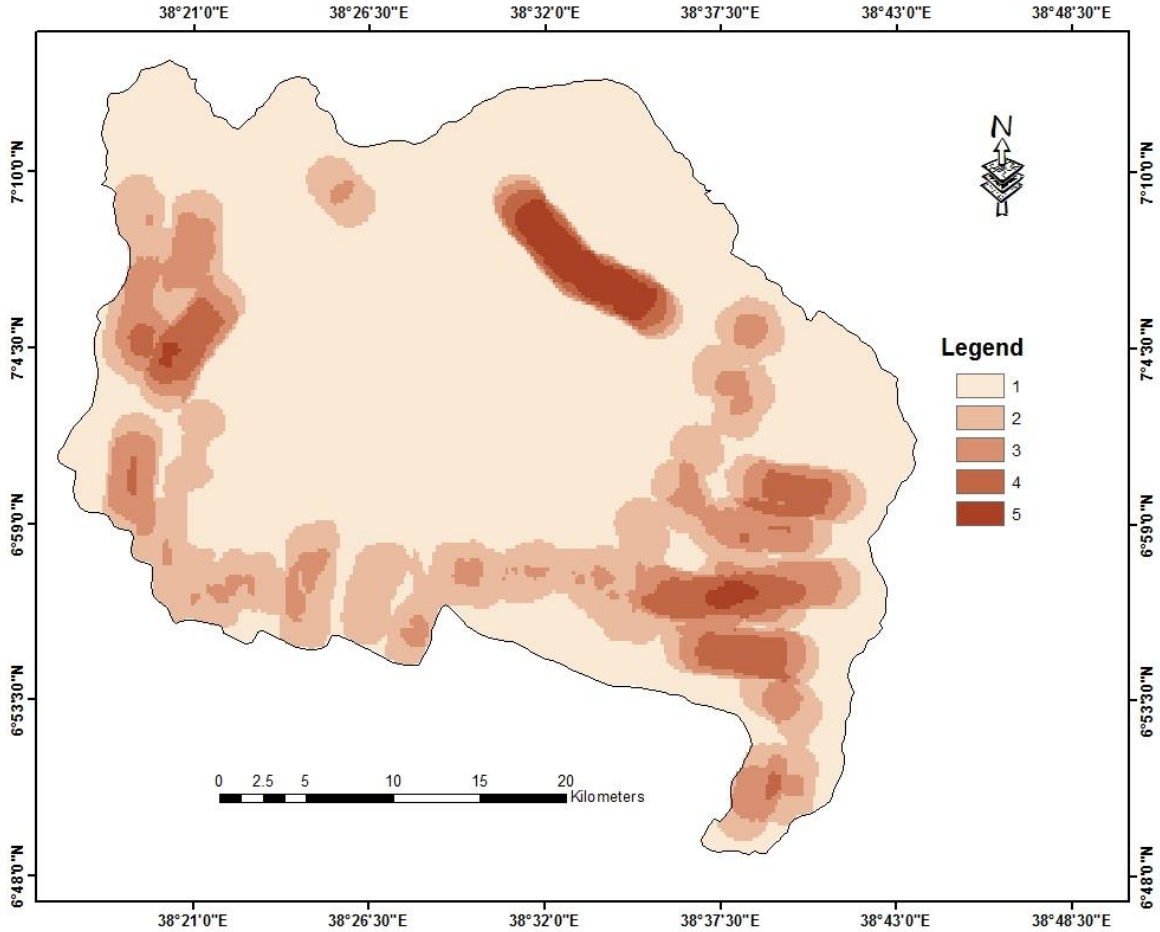


Figure 3.14 Reclassifed Lineament density map

3.5.1.3 Slope

Slope plays an important role in influencing the recharge of groundwater depending on the degree of gradient of the landscape as infiltration is inversely related to slope. Larger slopes produce a smaller recharge because water runs rapidly off the surface of a steep slope during rainfall, not having sufficient time to infiltrate the surface and recharge the

saturated zone. Flat areas are capable of holding the rainfall and facilitate recharge to groundwater as compared to steep slope area where water moves as runoff quickly. Slope map (fig. 3.15) was generated from SRTM digital elevation model (DEM). It varies from 0^{o}–68^{o}. The elevation decrease from east and south eastern part to the center of the study area. Based on the slope, the study area can be divided into five slope classes. The areas having 0^{o}–5^{o} slope fall into the 'very good' category because of the nearly flat terrain and relatively high infiltration rate. The areas with 5^{o}–11^{o}slope are considered as 'good' for groundwater storage due to slightly undulating topography with some runoff. The areas having a slope of 11^{o}–19^{o} cause moderate runoff and low infiltration, and hence are categorized as 'moderate'. The areas having a slope 19^{o}–$31^{o}$are considered as 'poor' due to higher slope and runoff and the area with a slope of 31^{o}–68^{o} are to be 'very poor'. (Fig.3.16) illustrates the reclassified slope map of the study area.

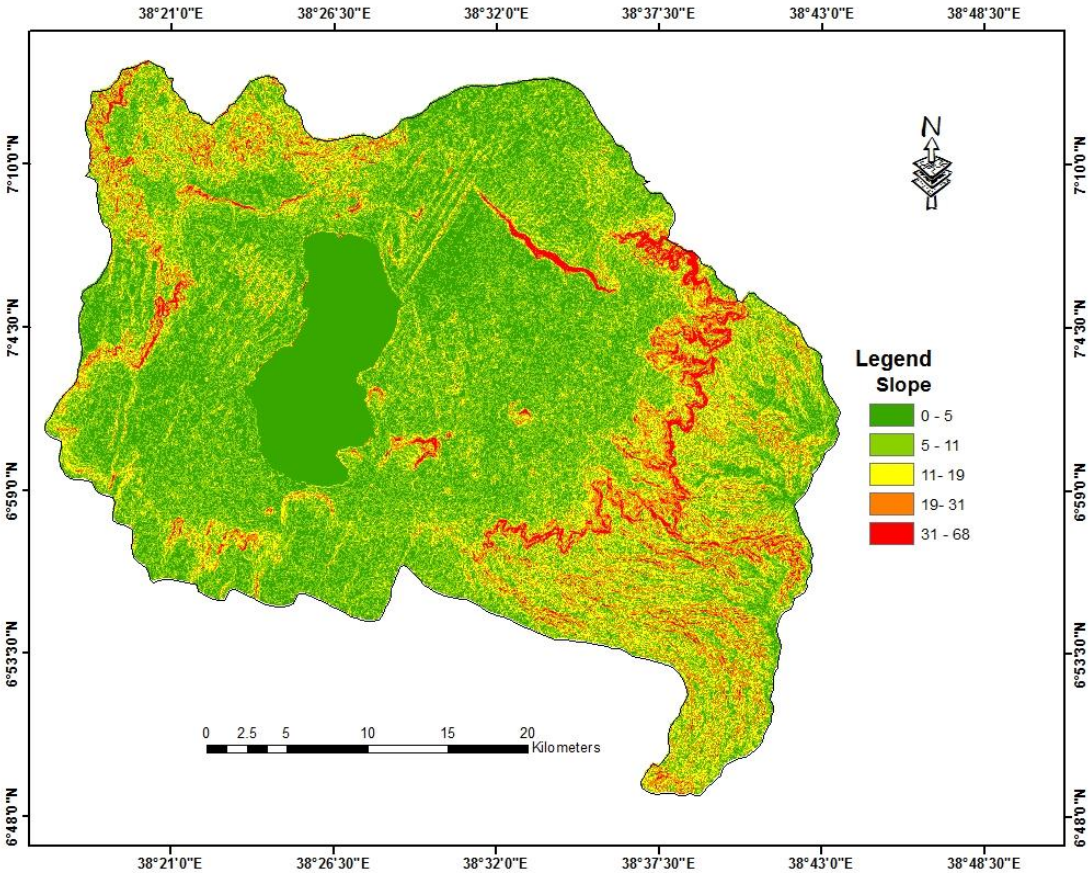


Figure 3.15 Slope map

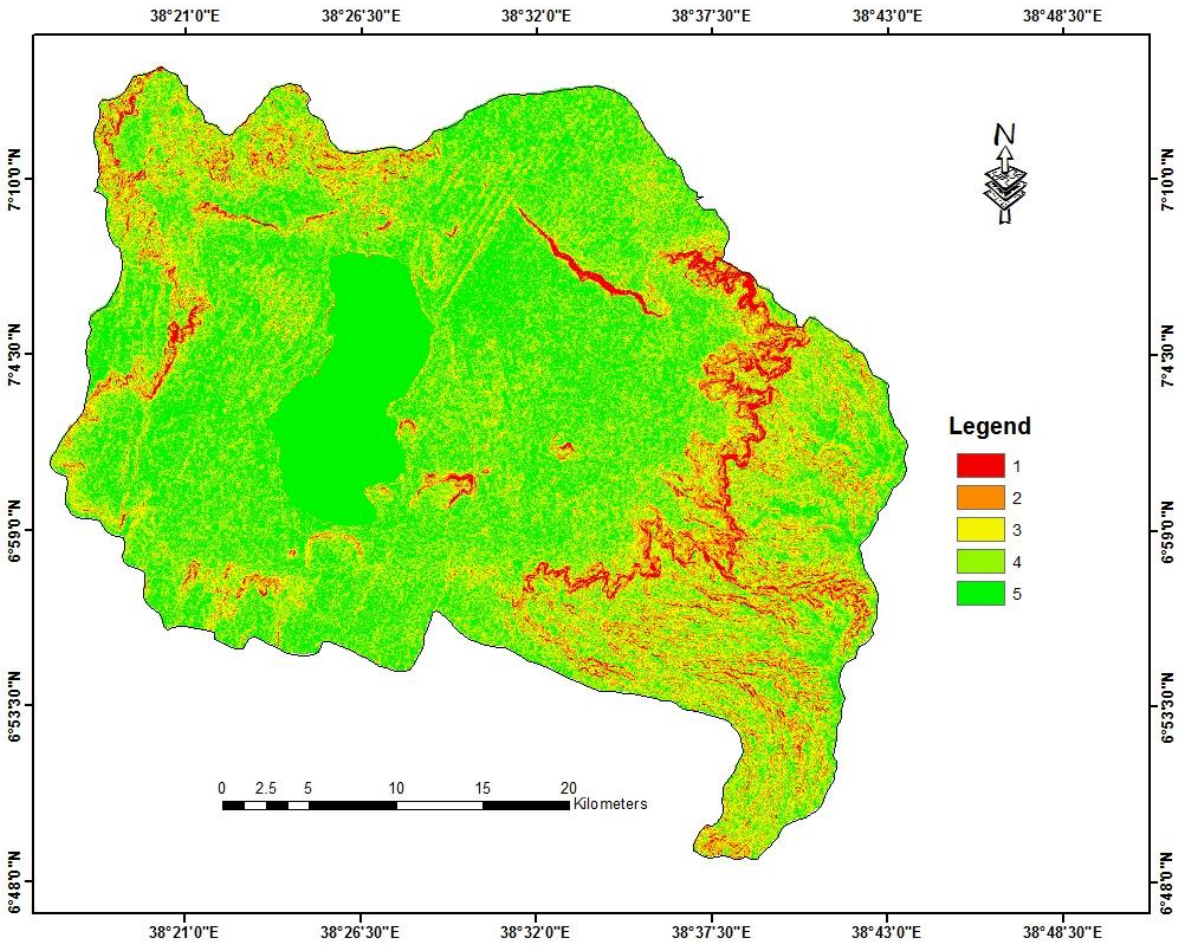


Figure 3.16 Reclassified Slope map.

3.5.1.4 Soil

Information on soil also forms an important input in mapping groundwater potential zones, e.g. coarse textured soil are generally permeable while fine textured soils indicate less permeability. Climate, parent rock, vegetation and physiography are responsible for the type of soil formed and plays an important role on ground water recharge through infiltration and loss through runoff. The type of soil and permeability affects the water holding and infiltrating capacity of a given soil.

Fluvisols

Are young soils developed in recent alluvial deposits of river plains, deltas, former lakes and coastal areas. Soil conditions are highly variable. In arid regions many soils are saline. Fluvisols with having a base saturation of 50 per cent or more, are EutricFluvisols. Fluvisols are generally good agricultural soils and often intensively used, although land use has to be adapted to floods, inundations or high groundwater.

Luvisols

Luvisols are soils with an argillic B horizion and a base saturation of 50 per cent or more. Most Luvisols have good agricultural potentialities. Base saturation is high and they have weatherable minerals. In soils with a heavy textured B horizon, permeability might be low, and drainage and good root distribution can be hindered.

Nitosols

Eutric Nitosols are found on almost flat to sloping terrain in the highlands. It is among the best agricultural soils. The physical properties are similar to those of the Dystric Nitosols. Chemically these soils are better, although available p contents are low.

Regosols

Regosols are soils without profile development, consisting of loose, non-alluvial soil material. They occur in areas with little precipitation; or on steep slopes subject to severe erosion. Those with lime accumulation are Calcaric Regosols. Eutric Regosols have a base saturation of 50 per cent or more. They have limited agricultural value, especially where soil depth is limited. Water retention in Regosols is low.

Andosols

Andosols occur in volcanic regions. They are formed in volcanic ash material. The ash material being very light, their bulk density is less than .85 g/cm3. Vitric Andosols have more than 60 per cent volcanic glass, they occur in rather arid zones.MollicAndosols have a mollicAhorizon.MostAndosols are good for agriculture. They can absorb much water and are very porous. Organic matter content is often high. Some Andosols, especially in the rift valley, have high sodium content and thus a limited agricultural value.

