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M.Sc. Degree Thesis Entitled

IDENTIFICATION OF GROUNDWATER POTENTIAL ZONES USING GIS AND REMOTE SENSING TECHNIQUES: A CASEOF ADAMA WATERSHED, OROMIA REGION, ETHIOPIA.

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A Thesis Submitted to the School of Post Graduate studies In Partial Fulfilment of the Requirements for the award of Degree of Master of Science In Geodesy And Geomatics Engineering.

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June, 2017

DECLARATION

I hereby declare that the thesis entitled ''Identification of groundwater potential zones using GIS and Remote sensing techniques: A case of Adama watershed, Oromia Region, Ethiopia" has been carried out by me under the supervision of Dr. Hassen Raja and Dr. Pernaidu Pasala. I further declare that this work has not been submitted partially or in full by any other person for an award of a degree in any other university.

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CERTIFICATION

This is certified that we have read and evaluated this thesis prepared under our guidance, by Kumera Soressa**,** entitled Identification of Groundwater Potential Zones using GIS and Remote sensing techniques: A case of Adama watershed, Oromia Region, Ethiopia and we recommend that it be submitted as fulfilling the thesis requirement.

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APPROVAL

As members of Examiners of the MSc Thesis, we certify that we have read, evaluated the thesis prepared by **Kumera Soressa** and examined the candidate. We recommended that the thesis be accepted as fulfilling the requirement for the degree of Master of Science in Geodesy and Geomatics Engineering.

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ABSTRACT

Groundwater is occurring within different hydrogeology environment, geologic formations and topographic settings are the factors that mainly control the groundwater distribution and development for different purposes. A systematic evaluation of groundwater is essential for the proper utilization and management of this precious natural resource. Integrated GIS (Geographic Information System) and remote sensing are efficient techniques in groundwater studies; in facilitate better data analysis and their interpretations of groundwater potential controlling parameters. In the present study, an attempt has been made to delineate and classify possible groundwater potential zones in the Adama watershed of the Ethiopian rift escarpment, found in Oromia using integrated remote sensing and GIS techniques.

The thematic layers considered in this study are Geology, geomorphology, drainage density, lineament density, rainfall, soil types, slope and landuse/cover. Further, the weights have been assigned according to their relative importance in groundwater occurrence and the corresponding normalized weights were obtained based on the Saaty's analytical hierarchy process. These weights were applied to obtain a unified weight map containing due weights of all input variables. The thematic layers were finally integrated using ArcGIS and IDRIS software to produce a groundwater potential zone map of the study area. Thus, five different groundwater potential zones were identified. In this study area, 47.94% moderate, 33.51% high, 16.73% low, 1.23% very low and 0.59% very high groundwater potential zones have been identified. The resulted groundwater potential zoning map validated by using 55 borehole data. Interestingly out of 55 boreholes 35 falls on the high, 20 boreholes are overlaid properly on moderate class of groundwater potential zone. Moreover no boreholes were found under low groundwater potential zones which reflects the accuracy of results. Finally, it is concluded that the integrated GIS and remote sensing techniques are very efficient and useful for the identification of groundwater potential zones.

Key words *Groundwater, Remote Sensing, Geographic Information System.*

ACRONOMYS

ASTER	Advanced Space Born Thematic Emission And Reflection Radiometer
AOI	Area of Interest
CGS	Council of Graduate Studies
DGS	Department of Graduate Studies
DEM	Digital Elevation Model
EMA	Ethiopian Mapping Agency
ERDAS	Earth Resources Data Analysis System
FAO	Food and Agricultural Organization
GIS	Geographic Information system
IDW	Inverse Distance Weighted
MSc	Master of Science
NMA	National Meteorological Agency
MoA	Ministry of Agriculture
RS	Remote Sensing
SGC	School of Graduate Studies
TM	Thematic Mapper
UTM	Universal Traverse Mercator
WGS	World Geodetic Survey

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CHAPTER 1

INTRODUCTION

1.1 Back ground

Groundwater is one of the most valuable natural resources, which supports human health, economic development and ecological diversity. Because of its several inherent qualities it has become an immensely important and dependable source of water supplies in all climatic regions including both urban and rural areas of developed and developing countries (Todd and Mays, 2005). Developments of our society are dependent on the availability and use of adequate water. This precious resource is sometimes scarce, sometimes abundant but unevenly distributed, both in space and time. Groundwater is the water that is found underneath the earth's surface at profundities where all the pore or open spaces in the soil, sediments, or rock are completely stacked with water. Groundwater of any structure whether from a shallow well or a significant well, devises and is refilled by precipitation. Groundwater is a piece of the hydrologic cycle, beginning when a piece of the precipitation that falls on the Earth's surface infiltrates through the soil and enters diving to wind up groundwater. Groundwater will at long last come back to the surface, discharging to streams, springs, lakes, or the oceans, to complete the hydrologic cycle.

Groundwater represents the second most abundantly available freshwater resources and constitutes about 30% of fresh water resources of the globe (Subramanya,2008). More than 1.5 billion people in the world are known to depend on the groundwater for their drinking water requirements. Groundwater has been a popular resource of water in many countries. Groundwater is easy to extract, and it remains well protected from the hazards of pollution that the surface water has to put up with. However, situations where in we have encountered overexploitation of groundwater resources are not uncommon.

Insufficient knowledge regarding the basics of groundwater is the primary reason why we have not been able to use groundwater resources to their full extent. Thus, there is a growing emphasis on groundwater management.

Water bearing formations of the earth's crust act as conduits for transmission and as reservoirs for storing water. The groundwater occurrence in a geological formation and the scope for its exploitation primarily depends on the formation of porosity. High relief and steep slopes impart higher runoff, while topographical depressions increase infiltration. An area of high drainage density also increases surface runoff compared to a low drainage density area. Surface water bodies like rivers, ponds, etc., can act as recharge zones (Murugesan, 2012).

Over the years the growing importance of groundwater based on an increasing need has led to unscientific exploitation of groundwater creating a water stress condition. This alarming situation calls for a cost and time effective technique for proper evaluation of groundwater resources and management planning. A groundwater developing program requires a large volume of data from various sources. Hence, identification and quantization of these features are important for generating a groundwater potential model of a study area.

The remote sensing and Geographic information system (GIS) tool can open new path in water resource studies. Analysis of remote sensing data and collateral information with necessary ground truth verifications help in generating the baseline information for groundwater targeting. Identification of groundwater occurrence location using remote sensing data is based on indirect analysis of directly observable terrain features like geological structures and their hydrologic characteristics. Application of GIS and RS can also be considered for multi criteria analysis in resource evaluation and mapping for water resource management. The use of remote sensing and GIS tools is appropriate method for groundwater potential zone studies.

Currently groundwater is gaining more attention due to drought problem, rural water supply, irrigation project and low cost of development it requires. Despite the extensive research and technological advancement, the study of groundwater has remained more risky, as there is no direct method to facilitate observation of water below the surface. Its presence or absence can only be inferred indirectly by studying the geological and surface parameters(Sisay, 2007). Some of the main factors that control groundwater occurrence in a given area are: Drainage Density, Slope, Landuse/Landcover, Soil, Rainfall, Geology, Lineaments and Geomorphology. The selected parameters have been prepared and classified in GIS environment, then weightage for each parameters and its classes have been assigned using Analytical Hierarchical Process, then weighted overlay analysis in ArcGIS used to find out the result.

Remotely Sensed data by its wide area coverage and multispectral nature help in identification and mapping of most of the above factors with selective ground checks in a cost effective manner. An integrated analysis of these factors together with the available well and ancillary data in the GIS environment helps in identifying the potential groundwater zones(Timothy, 1994). This helps in narrowing down the target areas for conducting detailed hydro geological and geophysical surveys on the ground and ultimately to locate the site for drilling. Considering the importance of Remote Sensing and GIS techniques, the present study has been undertaken in Adama watershed to identify and map groundwater potential zones.

1.2. Statement of problem

Lack of adequate potable and agricultural water supplies inhibits the progress of developing countries and is the cause of considerable hardship to humans worldwide, but through hydro geologic understanding is often critical for cost effective water development designed to alleviate these problems (Timothy et al., 1994). It is common to have problem in exploitation of groundwater in that unsuccessful rate of well production encounter and requires huge amount of investment cost to utilize this precious resources. Improper evaluation of groundwater and site selections is mostly expected to pose the problems (Abebe, 2006). Since the groundwater occurs out of our sight, deep in the subsurface, there is no direct method to facilitate observation of water below the surface. Its presence or absence can only be inferred indirectly by studying the groundwater occurrence and distribution controlling parameters(Sisay, 2007).

Despite water requirement is increasing very rapidly with the growth of human and animal population, and irrigation in the area, analysis of water resources has been fragmentary. Thus, Insufficient knowledge regarding the basics of groundwater is the primary reason why we have not been able to use groundwater resources to their full extent. In this study, GIS and remote sensing techniques is used to systematically assess the importance of each input parameters in the evaluation of groundwater occurrence and potential zone in the area.