Vertisols

These are heavy clay soils in flat areas, having a pronounced dry season during which they shrink and have deep cracks in a polygonal pattern. During the wet season the clay swells and causes pressure in the sub-soil. PellicVertisols are dark, usually occupying areas which are water-logged during the rainy season. Chromic Vertisols are brownish and better drained. Vertisols have fairly good, but limited agricultural potentialities. Land

preparation is difficult, dry soils are hard and wet soils are sticky. The moisture condition of the surface layer is only during a short period favorable to prepare land. Another difficulty is that the permeability of the subsoil is very low. Very often these soils are flooded or have stagnant water during the rainy season. The soil has high water retention, but relatively a small amount of water is available for plant growth. Rooting depth might be restricted because of the swelling and shrinking properties of the soil. Chemically these soils are good. Free $CaCo_3$ is often present as nodules in the profile. When precipitation is limited, salinity problems might occur. Because of the low permeability and the difficult drain ability of the subsoil, it is very difficult to improve such soils.

Xerosols

Xerosols are soils in arid and semi-arid regions, with a weakly developed A horizon. Those with an argillic B horizion, mostly at shallow depth, are Luvicxerosols. Those without a calcic horizon are Haplic Xerosols. Those with a calcic horizon are Calcic Xerosols. The calcic horizon may harden, forming a petrocalcic horizon. The agricultural value of Xerosols is low, except when they can be irrigated and when physical properties are good for irrigated crops.

Leptosols

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

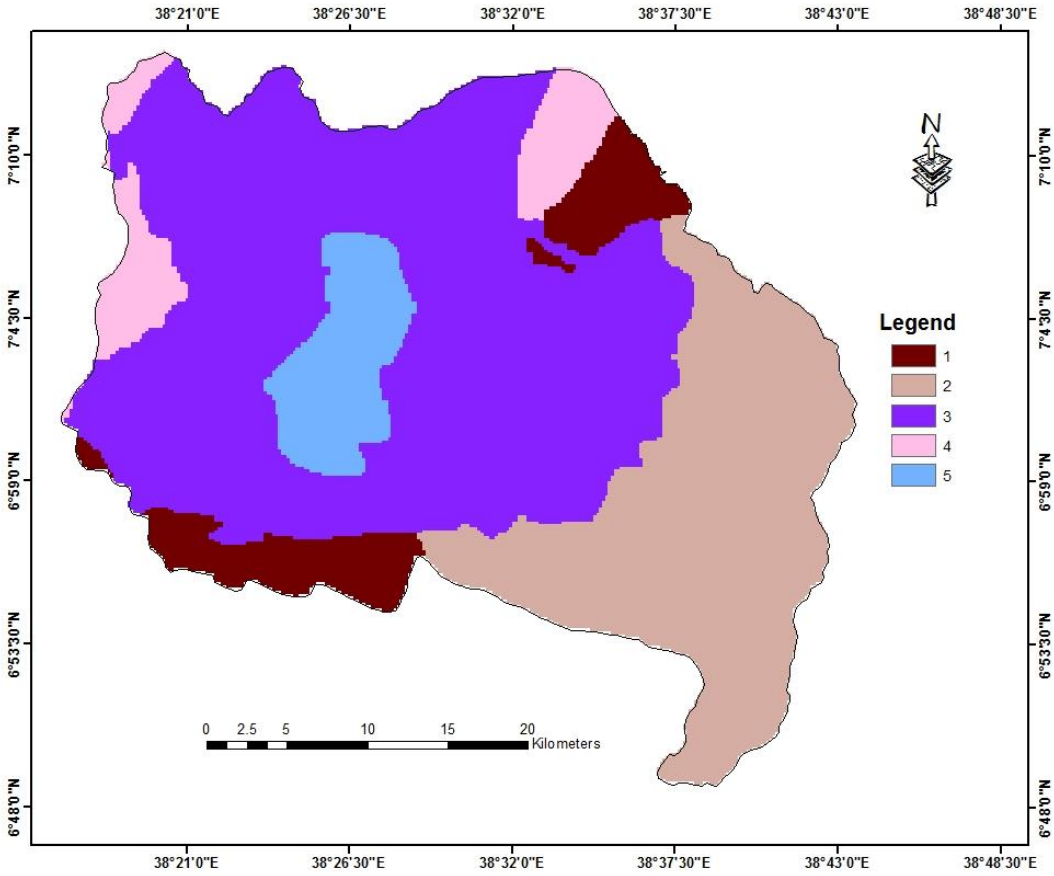


Figure 3.17 Reclassified soil map

3.5.1.5 Geology

The geology of the study area is the result of the geological activities that took place in the part of the Eastern Africa and Ethiopia. Following the regression of the Mesozoic sea to the south-east a major uplift occurred which is known as the Arebo-Ethiopian Swell. The upraised and up arched land mass fissuring under tension permitted the ascention of voluminous basaltic magma to form the Ethiopian flood basalt province (Mengesha et al.,1996). Superimposed on the uplifted swell, part of the great East African Rift system started in the Miocene. The uplift, subsequent rifting and volcanism in the rift and outside the rift resulted into the formation of the present physiography of Ethiopia. The MER that is part of the East African Rift (EAR) approximately runs in the north-east/ south-west direction from about the latitude of Addis Ababa to Lake Chamo. Large Volcano-tectonic collapse in the MER formed the Awasa Lake basin. Recent lacustrine and alluvial deposits, scoria cones, rhyolitic lava flows and associated ignimbrites, tuffs and volcanic ash form this basin. The rhyoltic lava flows and the associated ignimbrites, tuffs and ash

belong to the recent rhyolitic volcanic centers and the scoria cones to the recent plateau basalts. The escarpment and the mountains of the eastern margin of Lake Awasa basin are made up of Nazeret series, which is composed of ignimbrite, unwelded tuff, ash flow, rhyolitic flow, domes and trachyte. The northern, south western and western margins are made up of the Dino formation, which is characterized by ignimbrite, tuff, coarse pumice, water lain pyroclastic rocks with rare intercalation of lacustrine sediments. Either Dino Formation or Nazret series underlies the Awassa basin deposits.

Geological Units

Ignimbrite (Qdi)

Ignimbrite generally forms low relief, flat topped hills. It is light grey, porphyritic with visible lath shaped plagioclase feldspar and rock fragments of various size and composition. Glass shards are also common constituents. Weathering ranges from slight to moderate. Weak tuff layers up to 2−3m are sometimes found intercalating this unit.

Rhyolite

The morphological characteristics of the rhyolite are manifested by NS−NNE / SSW aligned, medium relief hills. The unit is fine grained with lath shaped, shiny feldspar and visible quartz. Lamination is at mm scale, revealing textural, color and composition variation. Columnar joints are well preserved towards up slope and diminishing to down slope. The exposed height of the unit at Boricha ridge is about 70m.

Welded fine tuff

It is fine grained, silt size tuff weathered. In most places the tuff is covered with brown silty clay soil overlain by sandy gravel soil. The tuff consists of pumice fragments and glass.

Basalt

The basalt is aphanitic, black, and hard, out crops (in Meribo village) with thin soil cover. Where as in Gidabo river valley, it is found at the deepest part of the valley over lain by rhyolite. The basalt in Meribo village is columenarly jointed with spheroidal weathering at the surface.

Obsidian

The obsidian flow forms the highest topography of Chebbi dome in the northern part of LakeAwassa. Obsidian unconformably overlies the welded and unwelded tuffs. As seen

from thin section obsidian has a glassy texture. The groundmass is made of glassy material some of the glassy material show parallel alignment.

Pyroclastic fall deposit

This unit is composed of alternating layers of silty sand, silty clay and gravely sand which are variable in thickness, composition and compaction. The pyroclatic fall deposit is generally affected by NS−NNE/SSW faults exhibiting series of elongated closed parallel basins and elevated blocks. The fault scarps are highly subjected to accelerated erosion and mass wasting.

Lapilli tuff

This unit is the other variety tuff featured by fragmental texture, composed of dominantly pumice fragments, average size of 4mm, quartz of 1mm and few glass shards. Weathering degree varies from slight to moderate; though tectonic joints are not well developed

There are non tectonic joints, which are non-persistent in azimuth, orientation and aerial extent.

Table 3.4 Weighted values for Geology

Types of lithology	Weight
Coarse unwelded pumicious pyroclastics	1
Hylaloclastite	2
Ignimbrite & tuff	4
Lacustrine sediment overlain by thick alluvium	6
Mildly alkaline transitional basalts	2
Welded lapilli tuff	3
Obsidian & pitchstone	1
Pleistocene basalt	2
Pumice &unwelded tuff	1
Pyroclastics& lacustrine deposit	4
Rhyolite lava flows	1
Trychyte lava flow	1
Unwelded coarse tuff	1
Volcano lacustrine sediment	5
Welded fine tuff	3
Moderately welded coarse tuff	3
Ignimbrite	4
Lake	7

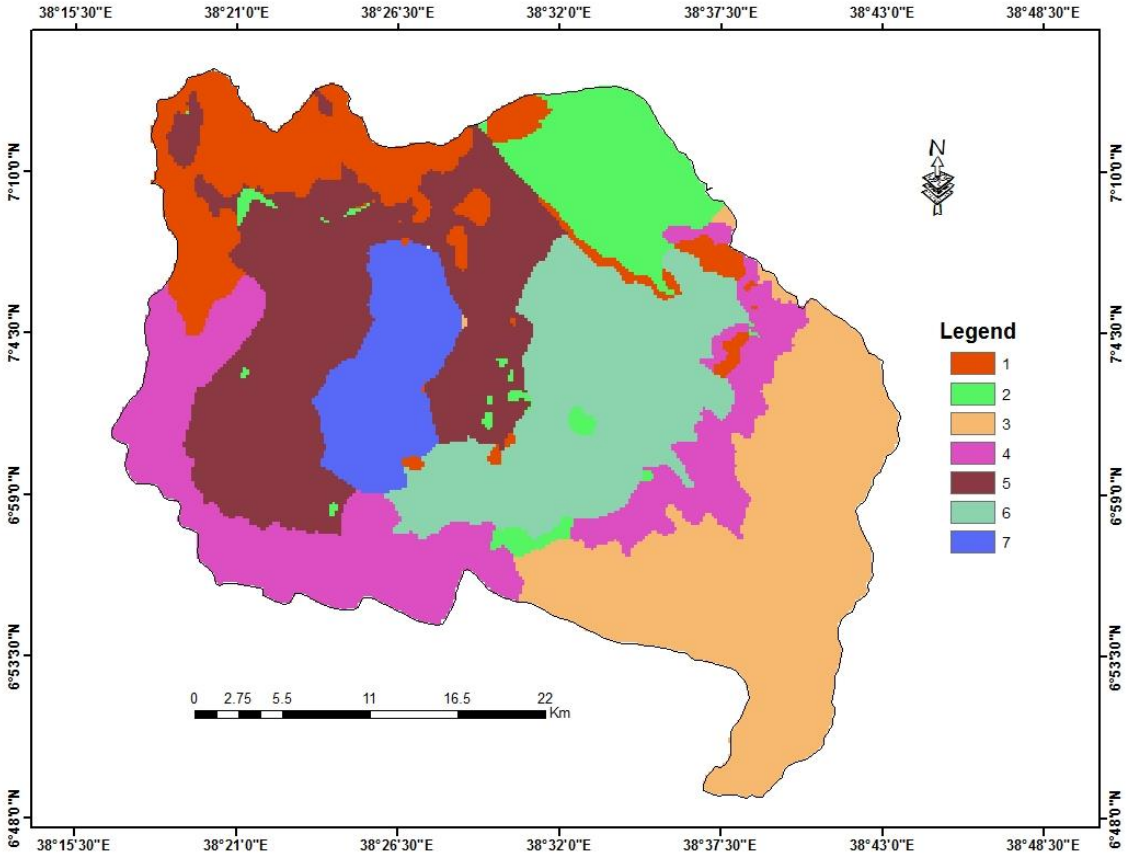


Figure 3.18 Reclassified geological map

3.5.1.6 Land use/Land cover

Landuse/landcover mapping is one of the important applications of remote sensing. 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. Land use plays a significant role in the development of groundwater resources. It controls many hydrgeological processes in the water cycle *viz* .infiltration, evapotranspiration, surface runoff etc. surface cover provides roughness to the surface, reduce discharge thereby increases the infiltration. In the forest areas, infiltration will be more and runoff will be less whereas in urban areas rate of infiltration may decrease. LU/LC of area has been analyzed using Supervised classification of 2015 Landsat 8 image. The land use/landcover map of the study area has been prepared and presented in (Fig. 3.19). The main land use/land cover categories delineated in the study area are as under;

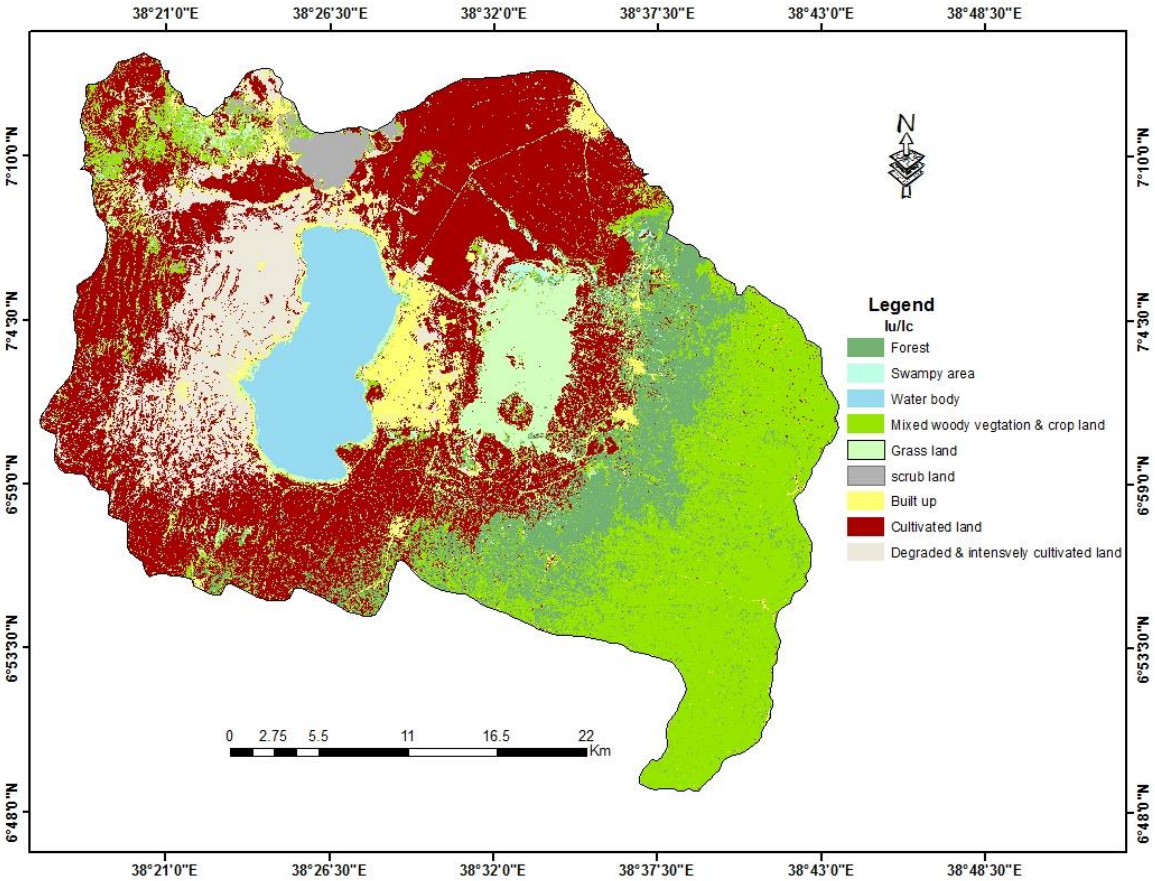


Figure 3.19 Landuse/Landcover map of the study area

Table 3.5 Weighted value for Lu/Lc

Land use	Rating
Water body& Swampy area	5
Forest & Mixed woody vegetation and crop land	4
Cultivated land and Degraded & intensively cultivated	3
Grass land	2
Built up & Scrub land	1