1.3. Objectives

1.3.1 General Objective

The main objective of this research is to identify groundwater potential zones in Adama Watershed by using integrated Geographic Information System (GIS) and Remote sensing Techniques.

1.3.2 Specific Objectives

- To identify factors for Groundwater potential zones and prepare thematic maps of each factors based on the available data interpretation and analysis that will be a good basis for detailed groundwater exploitation work.
- To identify groundwater potential zones through integration of various thematic maps with GIS and Remote Sensing techniques.
- To validate the Groundwater potential zones.

1.4. Research questions

- What are factors which influence Groundwater potential zones identification?
- How does Groundwater potential zones can be identified?
- What is the relative importance of Groundwater potential zones identification criteria?
- How the identified groundwater potential zones can be validated?

1.5. Significance of the study

The research study is expected to produce a groundwater potential zone map that demarcates the study area into different zones according to their groundwater potential and provide information for decision makers enable to retrieve as required for planning and management. The resulted detail map of the area can be one input for understanding of hydro geological systems of the area, and used as data for further research work.

The generated, collected and digitized data will be organized into the logical groups of entities to produce properly organized Geodatabase which will enable the responsible officers to make decision and review by concerned stakeholders and subsequent researchers to properly use water resources in the area.

1.6. The scope of the study

The scope of the study is limited to cover only Adama Watershed due to financial, time, and material constraints and the work will be concentrated on identifying the groundwater potential zone in Adama Watershed with the application of Multi Criteria Evaluation (MCE) technique in GIS environment.

1.7. Limitation of the study.

There was no definite smooth road of conducting a research. However the researcher tried to solve the above limitation with a systematic way to achieve the objective of the study, which is identification of the groundwater potential zones in case of Adama Watershed. The data collection period was very difficult by endless meeting of the officials and some bureaucracy staff, but the researcher was solved it frequently asking them. The limitation of the study are presented as follows:

i. Lack of well organized data about study area.
ii. Unwillingness of some officials to give data.
iii. Very limited budget for conducting field data collection was another major constraint for the researcher.

1.8. The Study Area

1.8.1. Location

Adama Watershed is located in Central Ethiopia, in Oromia Regional state. The watershed lies within longitude 38º 53' 00" to 39º 58' 00" East and latitude 8º 4' 00" to 9º 6' 00" North. The watershed area is located within the Awash River Basin. The total catchment area of the watershed is about 8,458 square kilometres and the topography of the watershed lies within 934-3058m above mean sea level.

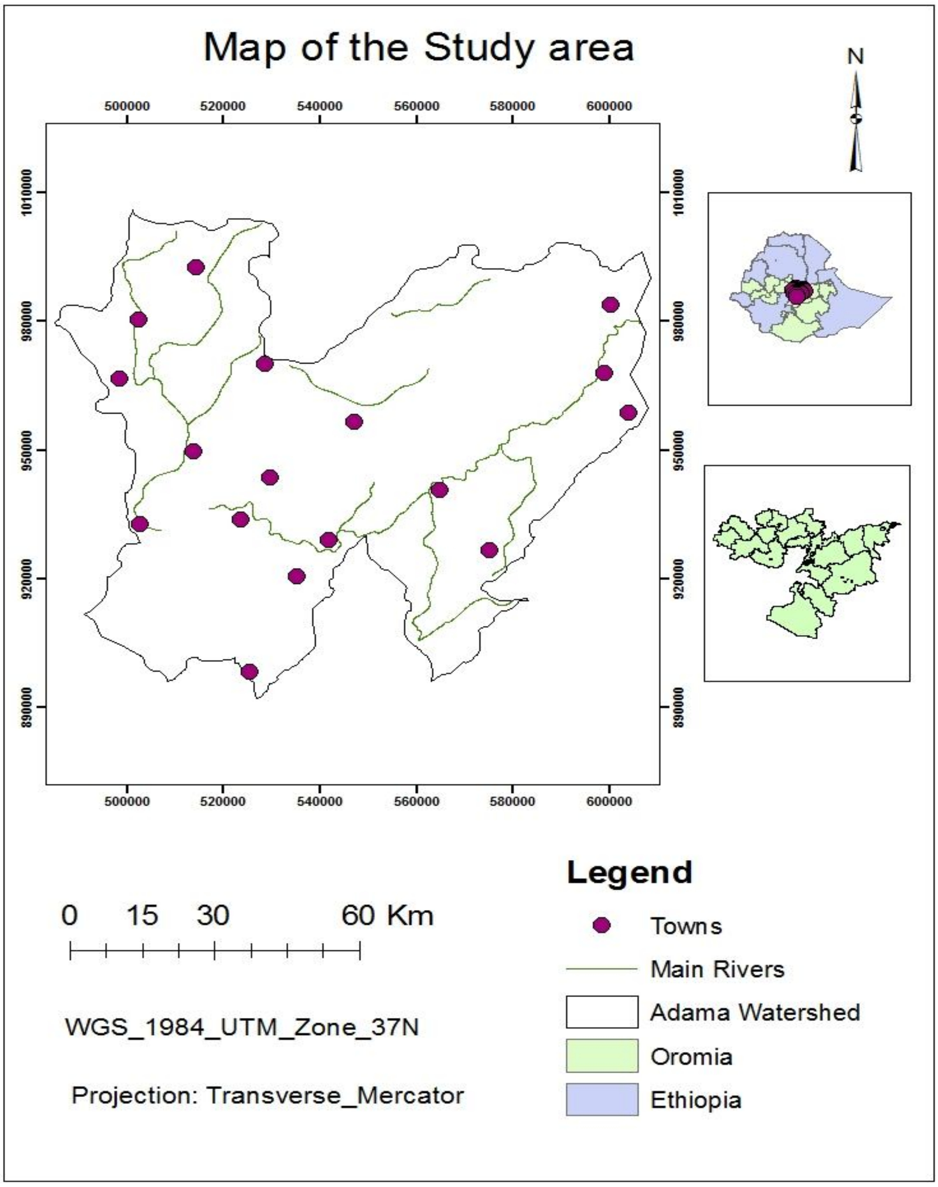


Figure 1.1. Location map of the study area.

Topographic information has been derived from ASTER DEM 30 m resolution data. In the study area the elevation ranges starting from 934m to 3058m. Water tends to store at lower topography rather than the higher topography. Higher the elevation lesser the ground water potential and vice versa (Gedebo,2005),

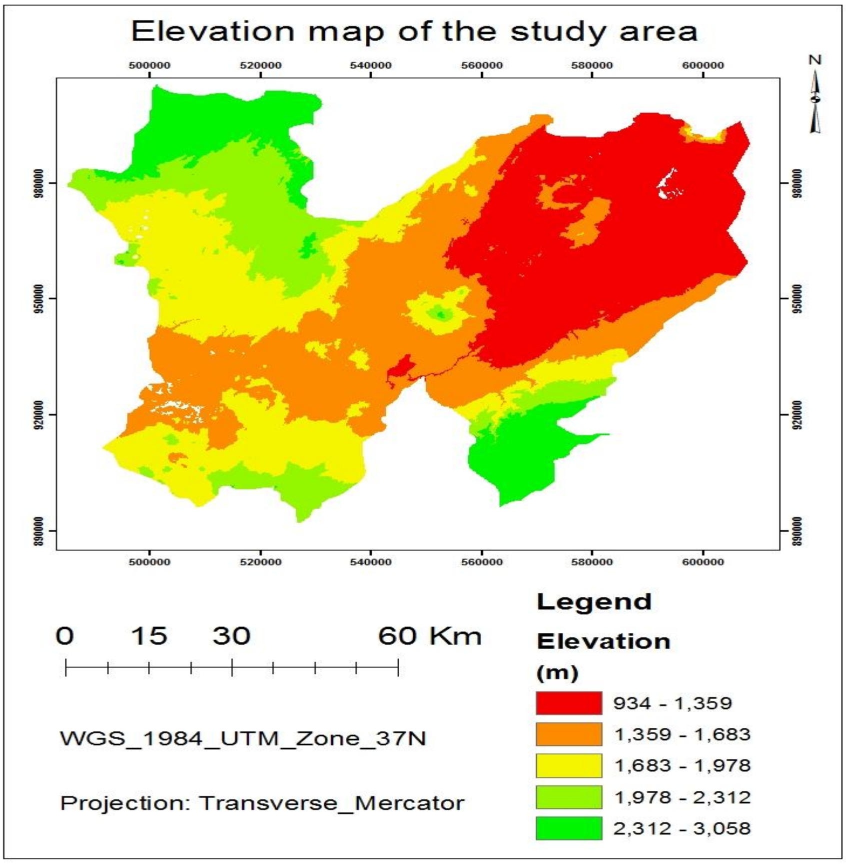


Figure 1.2. Map showing Elevation range of the study area.