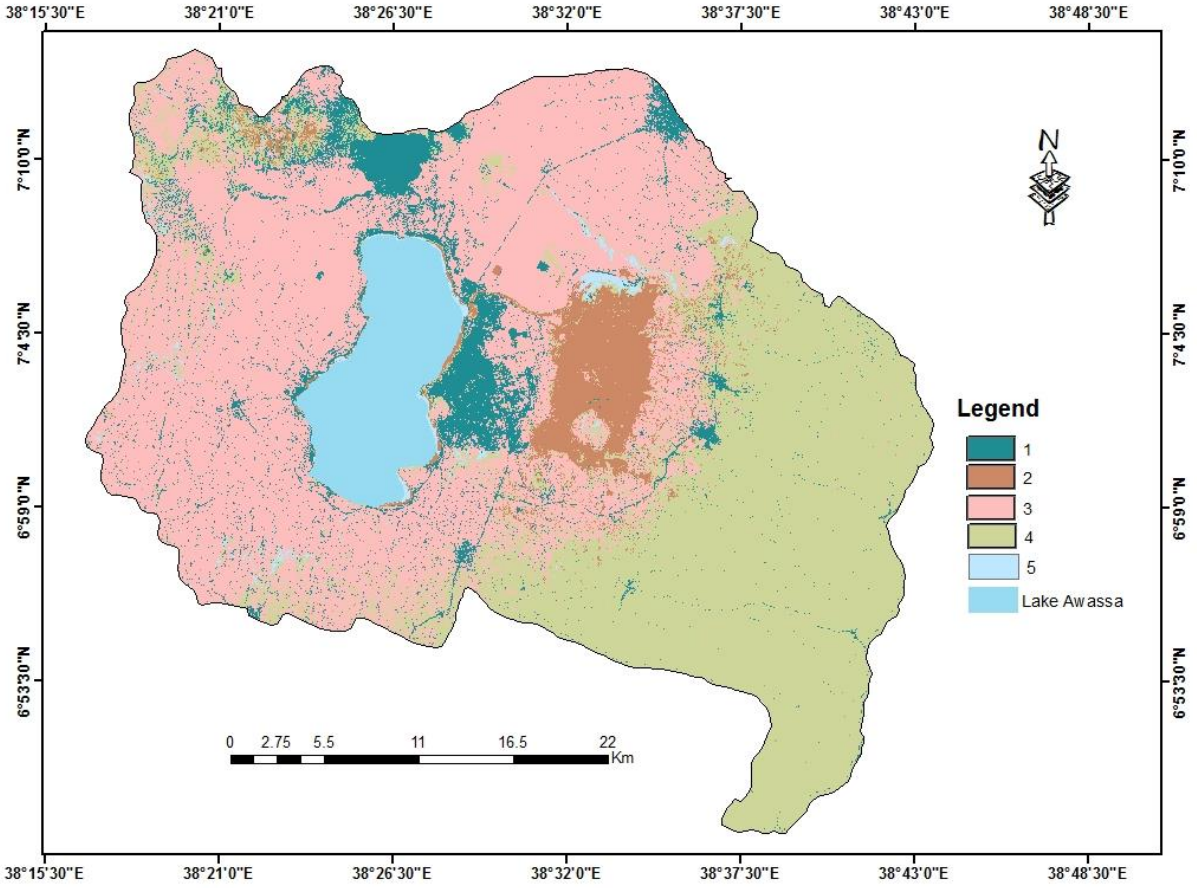


Figure 3.20 Reclassified land use/ land cover map

3.5.1.7 Geomorphology

Geomorphology is the study of the form of the Earth (landform), its description and genesis. It is a branch of Earth science, which has grown after the advent of aerial photographs and satellite data. Geomorphology, along with information on soil, water and vegetation has become one of the essential inputs in planning for various developmental activities. Geomorphology of an area depends upon the structural evolution of geological formation. Geomorphology reflects various land form and structural features. Many of the features are favorable for the occurrence of groundwater and classified in terms of groundwater potentiality. The geomorphology (fig. 3.21) of the catchment was classified as Steep escarpment, Hill, Ridge, Undulating surface and flat plain. Based on the favorability of groundwater potential the area was reclassified (fig.3.22)

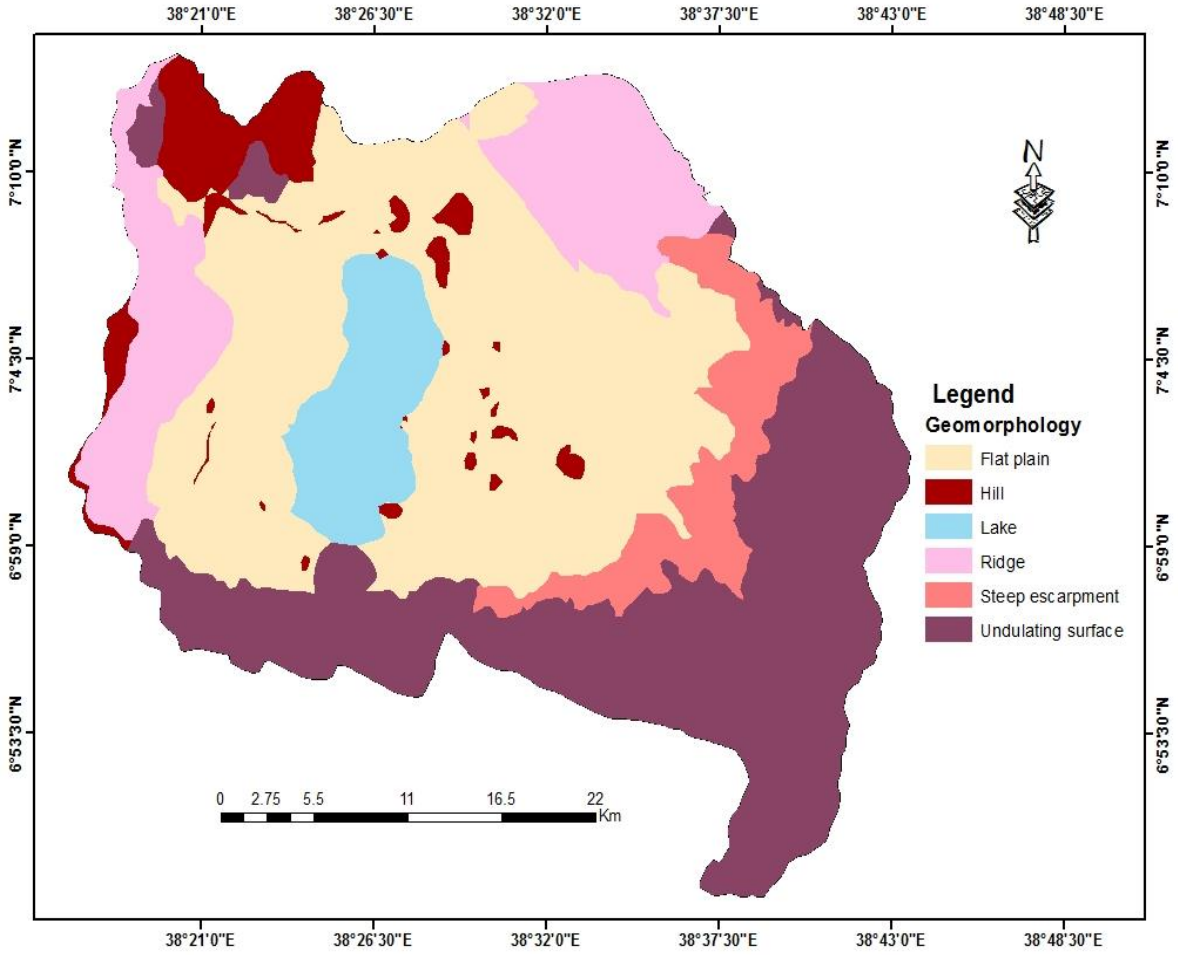


Figure 3.21 Geomorhological map

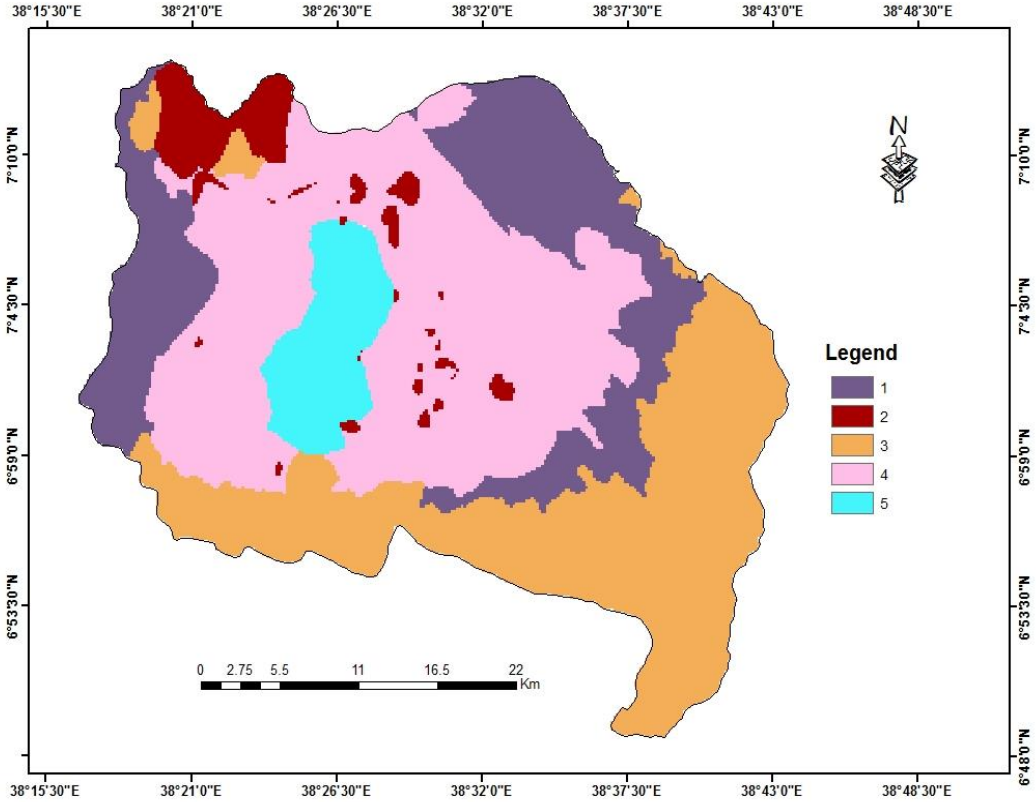


Figure 3.22 Reclassified Geomorhological map

3.5.1.8 Rainfall

Rainfall is one of the major sources for groundwater. It can be governed by the rainfall distribution, topography, land use /land cover, soil and geology. The area characterized by high rainfall amount shows high groundwater potential zones. Spatial distribution of rainfall was generated using rainfall data from National Meteorological Services Agency. Due to uneven distribution of the rainfall stations the rainfall data might not indicative of the exact figure but it gives workable rainfall distribution. 5 rainfall stations data of the past 30 years were used. The rainfall map (fig 3.23) was generated from point rainfall with output grid cell size of 100 m using IDW nearest neighbor interpolation techniques. Then rainfall is classified (fig.3.24) into 4 regions and weight is assigned based on their relevance to groundwater exploration.