1.8.2. Geology

The Adama Watershed lies on Quaternary volcanic rocks and sediments that are formed in association with the formation of the rift. The sediments that dominate the floor of the catchment are alluvial and lacustrine deposits. The volcanic products from the Boku volcano can be grouped as alkaline and per alkaline rhyolite lava domes, flows, and pyroclastic falls, which cover the floor complex ignimbrite deposits. The major products are rhyolite lava flows, obsidian flows, pumice falls, and spatter cones with associated basaltic lava flows. After the emission of these products, the caldera has been collapsed and given rise to post-caldera (intra-caldera) products such as scoria cones with associated basaltic lava flows. The major tectonic lines, which are aligned in NE-SW direction in the Rift floor, form numerous local graven and horst structures (Rift-in-Rift structures). Consequently, the city is bounded by NE-SW aligned tectonic lines and lies within the graven structure. The faults are younger than the outcropping volcanic rocks and are grouped as Wonji Fault Belt. The central volcanoes are rooted along these tectonic lines and are characterized by collapsed calderas, among which the Boku caldera occupies the southern part of Adama in the Main Ethiopian Rift (MER).

1.8.3. Soil types

The analysis to be made on the soil varies in accordance with the purpose of study. Agricultural study focuses on the performance of soil in supporting plant life while for engineering purposes it deals with the performance for supporting civil structures. On the other hand for hydrological purpose the emphasis is given on the water holding, transmitting and retaining capacity. The characteristic of soil is a result of topography, climate and type of parent material, age and environment. The soil development in the Adama catchment is mostly due to the physical disintegration and decomposition of volcanic rocks, deposition of alluvial and ashes. The weathering products are either remain in places and form residual soils or transported and deposited in the lowland central and southern parts driven by overland flow.

Although there is significant difference in the degree of weathering on the slopes of ridges, the soils formed there will be rapidly eroded and result in thin soil cover. In the localities where the topography is plain to gentle, the soil has thick profile. The type of parent material and the length of time to which the parent material is subjected to weathering, control the variation in the thickness of soil.

1.8.4. Climate

The Adama catchment is located within the Awash River Basin. The rainfall recorded at Adama City meteorological station for the past 10 years (2006- 2015) Indicated that the average annual rainfall is about 885.89 mm, the maximum monthly average rainfall is about 225 mm. Most of the rain occurs in summer season (June to September).

The mean annual temperature of Adama for these ten years is 22.05°C. It can be classified as semi-humid to semi-arid climate. In Adama the hottest month with the maximum mean temperature of these ten years is 30.60°C is May while the monthly minimum mean temperature is December with the temperature of 13.02°C. The maximum temperature varies between 25.77°C and 30.60°C while the minimum monthly values vary between 13.02°C and 18.25°C. This indicates that the fluctuation of temperature with monthly minimum & monthly maximum of the Adama is immense within this period.

CHAPTER 2

REVIEW OF LITERATURE

2.1. Historical context of Groundwater& its importance

Groundwater use took off to previously endless levels after 1950 in various parts of the world by the presentation of tube well and mechanical pumping designing in right on time twentieth century and their creating acclaim was seen after 1950. In Spain, groundwater use raised from 2 cubic kilometres for every annum to 6 in excess of 1960–2000 (Cortina et al., 2003). Indian subcontinent groundwater use raised from around 10–20 cubic kilometres for every prior year 1950 to 240–260 by 2000 (Shah, 2007). In the United States groundwater's offer in watering framework water rose from 23% in the year 1950 to 42% in 2000 (Winter, 1998). Chinese history records accidental cases of rancher lifting water from shallow wells by barrels for watering vegetables. Anyway Northern China had very nearly no flooding framework until 1950, and its tube well watering framework vanished simply after 1970.

Regardless of this exponential advancement in groundwater use in horticulture, the world is starting now exploiting simply a small amount of the earth's groundwater. At short of what 1,000 cubic kilometers for consistently overall groundwater use is a quarter of total overall water withdrawals yet just 1.5% of the world's yearly renewable freshwater supplies, 8.2% of yearly renewable groundwater, and 0.0001% of overall groundwater stores (assessed to be 7–23 million cubic kilometers) (Howard 2004). Its contribution to human welfare was enormous. Supplied of groundwater to private water necessities in distinctive human settlements, urban and normal, far and wide has been seen for the most part too. As demonstrated by various investigators, more than a far reaching section of the world's masses depends on upon groundwater for its drinking water supply The imperativeness of groundwater in our day by day life is as such.

- Provides guideline regarding design and construction of ground water structure.
- Water availability in the ground creates a sense of ownership amongst land holders.
- Availability shows there is no shortage of water for supplying the demand of irrigation.
- Generates a vast scope for development of different activities: agriculture, industries etc.

2.2 Global overview of Groundwater

In the last three decades, most water source globally has been from groundwater. In several countries the intense use of groundwater has turned the tide economically and socially. At present an estimated 70% of the world's population depends on groundwater for its basic domestic water services. Groundwater has been at the base accelerated agricultural production in rural economies in India, South Asia, China, North Africa and the Middle East (Ministry of Water resource Ethiopia, 2011). Even in the extensive large surface irrigation systems in South Asia and North Africa 30-50% of the water at farm gate comes from groundwater. Intensive groundwater development in Sub Saharan Africa still has to take off. In comparison Sub Saharan Africa does not have the large high yielding shallow aquifers that are found in Asia, but even where the groundwater potential exists it is not yet used intensively. The same is true for Ethiopia.

2.3 Groundwater in Ethiopia

Groundwater is the most important source of water supply for the great majority of the population and in some arid and semi-arid regions; it is the source of water in Ethiopia. The main sources of groundwater in the country are springs, hand-dug wells and drilled boreholes. For the last few decades, deep boreholes in peripheral regions the rift, and in some urban areas provide water for many small towns and rural villages (Pavelic, et al., 2012). Other main groundwater tapping systems are springs, widespread in the escarpment and the highlands, which supplies the great majority of the rural community, particularly in the rugged mountainous regions. According to Pavelic *et al*. (2012), in the rural settings, each spring is tapped to serve 200-500 people.

Hand-dug wells and springs often do not survive long droughts. The droughts have affected the livelihoods of the very poor members of the rural population and created large water supply problems, which characterize most parts of Ethiopia. This emphasizes to utilized groundwater in drilling shallow and deep wells, even if there are possibilities of developing springs and hand dug wells in order to acquire water security for drought mitigation and preparedness (Tamiru,2006).

Groundwater is used for domestic purpose, irrigation, Livestock watering, industrial purpose and others. While it's enormous importance, the government has given less attention to the groundwater sector. As a result, the hydrogeology of the country is poorly understood as compared to surface water systems. The only source of hydro geological information is the hydro geological map of Ethiopia at 1:2,000,000 scale and very few areas are mapped in detail. The available studies of the groundwater resources are very limited. Therefore, studies of the groundwater resources of the country in terms of quantity, quality, management, aquifer characteristics and water balance are of great importance (Pavelic, et al., 2012). In many parts of the country, groundwater is an important source of potable water. This is especially true for rural areas as well as for towns. However, the occurrence of groundwater is not uniform because it depends on various environmental and geological factors (Tamiru, 2006). The occurrence of groundwater is mainly influenced by the geology, geomorphology and climate of the country. The variability of these factors in Ethiopia strongly influences the quantity and quality of the groundwater in different parts of the country.

2.4. Application of Remote sensing & GIS for Groundwater delineation

Remote sensing operations in groundwater hydrology was a concerned, flying photos, and clear and close infrared satellite pictures had been utilized for groundwater examination likely since 1960s with essentially constrained achievement (Engman et al., 1991). The deplorable deficiency of unearthly determination did not permit much powerful use in groundwater prospecting. Nevertheless with the headway of high determination multi-supernatural satellite sensors, the utilization of satellite picture (numbering microwave picture) for groundwater prospecting through and through extended in late 1980s (Jackson et al., 2002). The utilization of remote sensing data had been wound up with an amazingly monetarily extra approach in groundwater prospecting and preparatory studies, due to high cost of depleting. For the most part, the examination of aeronautical photos or satellite picture is suggested before ground studies and dynamic work, in light of the way that it may dismissal low water-bearing strata and may in like way nonchalance the regions where field examinations (Revzon et al., 1983). It ought to be, then again, noted that the division of remote sensing does not take out the information gathering, which is still essential to assert the rightness of remote sensing information and their outline. Unmistakably, remote sensing collaborators minimize the measure of field information accumulation.

A review of GIS procurements in hydrology and water organization has been shown by a couple of authorities all through ahead of schedule nineties and mid-nineties. These studies indicate that GIS plays a great role in hydrology and water organization are fundamentally in a showing directed association. Regardless of the way that the usage of GIS in groundwater exhibiting studies goes by and by to 1987, its use for surface water showing has been more prevalent than for groundwater exhibiting because the open regulated GIS extensions are essentially of the zone surface; few standardized extents of hydrogeologic properties are available (Watkins et al., 1996). Watkins et al. (1996) present a fabulous layout of GIS procurements in groundwater stream showing and discuss its supportiveness and future headings. On the other hand, Pinder (2002) gives controlled procedure for groundwater stream and transport exhibiting using GIS advancement. The stream status of GIS and RS demands in groundwater hydrology is shown in succeeding fragments.

Many researchers have come out with procedures and techniques of generating the groundwater potential zone maps by identifying remote sensing based on spatial layers of groundwater controlling parameters using GIS.

Minor *et al*., (1994) have attempted to present a unique methodology on groundwater for exploration using the technique of remote sensing and GIS, particularly in developing countries. The scientist has developed interpretation strategies that integrate various data types to characterize groundwater resources for locating a well point. Field observations and several remote sensing platforms are essential to create GIS based hydrogeological model on any study area.

Sarkar *et al*., (2000) A Groundwater potential map was generated for micro watershed by using thematic maps of drainage, lineament, lithology, slope and land use. They employed a multi criterion approach that allowed linear combination of weights of each thematic map with the individual capability value which were converted to capabilities values. These capabilities values were multiplied with respective probability weight of each potential map. The groundwater occurrence was then classified into six categories of potentiality, namely excellent, very good, good, moderate, poor and very poor.

Raghuwanshi *et al.,* (2008) various thematic maps was prepared such as geological, geomorphological and lineament maps. The integrated hydro geomorphology map was prepared to assess the groundwater resources using remote sensing technique in and around the choral river basin, Indore and Khargone districts, Madhya Pradesh and revealed that the groundwater potential was moderate to poor in buried pediplains, plateaus, denudational and residual hills, lineaments/faults and narrow gorges . The groundwater prospects are good in alluvial plains, valley fills and meandering channels.

Pester et al., (2013) concentrated on the depiction for groundwater change with the assistance of a remote sensing . Existing toposheets and field perception information, have been used to concentrate data on the hydrogeomorphic peculiarities which comprises of covered pediment shallow valley fills, structural knolls, covered pediment moderate, slant guide and lineament thickness form . The focus of this study was to distribute the groundwater potential zones in Chatna square, Bankura District, West Bengal. Three characters (hydrogeomorphology, slant, and lineaments) that impact groundwater occasions were concentrated on and consolidated. All the data layers have been joined utilizing GIS examination and the groundwater potential zones have been depicted. The weighted file overlay strategy has been emulated to outline groundwater potential zones. From the results it was inferred that there is great pledge between the normal groundwater potential guide and the present groundwater borehole databases. The territory is considered by hard shake landscape still because of the vicinity of plantation surface along valley fills; it turned into the potential zone. The region has been sorted into four different zones: amazing, great, reasonable and poor.

Tewodros (2005) used remote sensing and GIS for groundwater potential zone identification in hard rock terrain of Bale Mountains. In this work thematic layers like drainage, lineament, elevation, slope, land cover, soil, rainfall, and biological factor (burrowing rodents) generated from satellite image and existing maps were combined in GIS environment for mapping groundwater potential zones within the study area. Similarly Sisay Libasse (2006) applied similar approach to generate thematic maps such as geology, geomorphology, lineament, soil, rainfall, slope and drainage for producing groundwater potential map of northern Ada'a plain. Remote sensing data with its advantages of spatial, spectral and temporal availability covering large area is a very effective tool in assessing, monitoring and conserving groundwater resources within short time. Remote sensing images can be used to produce different thematic maps that are important for the evaluation of groundwater resource. In this research parameters generated from remote sensing images were combined with other groundwater potential indicator parameters to produce the groundwater prospect map of the study area.

CHAPTER 3

DATA, SOFTWARE AND METHODOLOGY USED.

3.1. Data Used

In order to achieve the above mentioned objectives, the generation of new data and collection of secondary data have been carried out for the study area. The occurrence and movement of ground water controlling factors, such as geology, lineaments, rainfall, geomorphology, slope, drainage, and land use/land cover, and soil are collected from different organizations and individual entities are converted to characteristic spatial representation format in order to make them suitable for analysis.

The data used for this research are the following.

No.	Data types	Content	Data Source
1.	Land sat Image_2016 (30 x 30m resolution)	Different Landuse/Cover of the study area	USGS.gov
2.	Digital Elevation Model, (30 x 30m resolution)	Slope of the study area	USGS, 2016
3.	Geology (1:250,000)	Geologic unit of the study area	Ethiopian geology survey
4.	Geomorphology (1:1000,000)	Geomorphic units of the study area	Ministry of Agriculture
5.	Soil types (1:1000,000)	Soil type covering the study area	Ministry of Agriculture
6.	Drainage network	Contain streams	Extracted from DEM
7.	Meteorological data	Rainfall data	National Metrological Agency
8.	Existing borehole data	Location	East shewa zone water bureau

Table 3.1. Data used for the study.

3.2. Software used

Software used in this study is selected based on the capability to work on the existing problems in achieving the predetermined objectives.

3.2.1. ARCGIS 10.1

ArcGIS have been used to create the geodatabase, data input, data editing, data management and storage of data from different sources, performing spatial multi criteria, generating criteria maps and assigning weightage for each criterion, overlaying, analysis and visualization of output data, and etc. The groundwater availability factor map development was carried out using Arc Map10.1 software package. The factors that are input for multi criteria analysis should be pre processed in accordance to the criteria set to develop groundwater occurrence map.

3.2.2. ERDAS IMAGINE 2014

Erdas Imagine is a comprehensive geographic analysis and image processing system. The software has been used to perform pre-processing of satellite image, layer stake and preparation of Land use/Land cover data. The other software such as IDRISI 32, Microsoft office and google earth and others were used to achieve the objective of the study, which is identification of ground water potential zone of the study area.

3.3. Dataset Identification

The generated, collected and digitized data was organized into logical groups of entities concerning soil, geology, lineament density, drainage density, rainfall and physiographic factors (geomorphology, slope, Land use/Land cover). Then, individual entities assigned and converted to characteristic spatial representation format in order to make them suitable for analysis. After making decision on the research geodatabase, the data sets prepared so that it help to develop the following maps in the target area.

- Drainage density map and Slope map prepared using Digital Elevation Model (DEM)

- Land use/land cover map prepared from Landsat using supervised classification.
- Groundwater potential zone map prepared using overlay analysis using IDRIS and ArcGIS software's.

3.4. Multi Criteria Analysis.

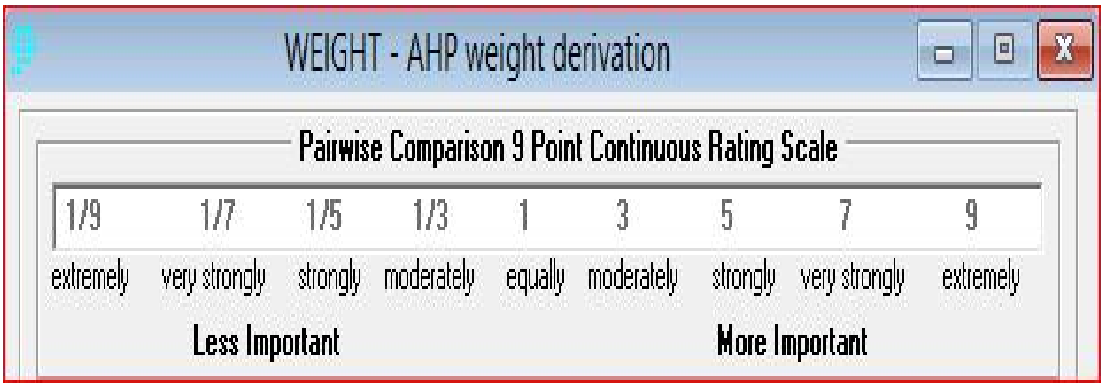
In this stage, digital image processing of the satellite data carried out for extraction of pertinent information. The groundwater exploration in the study area involved thematic map generation and their integration through GIS. Prior to integration of different information, individual class weights and map scores was assessed based on Satty's Analytic Hierarchy process where a pairwise comparison matrix prepared for each map using a nine point important scale.

The Analytic Hierarchy Process(AHP), introduced by Thomas Saaty (1980), is an effective tool for dealing with multi criteria decision making, and may aid the decision maker to set priorities and make the best decision. By reducing complex decisions to a series of pair wise comparisons, and then synthesizing the results, the AHP helps to capture both subjective and objective aspects of a decision. In addition, the AHP incorporates a useful technique for checking the consistency of the decision maker's evaluations, thus reducing the bias in the decision making process (Coyle:, 2004).