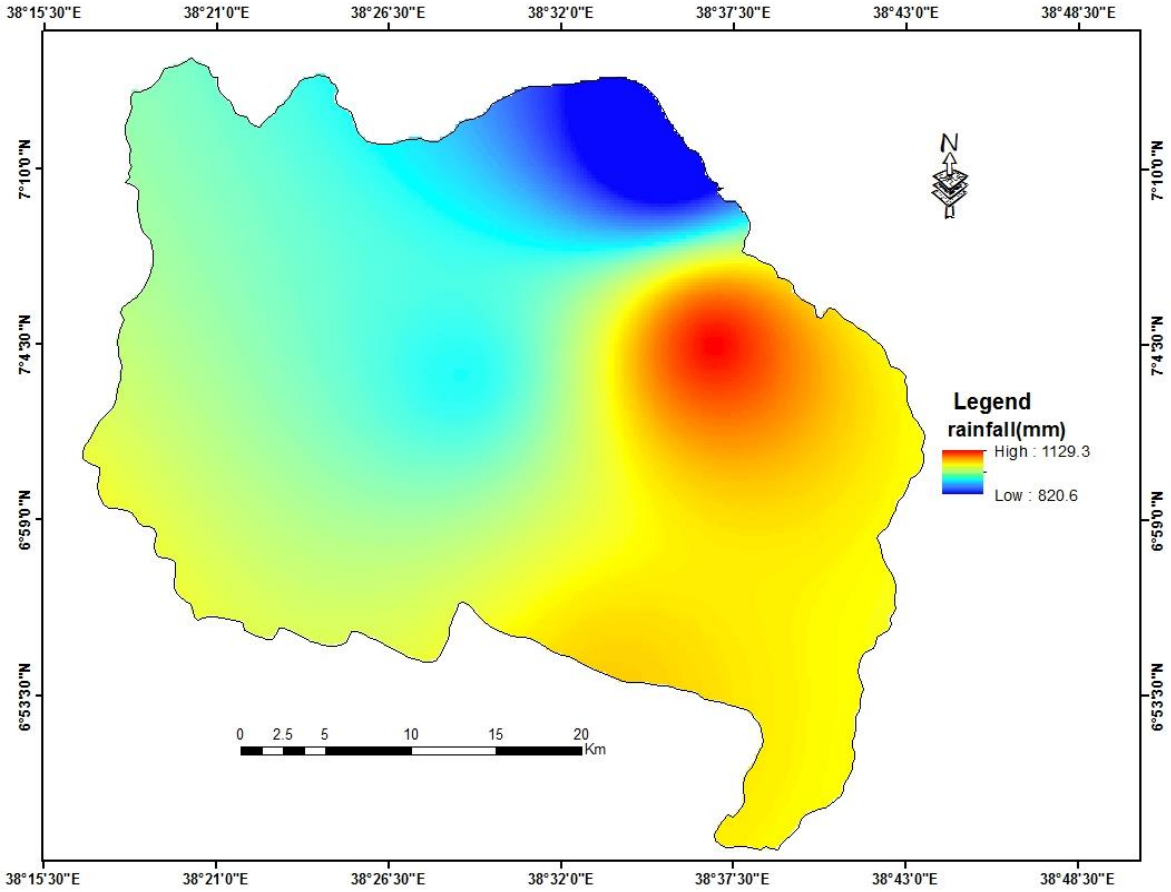


Figure 3.23 Rain fall map of the study area.

Table 3.6 Weighted values for Rainfall.

Classes	Weight
820.6–923.5	1
923.5–993.7	2
993.7–1037.3	3
1037.3–1129.3	4

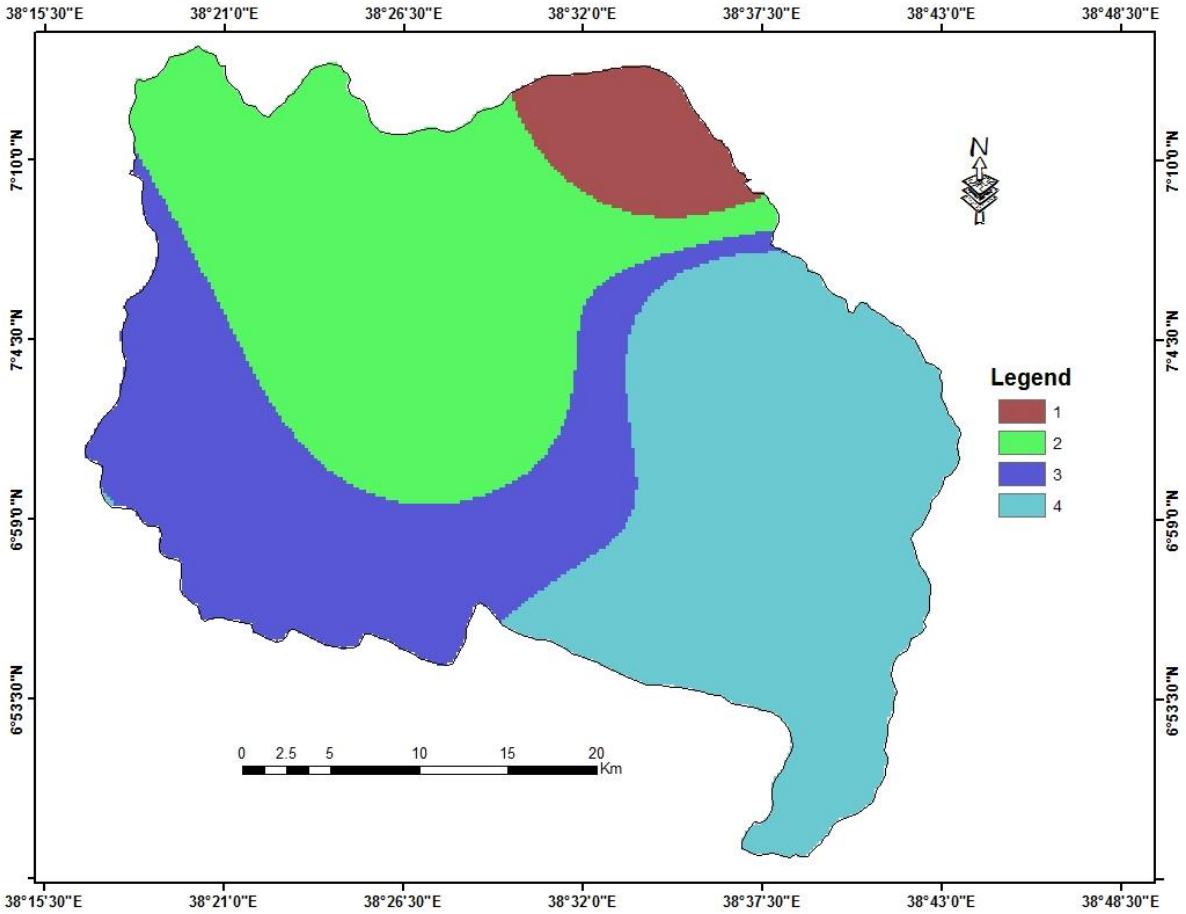


Figure 3.24 Reclassified Rainfall map

CHAPTER FOUR

4 Results and Discussion

4.1 Data integration in GIS Environment

To evaluate groundwater potential zones different parameters were considered then for each parameters maps were prepared. These maps were converted to raster data set, reclassified and given appropriate weight in order to integrate them for multi criteria evaluation (MCE). The least controlling factor gets small value whereas the highest controlling unit gets high value. Finally the maps were integrated using GIS software.

Geology, Geomorphology and lineament were taken as the principal factor for the distribution, occurrence and flow of ground water in the area. Geology is considered as the first principal factor since the distribution and magnitude of spring discharge, the degree of fracturing unit, the thickness of the formation, the grain size and the extent of weathering are some indirect evidence incorporated in geological properties and they define the ground water potential zone. In account of various geology; lacustrine sediment overlain by thick alluvium and volcano lacustrine sediments were assigned highest weight. Due to their porosity and impermeability; Ignimbrite and tuff, pyroclastic lacustrine deposit were assigned moderate value. Low value were assigned for rhyolite lava flow, obsidian and pitchstone and unwelded coarse tuff for their low porosity and less geological structures.

Consideration of geomorphology as the second main factor is due to the fact that infiltration of water in the ground depends on permeability of bed rocks, characteristics of soil and sediment cover and vegetation can be estimated using geomorphic classification using remote sensing imagery. Steep escarpment and ridge were assigned lowest value, undulating surface and hills were assigned moderate value whereas flat plain was assigned the highest value.

Lineament which are the third factor that controls groundwater occurrence are incorporated in geological characteristics of the area. For lineament density weight was assigned in increasing manner. The other factors (Slope, Soil, Drainage density, Lu/Lc and rainfall) are factors that are incorporated in characteristics expressional of Geology, Geomorphology and Structures.

4.2 Criteria weights and Map Scores

All the weighted thematic maps were integrated and defined criteria weight using IDRIS software and overlay analysis done using ArcGIS software and groundwater potential zone were identified.

To determine the relative importance or weights of each thematic map with another paired comparison matrix was prepared by pair wise comparison on Satty's importance scale. These matrices have the property of consistency known as consistency ratios (CR). Satty indicates that the matrices with CR ratings greater than 0.1 should be re evaluated. This way it helps to analyses the matrix to determine the inconsistency in defining the interrelationships. In this case the consistency value was 0.07 which is accepted (Fig 5.1). The weights were normalized by multiplying with 100 to avoid complexities of computation. These weights were applied in linear summation equation to obtain a unified weight map containing due weights of all input variables, which was further reclassified to arrive at groundwater potential map. The importance matrices and their weights are mentioned as follows:

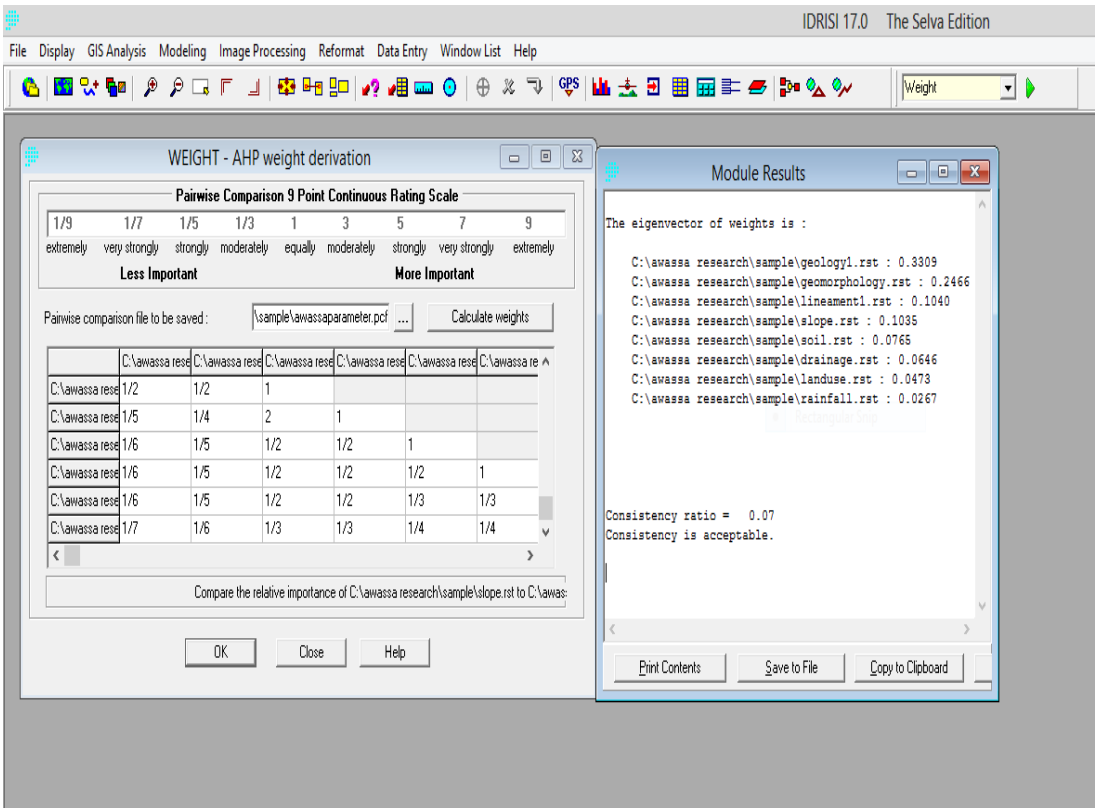


Figure 4.1 Weights of parameters determined using analytical hierarchy principle (AHP) nine point scales.

Table 4.1 paired comparison matrix

	geol	Geom	lin	slope	Soil	Draindn	lu/lc	Rainf	Weight	Weight (%)
Geol	1	2	2	5	6	6	6	7	0.3309	33
Geom.	1/2	1	2	4	5	5	5	6	0.2466	25
Lin	1/2	1/2	1	1/2	2	2	2	3	0.1040	10
Slope	1/5	1/4	1/2	1	2	2	2	3	0.1035	10
Soil	1/6	1/5	1/2	1/2	1	2	3	4	0.0765	8
Draindn	1/6	1/5	1/2	1/2	1/2	1	3	4	0.0646	6
Lu/Lc	1/6	1/5	1/2	1/2	1/3	1/3	1	4	0.0473	5
Rainf	1/7	1/6	1/3	1/3	1/4	1/4	1/4	1	0.0267	3

Consistency ratio = **0.07**

After categorization, all the reclassified thematic layers were integrated with one another Through GIS using the weighting overlay analysis as follows.