The AHP generates a weight for each evaluation criteria/factors according to the decision maker's pairwise comparisons of the criteria. The higher weight, the more important the corresponding factors. The AHP is a very flexible and powerful tool, the decisions may be inconsistent, and how to measure inconsistency and improve the decisions, when possible to obtain better consistency is a concern of the AHP.

To make comparisons, we need a scale of numbers that indicates how many times more important or dominant one element is over another element with respect to the criterion or property with respect to which they are compared. According to (Saaty, 2008) the comparison scale is consisting of values ranging from 1 to 9 which describe the intensity of importance(preference/dominance). A value of 1 expresses “equal importance” and a value of 9 is given for those factors having an “extreme importance” over another factor.

Figure 3.1. Ratings on Satty’s 9 – point continues scale.



To achieve the final target of the study, delineation of groundwater potential zones, different thematic layers; lithology, lineament density, drainage density, geomorphology, slope, soil, and land use/land cover and rainfall are integrated.

3.5. Factor development

The different polygons in the thematic layers labelled separately and then they were converted to raster and registered. In the final thematic layer initially each one of the raster qualitatively the final potential groundwater map visualized into one of the categories like (i) very high (ii) high (iii) moderate (iv) low (v) very low in terms of their importance with respect to groundwater occurrence and suitable weights was assigned.

3.6. Methodology used

The methodology employed is summarized in the flow chart below. All data are integrated in Geographic Information System (GIS) and analyzed to assess the groundwater controlling features. Finally groundwater potential map can be prepared based on GIS analysis.

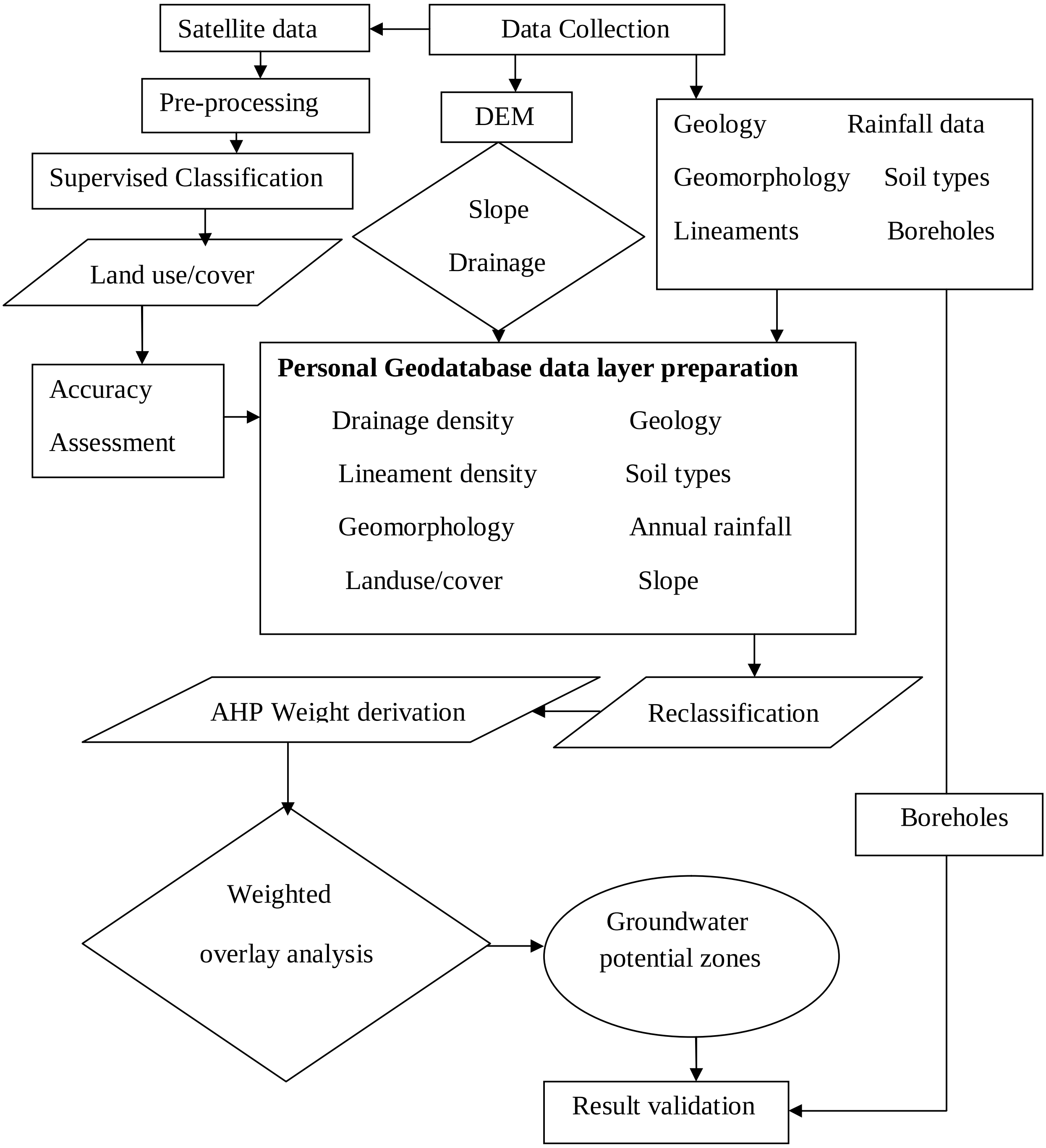


Figure 3.2. Flow chart of the methodology.

3.7. Data Analysis

Exploration of groundwater initially involves the application of remote sensing and GIS before conducting any fieldwork, geophysical prospecting, and drilling test. This will reduce effort, time and money used in exploration and also increase the accuracy of finding groundwater. Keeping this in view, the present work has been attempted on hard rock terrains of Adama and the surrounding areas by integrating newly generated and existing thematic layers that influence the occurrence and distribution of groundwater.

Eight thematic layers were considered for the determination of groundwater potential zones in Adama watershed. These are: drainage density, lineament, slope steepness, land use/cover, soil, rainfall, geomorphology and geology. Different classes were identified for each criterion and arranged in their order of weight. Appropriate weightage has been defined on the basis of their contribution to the groundwater potentiality or availability. In order to demarcate the final groundwater potential zone a methodology has been followed. (see Figure: 3.2).

3.8. Groundwater occurrence controlling parameters in the study area.

As mentioned in the methodology the selected eight parameters have been created using GIS techniques and it has been ranked based on the Satty's analytical hierarchical process. The main factors responsible for groundwater resource development are: rainfall, geology, geomorphology, land use/land cover, drainage density, slope, soil and lineaments. The detailed discussion of each parameters and Thematic maps for each parameter prepared as follows:

3.8.1. Drainage density

Drainage density is defined as the closeness of spacing of stream channels. The drainage density is an inverse function of permeability (Hutti, 2011). Drainage density indicates rock permeability, infiltration rate and recharges capacity (Tesfaye, 2010). They are reflection of the rate that precipitation infiltrated compared to surface runoff. Where rocks are highly permeable, infiltration to groundwater is high, and less water is transported in rivers as surface water, but where rocks have low permeability there is little infiltration and more surface water runoff. Low drainage density is therefore related to higher recharge and higher groundwater potential (Thangarajan, 2007).

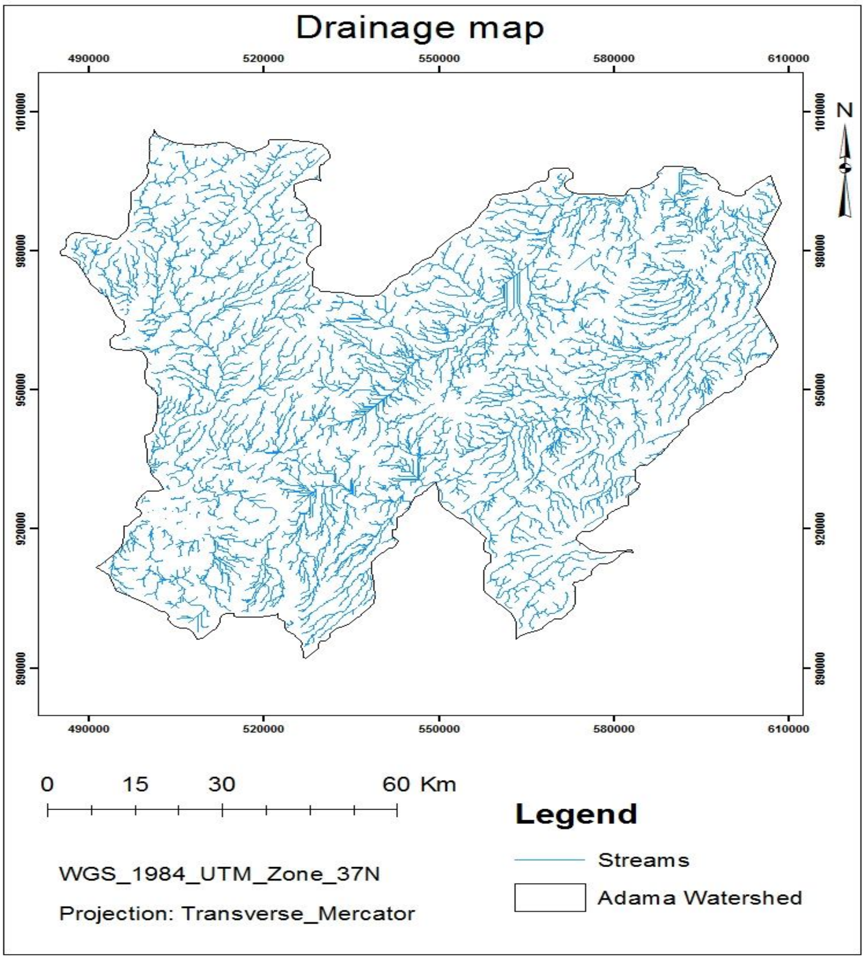


Figure 3.3. Drainage network map of the study area.

Drainage of the study area is one of the practical approaches to know the geological and structural control of land form evolution. Comparison of the drainage system and structure of the area has shown that the drainage system of the area is structurally controlled following lineaments directions (figure 3.4).

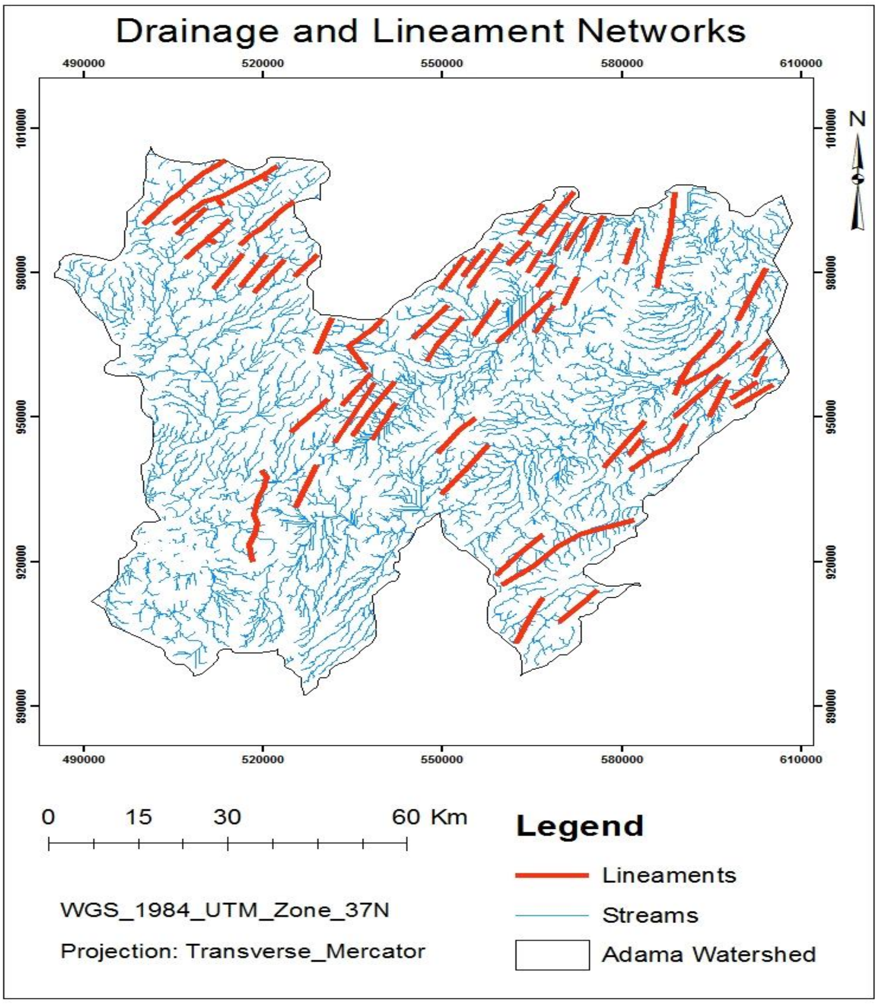


Figure 3.4. Comparison of Lineament and Drainage orientation.

Drainage density delineated using ArcGIS processing tools of ASTER DEM data of the study area after consecutive processes such as Importing of DEM data, filled sinks for undefined values ,created Flow Direction, Created Flow Accumulation, created Stream network, generated Stream Order and finally converted Stream Order to drainage density. Finally, it was calculated using kernel density analysis tool in ArcGIS software and the area has been reclassified into five classes: 0 - 0.48, 0.48-0.73, 0.73 - 0.97,0.97 - 1.27 and 1.27 - 2.01 as shown (figure: 3.5).

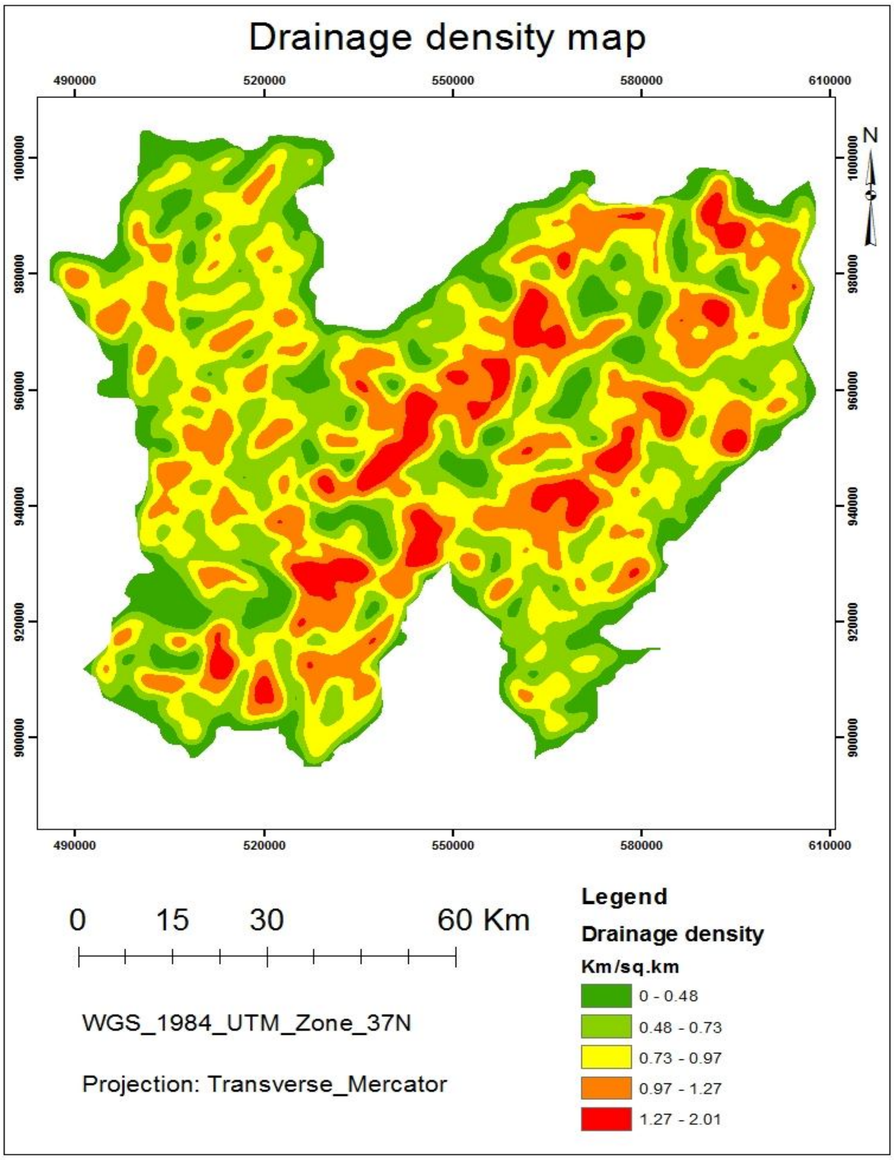


Figure 3.5. Drainage density map of the study area.

A low drainage density region causes higher infiltration rate and it yields in better groundwater potential zones as correlated to a high drainage density region (Murasingh, 2014). The higher weight was given to the low drainage density regions and the lower weight to the high drainage density areas, shown in (Table:3.1).

Criteria	Classes	Ranking with word	Weight
Drainage density	0 - 0.48	Very high	5
	0.48 - 0.73	High	4
	0.73 - 0.97	Moderate	3
	0.97 -1.27	Low	2
	1.27 - 2.01	Very low	1

Table 3.2. Weightage of drainage density for ground water availability.