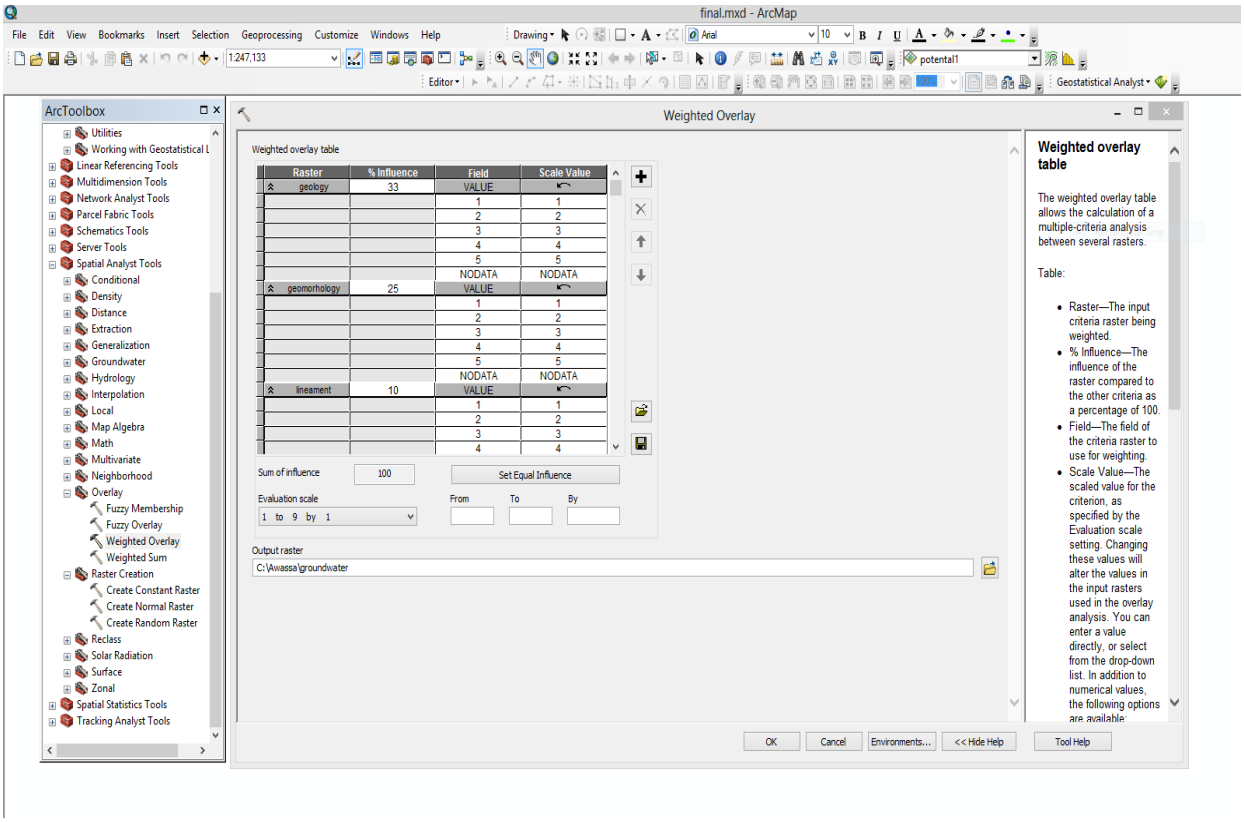


Figure 4.2 Weighted Overlay analysis table to produce Groundwater potential zone map.

The following equation was used for the generation of the groundwater potential zone map(GPZM):

33 × Geology map+25*geomorphology map + 10* lineament density map + 10* slope map + 8* soil map+6* drainage density map + 5* Land use/ Land cover map + 3*rainfall map=GPZM

From the composite layer, the delineation of groundwater prospect zones was made by grouping the polygons into different prospect zones: poor, fair, moderate and good.

4.3 Ground water potential zone map

The hydrogeological map generated from the model using several controlling factors has delineated areas with good, moderate, fair and poor potential of groundwater (fig.4.3).The areas showing high potential is characterized by lacustrine sediment overlain by alluvium deposit and volcano lacustrine sediments and the topography is flat to undulating surface. Low potential appears in the eastern and south eastern part of the study area the area is known for its ridge topography

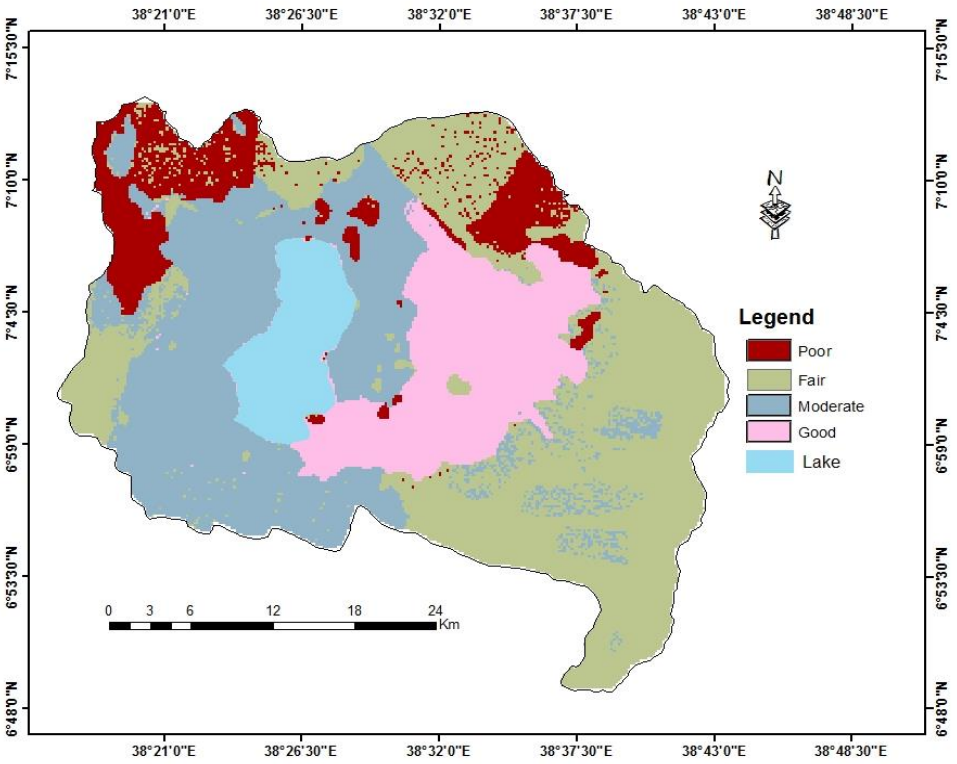


Figure 4.3 Groundwater potential zone map of the study area.

High ground water potential zone

The area east of Lake Awassa is classified as high potential aquifer. The area is covered with thick lacustrine sediments that are overlain by young alluvial sediment deposits, transported from the eastern highland. The area cover 143 $km^2$of the catchment highly permeable water bearing bore holes, numerous springs are found in this part of the area.

Moderate ground water potential zone

Awassa corbetti caldera receives quite significant amount of recharge from the escarpment. There are either no springs or perennial streams on this part of the catchment. Hence, the source of the recharge is limited in time and amount. The area covers 413$km^{2.}$

Fair ground water potential zone

Mainly welded tuff occurs in the eastern highland, adjacent to the rift margin in the Awassa area. The area which covers total area 308km^2, receives high rainfall, but favors high runoff, because of its hilly topography .Considerable volume of rainfall is lost as run off to Awassa caldera with very small proportion of water left for infiltration.

Poor groundwater potential groundwater zone

This zone is characterized by hilly topography that favors high runoff and low recharge to ground water. Hydro structures are poorly developed. Hence, runoff is favored over infiltration Typical geological unit grouped under this class are pumice& tuff and obsidian & pitchstone. The area receives lesser rainfall than other areas and it covers 489km^2**.**

4.4 Model validation

The delineation of groundwater through integration of thematic layers obtained from remote sensing interpretation and other secondary data has found to be effective for analyzing the information content of each layer in a GIS environment.

It was found that the zonation of groundwater potential by integrated GIS and remote sensing techniques was in close agreement with the available point source inventory data(Fig.4.4).Most of Hand dug wells and Boreholes are located in areas where there is very high to moderate potential zones.

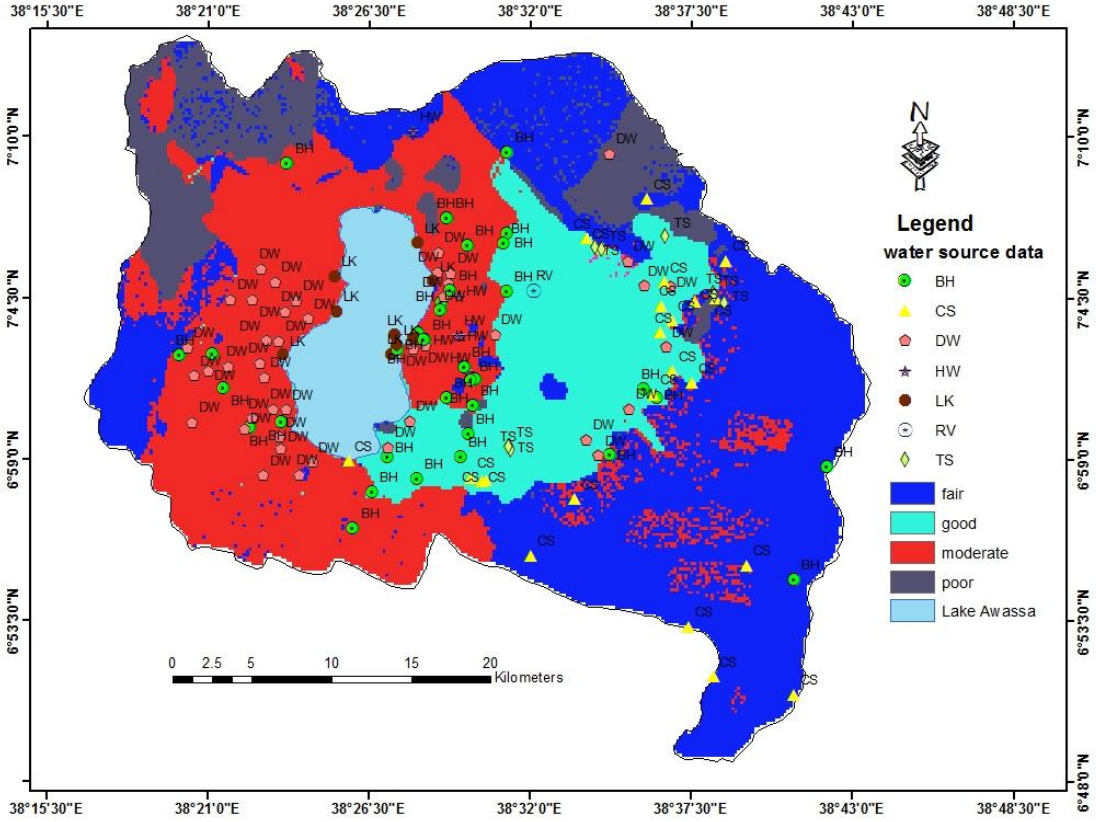


Figure 4.4 Distribution of boreholes and springs with discharge in groundwater potential zone Map.

4.5 Water chemistry

The chemical quality of Ground water largely depends on the nature of rock formation, physiography and soil environment. In this part the hydro chemical characteristics of the area for domestic uses are discussed. The Hydro chemical data is resulted from different water inventory sources like boreholes, hand dug wells, spring, lake and river. A total of 216 water samples were used from secondary data; Most of the samples were collected from deep bore holes. The analysis is crucial for the recommendation of water quality of the study area for human consumptions comparing to WHO standards. The main hydro chemistry of natural water characteristics of the study area can be expressed by parameters like PH, TDS, EC, Eh, HCO_3, SO_4, Cl^-, Ca^{2+}, Na, Mg^{2+} , K^+, F^-& NO_3 have been used.

Physical Parameters

Total Dissolved Solvent (TDS)

TDS varies from 29mg/l to 1823mg/l. Desirable unit for TDS in drinking water as WHO is 1000mg/l. The Northern part of the catchment has very high TDS (>1000) which is not advisable for drinking purpose but the rest of the catchment has appropriate amount of TDS. Generally TDS of water samples increase from the Eastern escarpment towards the lowlands.

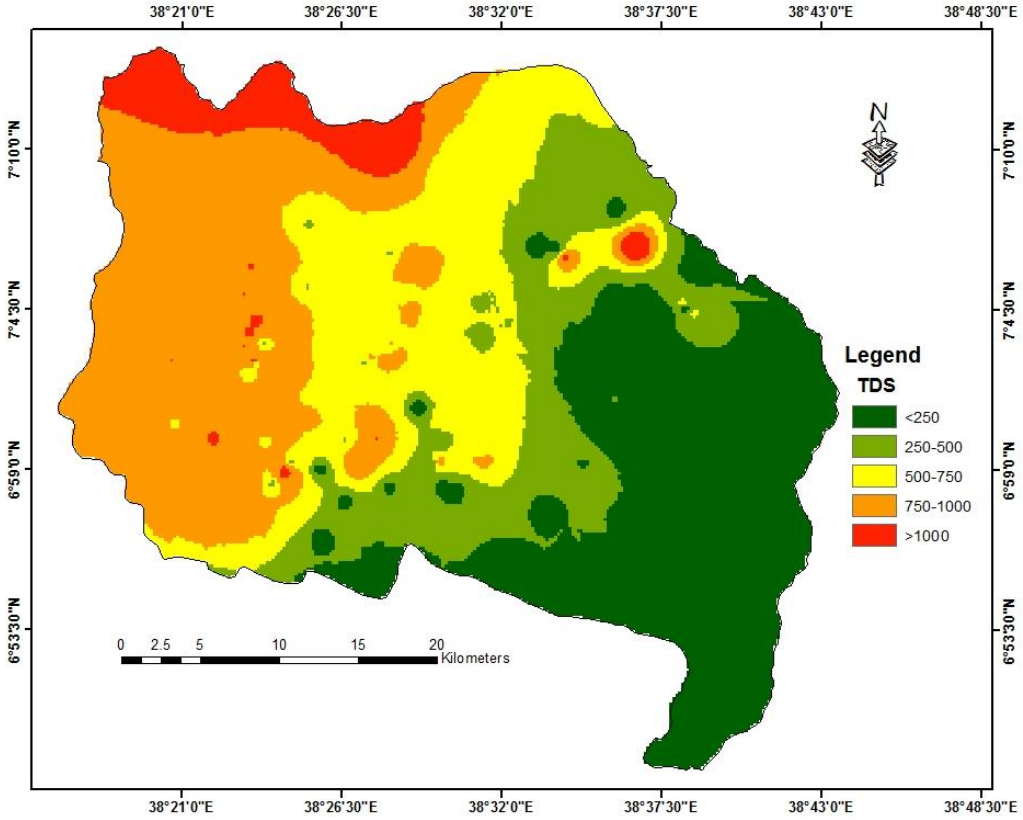


Figure 4.5 TDS of the study area

Hydrogen Ion Activity(PH)

PH is a measure of water's acidity or alkalinity. It ranges from 0 (strongly acidic) to 14 (strongly basic). For most natural waters, the range of PH is between 6.5 and 8.5. The field measured PH is 5.2 to a maximum of 8.9. Most of the study area lies within the standard but the water around the lake area has high PH value. These shows that the natural water in the area have a good quality in terms of PH value for the sampled water points. However there are some exceptions.