3.8.2. Geology

The comparison of geologic unit was done in terms of their importance with respect to groundwater occurrences by considering their characteristic such as rock type and thickness, fracture density, compactness, the type and degree of cementation and the weightage were assigned based on their influence in groundwater(Table: 3.2). The most part of the study area comprises Rhyolitic volcanic centers and Tranchites which have massive nature and very low permeability(Adane,1999).

The lacustrine sedimentations are the results of deposition (Mohr, 1962) and they are interbedded with Pliocene Pleistocene ignimbrite in lakes region and on the rift shoulders and the surrounding areas in particular (Mohr, 1962). These fine grained deposits are generally brown yellowish, thinly stratified and often contain abundant volcanic matrix. Their thickness ranges from less than 5 m up to 8 m. In these successions, volcanic layers are frequent and become predominant and coarse grained. Due to their fine grained composition and compactness, these deposits have low porosity and permeability (Adane, 1999).

The Nazret unit is widely present in the parts of the study area. The units are affected by the trending lineaments, it consists sequence of welded ignimbrites, with flow units that have thicknesses varying from 5 to 15 m. This unit is a basal unit grouped under the intra rift complex and may constitute the upper part of Nazret Group (Kazmin and Berhe.,1978) with respect to age constraints. This unit includes various welded and often jointed columnar ignimbrites. Welded ignimbrite with well developed vertical joint and fracture provide high to moderate permeability (Adane, 1999).

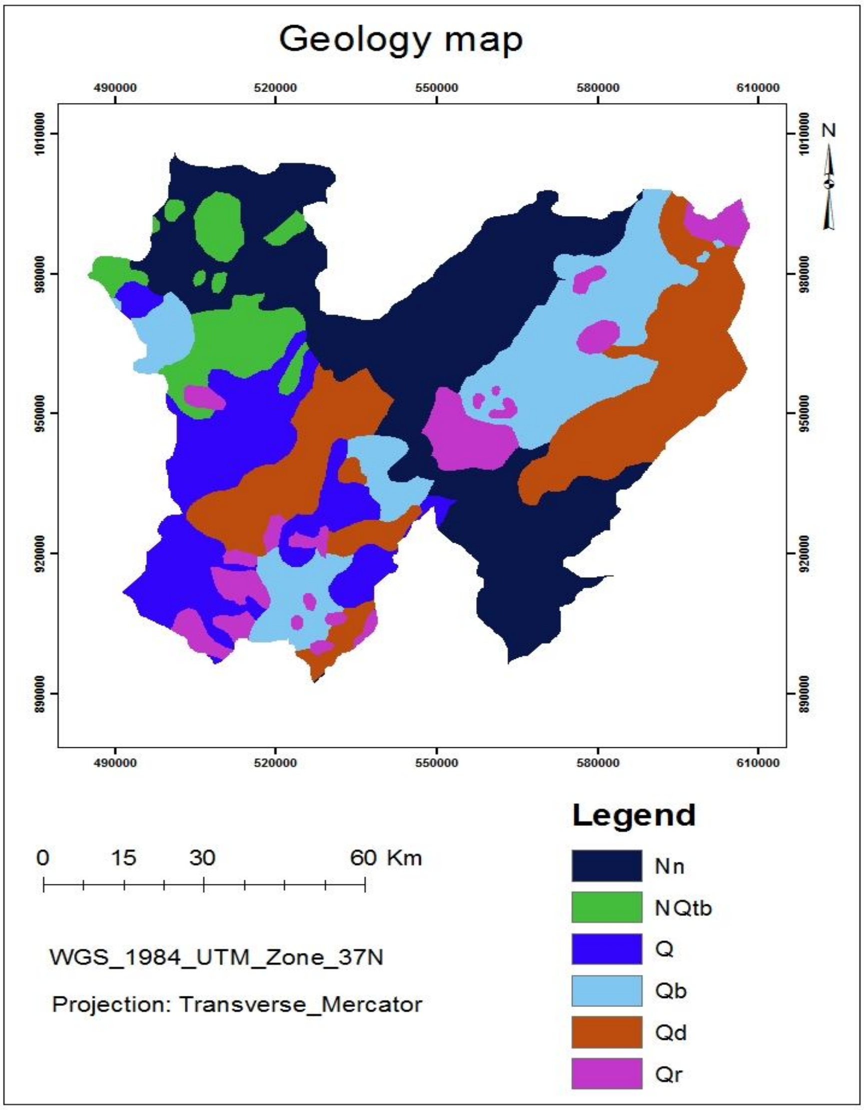


Figure 3.6. Geology map of the study area.

Criteria	Classes	Ranking with word	Weight
Geology	Rhyolitic volcanic centers (Qr)	Very low	1
	Tranchites(Nqtb)	Low	2
	Alluvia and lacustrine deposits(Q)	Moderate	3
	Alkaline basalt(Qb)	High	4
	Ignimbrites(Qd)	High	4
	Naziret series(Nn)	Very high	5

Table 3.3. Weightage of Geology of the study area.

3.8.3. Geomorphology

Geomorphology is a study of earth structures and also depicts the various landforms relating to the Ground water potential zones and also structural features. In groundwater exploration geomorphology plays an important role in identification of favorable zone for groundwater. More promising groundwater is in flood plains, alluvial fans and valley fills that are associated with thick alluvial and weathered materials to give high porosity and permeability. Pediments generally are not favorable for groundwater potential zones(Verstappen, 1983). Lower Plateau and plains were considered best targets of groundwater occurrence through facilitating recharge and as a circulation of water by way of interflow at shallow depth, above the groundwater level(Verstappen, 1983). The study area comprises Undulating high plateau, Low plateau, Lava platforms and plains, Alluvial plains- Awash and Lakes. Based on the importance for Geomorphological features the weightage was assigned (Table:3.3).

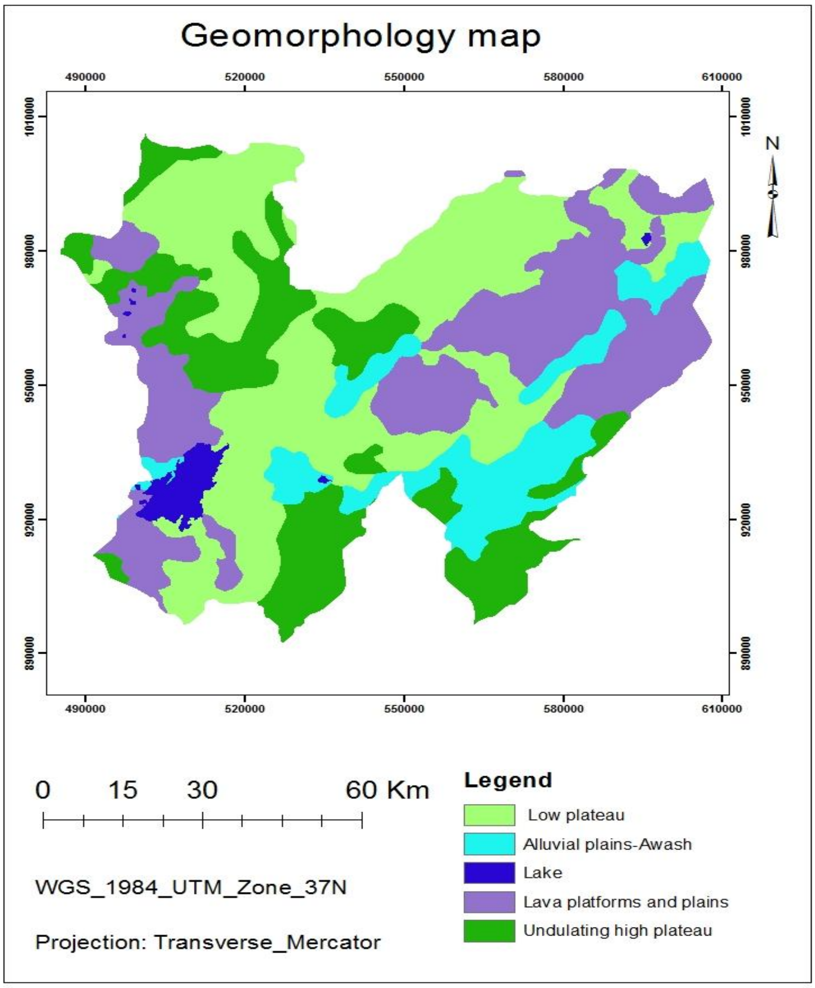


Figure 3.7. Geomorphology map of the study area.

Criteria	Classes	Ranking with word	Weight
Geomorphology	Undulating high plateau	Very low	1
	Low plateau	Low	2
	Lava platforms and plains	Moderate	3
	Alluvial plains- Awash	High	4
	Lakes	Very high	5

Table 3.4. Weightage of geomorphology of the study area.

3.8.4. Land use and Land cover (LU/LC)

Satellite image of Land sat 8 sensor has been used. From this image, 6 bands were used having spatial resolution of 30 meters. These images were imported to ERDAS IMAGINE 2014 software and the study area was subset from the full scene. The main task in this stage was to carry out analysis and interpretation of satellite data, in order to produce thematic map of land use/cover map. This was followed by processing the digital images using the various processing techniques: pre-processing, classification and accuracy assessment.