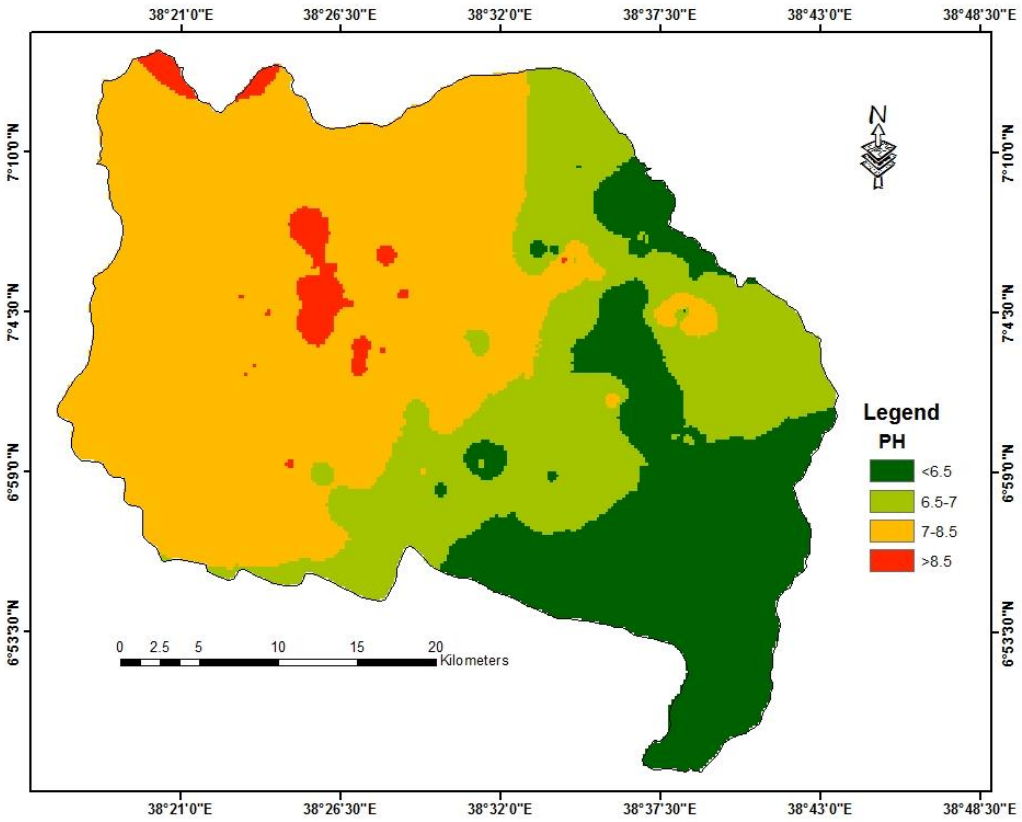


Figure 4.6 PH of the study area

Electrical Conductivity (EC)

Electrical conductivity is the ability of the substance to conduct an electric current. Pure water is a poor conductor of electricity, but minerals dissolve in water, and the resulting ions conduct electricity. In general the larger the value of specific conductance, the greater the concentration of dissolved solids in the water sample and the poorer the water quality. The chemical analysis shows very high electric conductivity (EC) in North western part of the study.

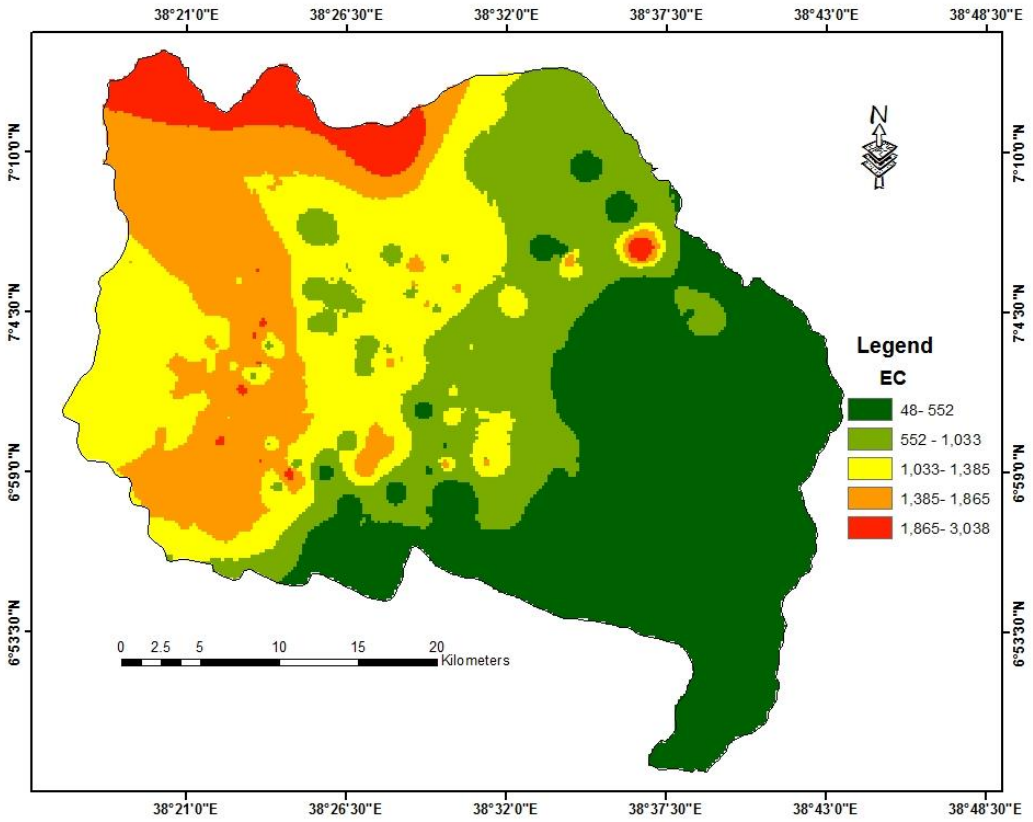


Figure 4.7 EC of the study area

Redox potential (Eh)

The high (+) Eh values in the eastern side of the study area indicate an oxidizing environment whereas the western side, with (-) Eh, is predominantly a reducing environment. The eastern side of the study area (fig), which is identified as oxidizing environment, coincides with low EC values. The low EC value is indicative of shorter residence time. This zone, which has high Eh and low EC, is considered to be an area of groundwater recharge. The western side with negative Eh value may indicate longer residence time, since recharge has taken place. Anaerobic subsurface environment has led to the development of negative Eh values. The groundwater flow as inferred from Eh values is more clearly depicted in the eastern side than the western side.

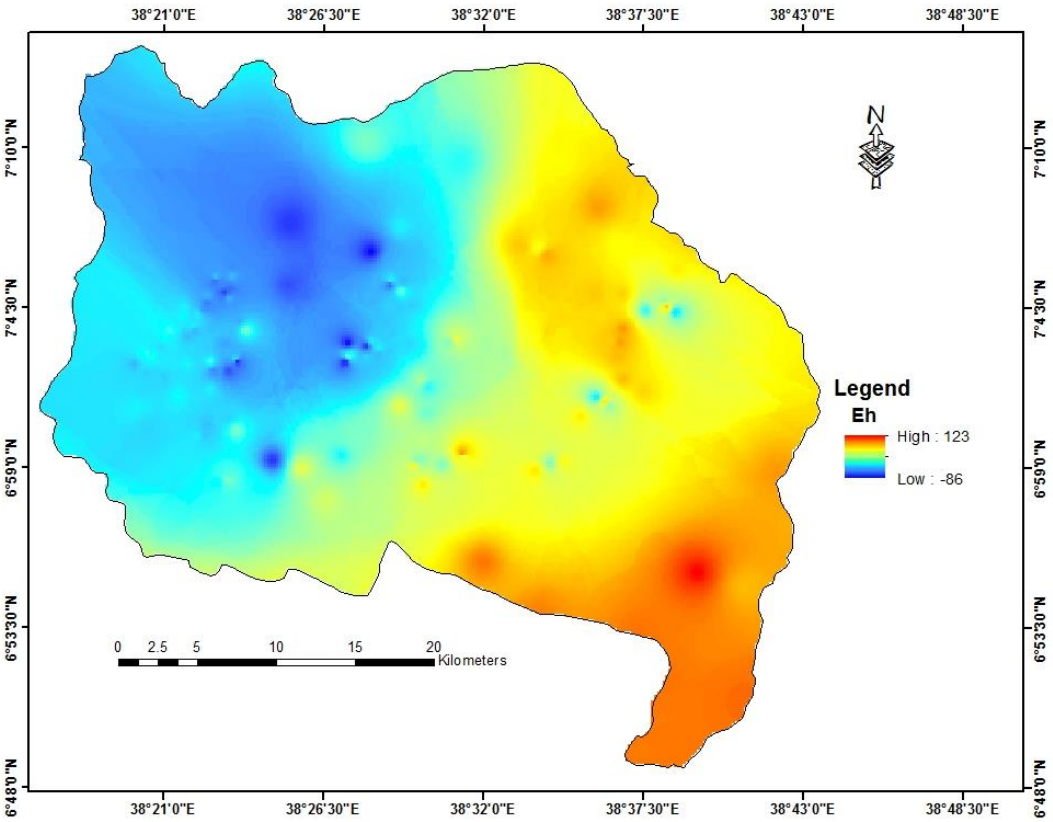


Figure 4.8 Eh of the study area

Cations and Anions

Sodium ion(Na^+)

The WHO guideline for drinking water is 200mg/l. The sodium concentrations in most part of the study area satisfy the standard except the Northern part of study which has more than 350mg/l of sodium.

Calcium ion (Ca^{2+})

The WHO guideline for drinking water is 200mg/l. The Calcium concentration in all water samples in the study area is below the desirable level of the standard.

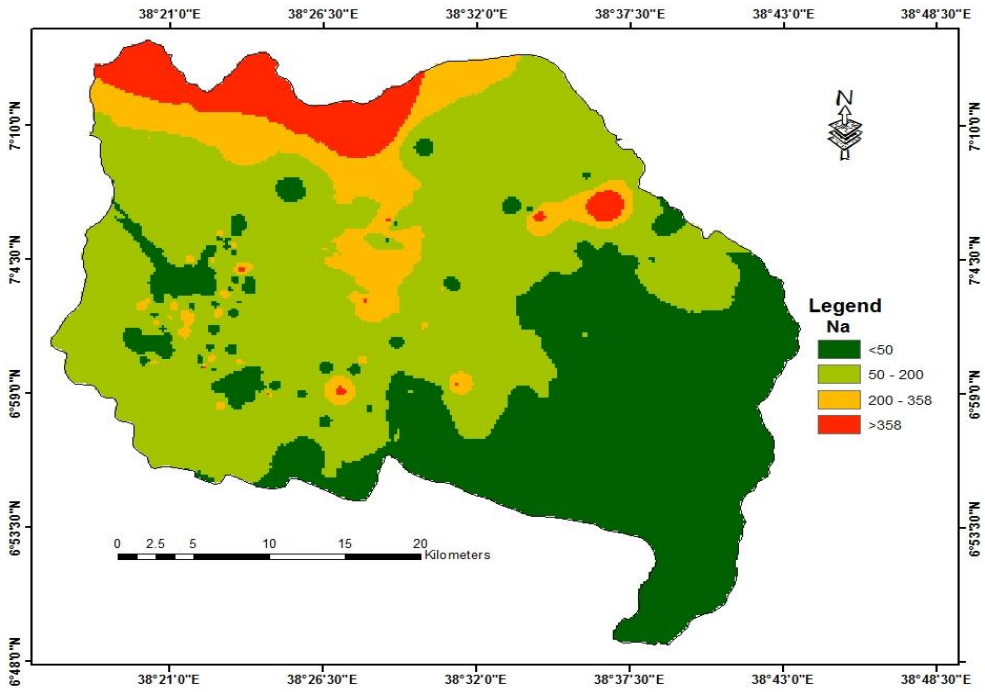


Figure 4.9 Na of the study area

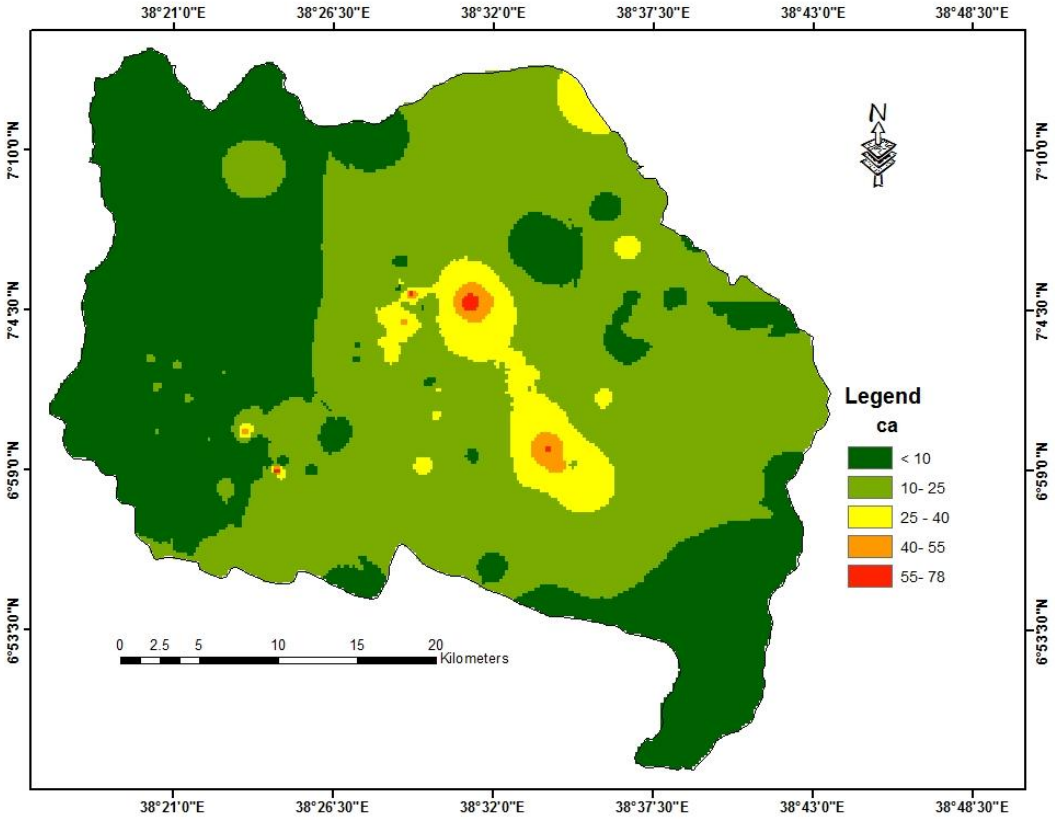


Figure 4.10 Ca^{2+} of the study area

Bicarbonate (HCO_3^{2-})

The presence of carbonates and bicarbonate influences the hardness and alkalinity of water. The relative amounts of carbonates, bicarbonate and carbonic acid in pure water are related to the PH. As result of the weathering process, combined with PH range of surface waters, bicarbonate is the dominant anion in most surface waters. In study area, the maximum bicarbonate ion concentration is 1,700 mg/l

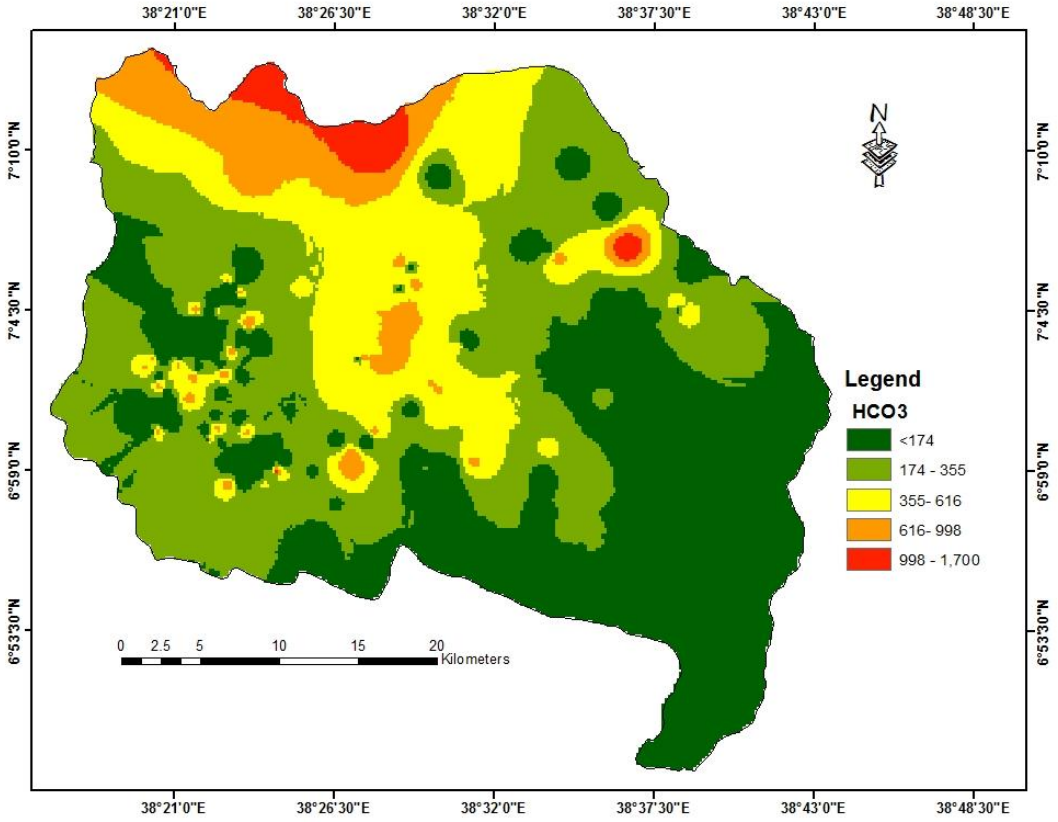


Figure 4.11 HCO_3 of the study area

Fluoride ion (F^-)

The eastern and southern side of the study areas shows very low concentration of fluoride (<1.5 mg/l). This is the area, which has been identified as major ground recharge zone on the basis of its low EC and high Eh values. Most of groundwater samples have shown a fluoride concentration in the range of 6 to 10 mg/l. The concentration in LakeAwassa is 6.4 mg/l. The highest concentration (27.6mg/l), in study area, is shown by Shalo-Oua hot spring (HS3) whose temperature is 86.6^oC. Surprisingly, the other two thermal springs (HS5and HS7) show relatively very low concentration (1.2 and 5.4 respectively). Fluoride is an essential nutrient to healthy dental growth, provided its concentration is in the range of 0.5 to 1.5 mg/l. The study area can be sub divided in to two, on the basis of fluoride

concentration: high fluoride area, Northwestern part (Awassa caldera) and low fluoride area (east and south). Fluoride zoning is helpful, to guide people where to develop water resource for domestic purposes or to design appropriate remedial measures.

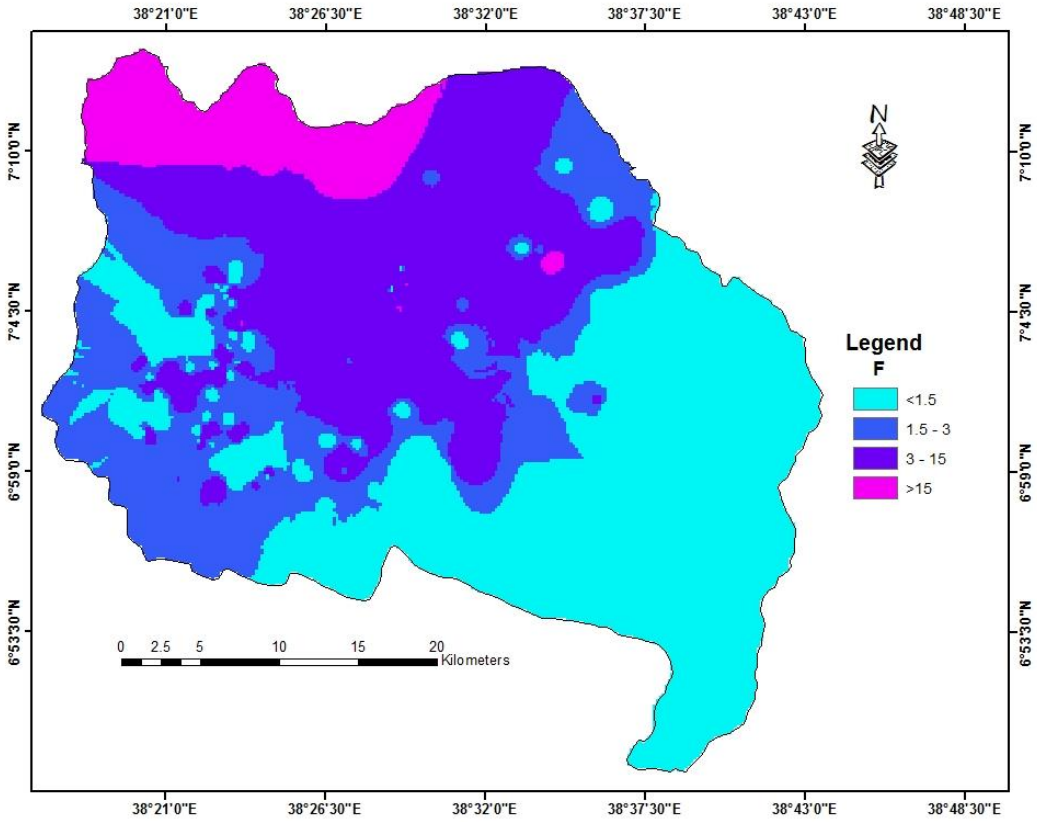


Figure 4.12 F^- of the study area

Classification of Natural Water

Classification of natural water is used to express the groundwater chemistry on the Hydro chemical map. Hydro chemical types are classified based on Aquachem Software.The ion concentration in most of the water samples is dependent on elevation, litho logy, structures and climatic conditions.

From the Piper diagram it can be established that all waters within the catchment are similar in overall chemical characteristics in which **sodium bicarbonate (**Na-HCO_3)is the dominant water type, differing only in the degree of salinity. Thus, the groundwater, surface water and Lake Awassa belong to one hydrochemically homogeneous system. The second dominant water type is Na-Ca-HCO_3.

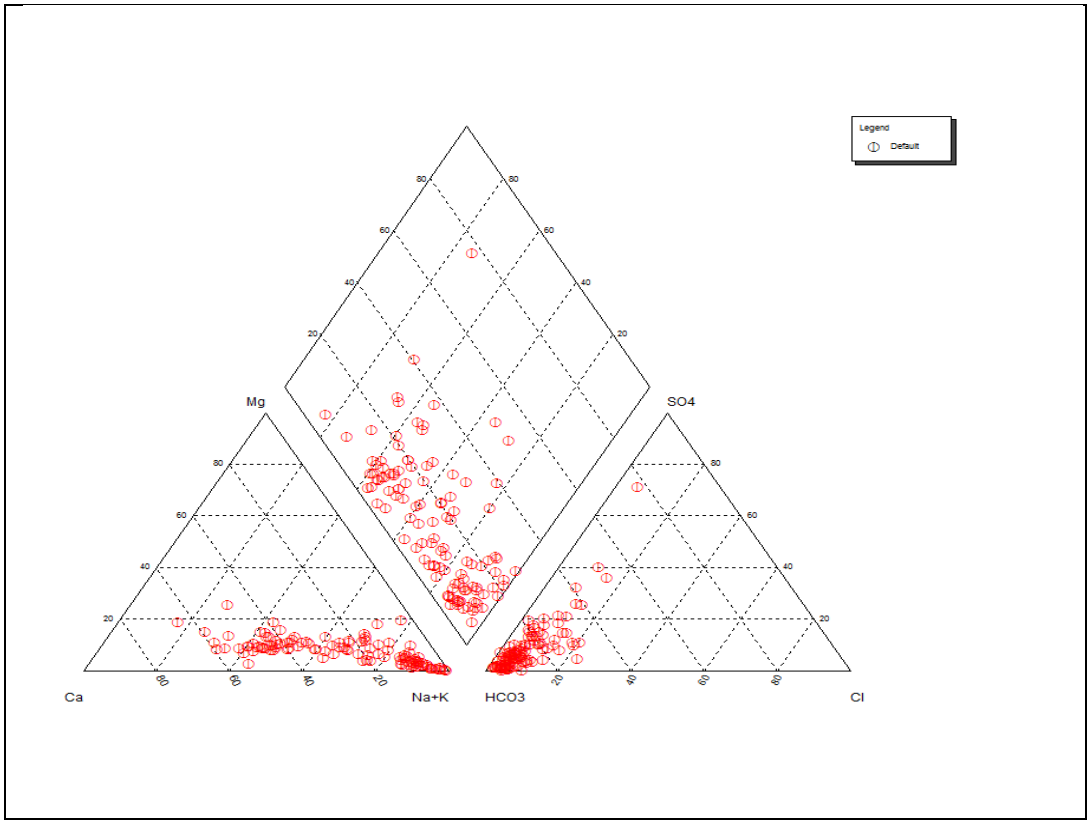


Figure 4.13 Piper diagram

Generally, in terms of quality and potential of ground water, the area having good potential groundwater of the lacustrine area which contain numerous springs that has the best quality.

CHAPTER FIVE

5 Conclusion and Recommendations

5.1 Conclusion

The delineation of preliminary groundwater potential zones through the integration of different thematic layers obtained from remote sensing interpretation and other secondary data has found to be effective techniques for analyzing the information content of each layer in GIS environment. The analysis would give meaningful results without the need of conducting geophysical and test drilling which are time, effort and cost consuming activities. This technique would give broad ideas about the groundwater potentiality of the areas and then minimize the areas where detail groundwater exploration activities to be carried out to study sub surface aquifer condition (storability and conductivity) through geophysics and drilling test.

Paired Comparison matrix analysis indicates that all parameters are significant but the most effective parameters in the area are: geology, geomorphology, lineament density and slope.

The study has resulted the groundwater potential zone map for the Lake Awassa catchment which identified and delineated in four categories namely high, moderate, fair and poor. In terms of quality the ignimbrite unit with good potential ground water has the best quality in the study area.

Most of the high potential areas represented by Lacustrine sediment overlain by thick alluvium, Ignimbrite unit, which coincide with the low slope and high lineaments density areas and in contrary zones with poor groundwater potential lie in the hilly ranges where mildly alkaline transitional basalts, rhyolite lava flows, trychyte lava flow and obsidian and pitch stone exist.

Generally, it can be concluded that Integrated GIS and remote sensing techniques are very efficient and useful time and cost effective tool for the identification/delineation of groundwater potential zones.

5.2 Recommendation

- The good model outputs in such areas require experts experience and knowledge of the hydrogeological condition/environment and the variability's and their roles of parameters for better field calibration than in other areas where geology and geological structures are less complicated. The field observation and measurement should be given due consideration for effective and sustainable use of the resource.
- For local potential zoning such maps are good, but the well sitting should be supported by other methods such as geophysics as there are places which seem suitable for water storage, but water table is very deep due to fault effect, and the sediments or rocks filled into and affected by the faulting
- Great care should be taken for water quality analysis before developed water schemes are connected to water supply schemes in the area to avoid unnecessary health impact of the community, or springs that have good water quality should piped preferably to the even if from far to areas where the groundwater has high fluoride.

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Appendices

Appendix A:Monthly rainfall in mm at Awassa station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1980	13.8	15.5	38.3	110.6	112.5	73.8	88.3		40.2	139.1	34	0
1981	0	25	198.7	135.9	48.3	127.2	132	155.9	157.3	52.4	7	0
1982	49.6	46.6	62.6	92.1	70.8	121.1	166.3	117.1	72.7	95.9	84.4	12.4
1983	60.5	47.9	56.3	186.4	238.8	76.1	102.8	125.9	153.9	90.6	14.2	6.4
1984	0	0	36.5	17.4	170.2	70.7	96.1	92.7	165.7	27.4	34.5	13.3
1985	9.2	0	75.7	201.9	93.3	106.9	146.1	80.7	116.6	50.2	12.8	8.3
1986	0	34.7	69.6	109.8	167.2	193	153.3	194.2	171.8	57.3	22.8	18.4
1987	0.1	11.8	151.4	127.8	230.8	58	97.3	108.1	68.8	100.1	0.4	4.1
1988	25.8	68.5	17.5	80.9	100.1	110.9	117.7	138.8	205	83.9	1.3	6.6
1989	38.8	49.9	62.8	211.8	95.2	123.8				40.9	22.3	
1990		93.7	121.1	89.9	85.3	44.4	139.5	39.5	94.1	27.3	7.6	3.8
1991	12.3	90.6	87.4	48	129.5	116.7	109.2	90.6	104	21.6	12.2	44.8
1992	23.4	83.5	73	109	60.5	83	92.8	123.6	74.5	142.3	80.1	16.6
1993	101.6	109.1	22.3	104.9	165.3	46.7	54.7	130.8	47.8	130.8	10.5	3.9
1994	0	4.7	56.8	108.7	80.8	146.2	195.7	118.9	68.9	58.8	19.1	2.9
1995	0.8	21.4	61.8	156.1	43.6	118.7	175.7	134.7	166.8	22.3	18.3	84.2
1996	78.4	36.9	89.6	113.8	161.5	243.3	121.2	108.7	145	69.6	19.7	1.4
1997	23.4	1.7	75.1	125	73	111.2	98.6	113.9	118.9	157.1	132.2	24
1998	92	140	90.8	86.4	88.4	56	172.9	108.3	109.6	193.3	10.6	0
1999	19.8	0.4	105.5	27.1	64.7	99.8	135.1	83.8	115.4	120.4	20.1	16.8
2000	1.1	0	11	132	145.1	36.4	80	179.3	87.6	110.7	29	9.3
2001	1.8	39.9	122.7	67.2	233.7	137.5	93.4	131.7	89.7	80.2	2.6	21.3

2002	52.5	2.4	128.7	119.6	85.2	91.9	76.6	190.4	83.2	37.3	0	51.5
2003	30.4	2	78.2	179.1	40.4	110.5	74.5	76.1	85.5	53.4	6.2	152.6
2004	46.2	94.2	42	83.1	81.5	75.7	75.4	117.1	116	57.1	94.2	15.2
2005	81.1	7.7	120.9	156	144.5	73.2	150.9	61.3	122.2	28.4	46	10.4
2006	1.7		139.2	145.9	74.4	108	171.1	169.3	194.9	56.9	79.2	48.3
2007	18	56	70.4	112	166.1	225.4	129.1	105.1	233.8	33.1	3.7	0
2008	33.7	7.5	3.4	57.8	121.4	118.2	120.5	123.5	160	66.1	97.1	5.8
2009	32.8	9	60.3	45.6	103.1	51.6	92	112	81.7	41.6	4.1	69.9
2010	26.6	58.4	124.5	96.1	173.5	52.9	132.5	136.6	96.1	47.1	32	56
2011	2.3	7.1	55.5	73.7	193.6	65.5	150.8	155	125.5	5.5	88.2	0.2
2012	0	2.4	13	210.5	91.3	89.8		87.2	86.8	15.2	23.2	13.1
2013	23.4	1			143	132.4	209.4	163.1	117.7	77.5	22	0
2014	23.4	26.3	91.5	104.5	198.7	98.4	104.6		164	105.3	19.1	

Appendix B:**Monthly rainfall in mm at Haisawita station**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001	2.6	36.9	150.4	81.5	246.4	106.4	108.2	138.9	171.0	176.4	19.1	54.1
2002	62.6	15.4	125.7	91.3	121.5	72.7	47.7	76.8	141.4	27.0	3.6	
2003	18.1	45.4	109.1	174.1	21.7	64.4	70.2	151.1	195.0	110.8	30.1	39.0
2004	91.1	62.6	77.3	126.7	39.1	53.5	97.1	88.3	248.8	96.3	33.3	13.8
2005	53.2	12.0	213.4	210.3	217.2	83.3	89.2	48.7	210.7	85.4	72.2	
2006	13.3	80.8	161.1	220.8	140.3	136.9		167.9	168.6		18.9	66.3
2007	64.5	64.5	192.2	367.6	139.1	92.8	104.7	121.3	259.4	67.3	2.8	0.0
2008	3.3	0.0	0.0	59.2	262.6	122.7	91.7	124.2	106.0	75.9	72.4	12.2
2009	23.0	29.2	112.4	64.6	70.0	96.5	80.5	86.1	78.6	104.2	8.8	106.6
2010	43.4	83.1	135.9	206.4	190.5	68.2	137.3	171.9	192.9	53.9	58.7	24.7
2011	24.9	8.2	56.3	103.1	288.8	125.1	108.9	189.3	125.1	95.9	54.9	
2012	0.0	0.0	40.1	67.9			183.1	149.2		32.8		4.9
2013	32.2	11.0	129.6	155.4	142.7	80.0	110.4	241.6	107.1	129.0		0.0
2014	20.8	72.2	187.2	144.4	238.4	23.9	168.8	97.9	190.6	120.0	136.6	0.0

Appendix c:Monthly rainfall in mm atShashemene Station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	0.0	0.0	3.3	257.0	244.7	45.6	92.3	52.3	105.4	150.8	21.0	13.9
2001	0.0	6.8	151.1	37.6	89.9	92.9						
2002			14.0	41.1		33.5	18.5	60.5	67.9	9.5	0.0	39.8
2003	7.3	22.3	68.3	90.1	19.0	61.9	70.8	88.8	117.7	8.3	10.3	34.9
2004	35.0	29.5	25.9	116.2	70.1	80.4	93.6	97.7	49.6	48.3	5.3	8.5
2005		3.2	71.0	129.3	71.0	7.3	72.7	46.3	66.4	39.6	39.8	23.0
2006	0.0	19.2	71.3	92.6	91.6	32.2	78.6	45.3	121.9	40.0	11.5	10.4
2007		11.4	64.8	91.6	96.6	65.8	44.3	63.7	117.9	28.3	1.2	0.0
2008	4.2	3.2	1.0	28.4	40.0	69.1	76.5	109.2	49.9	113.2	74.9	0.0
2009	27.9	13.4	22.7	67.7	58.4	28.7	52.8	30.0	29.5	34.1	7.2	28.8
2010	14.5	46.5	51.6	85.6	89.8	25.2	36.9	26.7	35.8	3.0	1.0	38.4
2011	3.2	2.0		32.1	108.5	32.4	75.3	37.4	31.7	1.0	36.0	6.2

Appendix D:Monthly rainfall in mm atWendo Genet Station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	0.0	0.0	6.9	114.6	104.6	29.7	83.0	83.4	204.2	226.8	63.7	26.6
2001	0.0	58.5	183.2	87.3	235.3	139.5	100.2	169.2	198.7	106.3	1.3	11.3
2002	84.7	15.8	205.3	103.6	146.4	93.4	65.1	93.6	83.6	31.7	0.0	75.7
2003	26.9	52.2	98.1	165.7	31.6	102.0	133.9	141.0	140.1	85.2	0.0	0.0
2004	65.7	16.4	45.4	119.4	127.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2005	77.1	10.2	132.2	156.5			94.4	77.1	147.3	130.7	73.0	21.7
2006	0.0	30.5	157.3	247.0	151.6	70.4		147.4	180.4	97.3	32.3	30.4
2007	28.2	23.9	75.7	232.7	115.7	255.8	69.7	174.1	179.8	74.9	0.8	8.9
2008	1.8	0.0	16.5	51.4	67.9	144.0	53.5	174.5	147.9	68.1	127.5	0.0
2009	35.2	22.8	71.3	43.6	61.7	38.0	67.7	80.1	54.3	145.5	0.0	77.2
2010	112.8	61.3	188.0	181.9	105.6	175.8	169.9	223.0	96.0	26.9	61.1	21.6
2011	10.2	18.4	51.1	71.9	248.3		274.5	234.4	157.9		111.4	6.2
2012	0.0		3.2	117.9		69.5		121.2	96.2		28.3	13.3
2013	15.2	6.3	94.1	102.4	110.8		239.5	188.8				

Appendix E:**Monthly rainfall in mm atYirbaDibancho.**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	0.9	0.0	15.2	95.4	188.6	34.3	104.6	123.1	133.4	121.9	62.0	24.2
2001	9.2	14.8	199.2	97.0		167.8	120.1	97.0	146.2	184.5	6.2	54.1
2002	72.2	32.5	133.0	92.1	93.7	54.9	50.7	128.5	146.6	48.4	0.0	112.3
2003	12.4	7.4	105.6	173.3	41.4	119.9	101.2	200.3	194.4	59.0	25.7	56.9
2004	86.5	138.8	51.2	163.8	108.1	34.7	58.9	80.4	158.9	138.5	47.6	25.0
2005	37.7	31.2	105.1	223.3	295.6	46.6	87.5	107.0	217.7	90.3	94.7	1.4
2006		65.9	135.3	191.1	117.3	87.4	94.9	79.0	99.2		10.9	47.2
2007	69.5	67.3	128.1	144.3	141.5	133.0	53.9	161.3	140.0	69.9	6.4	0.0
2008	8.4	17.1	5.4	98.7	143.6	105.4	86.3	92.3	195.3	104.7	74.1	0.0
2009	33.0	21.1	104.4	50.8	90.6	71.8	90.6	106.5	51.3	104.8	0.0	38.4
2010	39.1	55.0	161.0	266.5	243.3	125.3	53.4	94.5	117.6	23.5	66.4	12.7
2011	8.4	14.5	46.5	182.8		65.1			115.7			23.0
2012	0.0		43.6	130.1		30.6	151.7	83.1	55.4	4.7	18.4	68.3
2013	72.7		74.3	178.4	34.4	39.0	134.6	130.8	241.6		16.2	8.1

Appendix F: Water inventory location

SAMPLE ID	X	Y	Z
BH3	454990	794978	1879
BH4	447033	791288	1751
BH6	443247	787145	1751
BH7	446991	782483	0
BH8	442856	781844	0
BH9	442779	781335	0
BH10	441848	779460	1756
BH11	441401	779904	1733
BH12	440128	779062	1906
BH13	445009	777028	1730
BH14	443231	775814	1750
BH15	444891	775368	1736
BH16	444574	773563	1658
BH17	444086	772115	1674
BH19	439500	772100	0
BH20	441362	770748	1873
BH21	438521	769883	1887
BH24	439293	763859	1891
BH25	436541	763710	1970
BH26	429989	763353	1957

BH28	434404	759498	1871
BH29	438015	759244	2288
BH30	437181	756601	1826
BH31	430804	755288	1787
BH32	435598	752687	1654
BH33	431250	752170	1800
BH34	431299	747854	1637
BH38	433187	790548	1720
BH43	426416	778488	1805
BH44	428480	778614	1779
BH45	429138	776451	1703
BH47	430824	773951	1732
BH48	432817	774293	1771
BH49	455627	776365	1749
BH50	456448	775840	1779
BH51	453503	772256	1679
BH54	467137	771511	2696
BH55	465072	764373	2772
HW1	431499	799258	1783
HW2	437301	799860	1750
HW3	441112	792579	1797
HW4	443985	782246	1727
HW5	444116	779738	1712
HW6	444066	779743	1779
HW7	443874	779764	1711
HW8	444530	777465	1754
DW1	453439	791221	1810
DW2	455612	782890	1742
DW3	457255	782872	1678
DW5	457004	779044	1717
DW6	454686	775165	1778
DW7	452744	772218	1740
DW8	452000	773211	1686
DW12	439509	772724	1830
DW15	440863	774376	1654
DW16	441086	778907	1906
DW17	441823	779103	1721
DW18	446254	779830	1654
DW22	443037	782227	1779
DW23	443282	783063	1747
DW24	443429	783712	1705
DW25	442601	783759	1741
DW27	442636	785021	1785
DW30	431531	783983	1797
DW33	432378	783143	1790

DW40	430971	782021	1821
DW43	429591	782050	1672
DW46	432993	781279	1634
DW55	431880	779484	1584
DW62	426882	778994	1697
DW68	429445	777840	1819
DW69	431402	778053	1728
DW73	428165	777563	1757
DW74	427283	777249	1683
DW83	427174	774333	1667
DW86	430975	774571	1712
DW89	430456	773897	1820
DW97	431664	770968	1849
DW100	433918	771026	1812
DW103	434741	771816	1641
DW105	418913	767227	2037
DW106	424724	764354	1978
DW107	434955	748998	1834
CS1	464441	798695	2000
CS2	455746	788356	1906
CS4	451992	785880	1730
CS6	461987	787362	2200
CS7	461555	786954	2180
CS8	462876	786900	2075
CS9	460747	784454	1642
CS10	456672	781620	1702
CS11	458776	781867	1925
CS12	460084	782090	1797
CS13	457323	780700	1678
CS14	456608	779956	1785
CS16	457343	777517	1717
CS17	458592	776758	1781
CS18	456186	776054	1639
CS19	462037	765283	2436
CS20	451238	769452	1667
CS21	445646	770671	1740
CS22	445381	770562	0
CS23	444676	770823	1729
CS24	436985	771887	1710
CS25	443002	760888	1859
CS26	448464	765928	1918
CS27	451888	762462	2195
CS28	458388	761450	2672
CS29	459946	758292	2626
CS31	464996	757168	2657

CS32	438672	750022	1842
CS33	432014	750919	1720
CS34	430472	758306	2101
HS3	452526	785341	1733
HS4	456965	786018	2532
HS5	459944	782463	1929
HS6	460642	781786	1710
HS7	447156	772809	1707
HS8	447189	772574	1724
HS9	432212	746480	1893
LK1	441388	785594	1683
LK3	439907	779806	1763
LK4	441060	779619	1761
LK6	439731	778581	1686
LK11	432893	778614	1747
LK13	436137	783475	1728