3.8.4.1. Pre-processing

This operation is done to correct distorted or degraded image data to create a more faithful representation of the original scene. It involves initial processing of the image data to correct for geometric distortion, to calibrate the data radiometrically and to eliminate noise present in the data (Lillesand, 1994). Remote sensing imageries are inherently subjected to geometric distortions. These distortions may be due to the perspective of the sensor optics, the motion of the scanning system, the motion of the platform (the platform altitude and velocity), the terrain relief, or the curvature and rotation of the earth (Lillesand, 1994). Geometric corrections are done in order to compensate for these distortions so that the geometric representation of the imagery will be as close as possible to the real world. Image enhancement is applied to image data in order to more effectively display or record the data for subsequent visual interpretation. These techniques are most useful because many satellite images, when examined on a colour display give inadequate information for image interpretation.

3.8.4.2. Image Classification

Image classification involves the analysis of multispectral image data and the application of statistically based decision rules for determining the land cover identification of each pixel in an image. Image classification depends on the brightness value of each pixel and it categorizes pixels of nearly the same values. According to Lillesand (1994), the overall objective of image classification procedures is to automatically categorize all pixels in an image into land use land cover classes. Notice that data are transformed into information. Multispectral classification is one of the most often used methods of information extraction. In classifying the images, supervised image classifications technique were applied. Supervised classification requires a prior knowledge of the scene area in order to provide the software with unique training classes. It is up to the user to define the original pixels that contain similar spectral classes representing certain land cover classes.

3.8.4.3. Accuracy assessment

Accuracy assessment is a general term for comparing the classification to geographical data that are assumed to be true, in order to determine the accuracy of the classification process. To assess the classification accuracy, confusion matrix was employed. The confusion/error matrix consists of rows and columns. The rows represent the classification values and the column represents facts from the field. The diagonal line of the error matrix represents the number of pixels that were correctly classified. The overall accuracy index is produced by dividing all the pixels correctly classified by the total number of pixels in the matrix. The producer accuracy index is produced by dividing the number of correctly classified pixels that belong to a class by the sum of the values of the column of the same class. The user accuracy index is produced by dividing the total number of correctly classified pixels that belong to a class by the sum of the values of the rows of the same class. By having this, in this study the overall classification accuracy is (7 + 6 + 10+ 2 + 9) / 37 which is equal to 0.918 or 91.8 percent (Table 3.5)

Class Name	Built-up	Water body	Bare land	Vegetation	Agricultural land	Row total	Producers accuracy	User accuracy
Built-up	7	0	1	0	0	8	100.00%	87.50%
Water body	0	6	0	1	0	7	100.00%	85.71%
Bare land	0	0	10	0	0	10	90.91%	100.00%
Vegetation	0	0	0	2	0	2	100.00%	100.00%
Agricultural land	0	0	0	1	9	10	100.00%	90.00%
Total	7	6	11	4	9	37		

Table 3.5. Error matrix showing the classification accuracy of the true land cover.

The overall classification accuracy of 91.8% and overall Kappa statistics of 0.918 was achieved, which is feasible for further application. The kappa coefficient lies typically on a scale between 0 and 1, where the latter indicates complete agreement, and is often multiplied by 100 to give percentage measure of classification accuracy. Kappa value is characterized in to three grouping: value greater than 0.8 represents strong agreement, 0.4 - 0.8 represents moderate agreement and that of less than 0.4 is considered as poor agreement (Congalton, 1991). The reasons for the errors may include the similarity of reflectance of settlement, grazing land and cultivated areas. In addition, the land use land cover dynamic nature of the area may also introduce the classification error.

Due to anthropogenic activities the land surface has been modified enormously in the recent years. The surface covered by vegetation like forests and agriculture traps and holds the water in root of plants whereas the built-up and rocky land use affects the recharge of groundwater by increasing runoff during the rain, so it is necessary to study what kind of features are covered the study area's land surface. The Landsat 8 satellite image has been used for the study to find out the land use and land cover of study area. The supervised classification method has been used and the study area is covered by five different classes such as Agricultural land, Vegetation, Built up, Water body and Bare land. The weight assigned based on water logging and runoff properties of LU/LC.

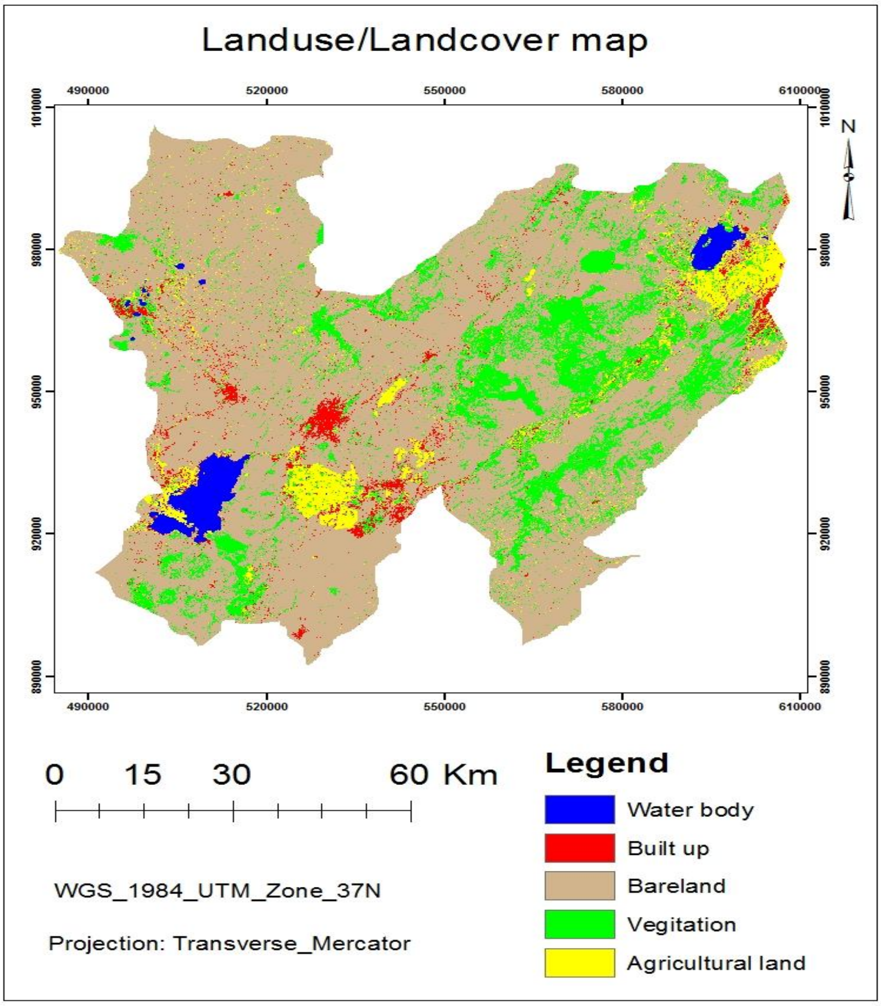


Figure 3.8. Landuse/Landcover map of the study area.

Classification of land use/cover for analysis was done based on their character to infiltrate water in to the ground and water hold capacity on the ground. The water bodies were given the highest weight over other land use features since its incessant recharge to ground, ensued by Evergreen forest only, which pull maximum amounts of water from the deep root zone for sustaining, resulting the present of water below the ground surface (Tesfaye, 2010) and

(Murasingh, 2014). The bare land was given less weighted after agricultural land since is a crop which required huge amount of water and thus it act as a good groundwater recharge. whereas bare land is lack of vegetation cover which was sandy fields, bare rocks, saline and alkaline lands etc. For this reason it was given less weight. Generally settlements are found to be the least suitable for infiltration (Table 3.4).

Criteria	Classes	Ranking with word	Weight
Land use/ Land cover	Water body	Very high	5
	Vegetation	High	4
	Agricultural land	Moderate	3
	Bare land	Low	2
	Built up	Very low	1

Table 3.6. Weightage of Landuse/cover of the study area.

3.8.5. Lineaments

Lineaments are linear geomorphic features that are the surface expression of zones of weakness or structural displacement in the crust of the earth. Lineaments are structural lines such as faults, which often represent zones of fracturing and increased secondary porosity and permeability, and therefore of enhanced groundwater occurrence and movement (Tesfaye, 2010). The characteristic of lines features may represent deep seated faults, fractures and joints sets, drainage lines and boundary lines of different rock formations (Shivaji, 2014). The hard rock terrain the storage and movement of groundwater is controlled by the secondary porosity i.e. presence of lineaments and fractures. The lineament data was provided important information on subsurface fractures that may control the movement and storage of the groundwater in the study area.

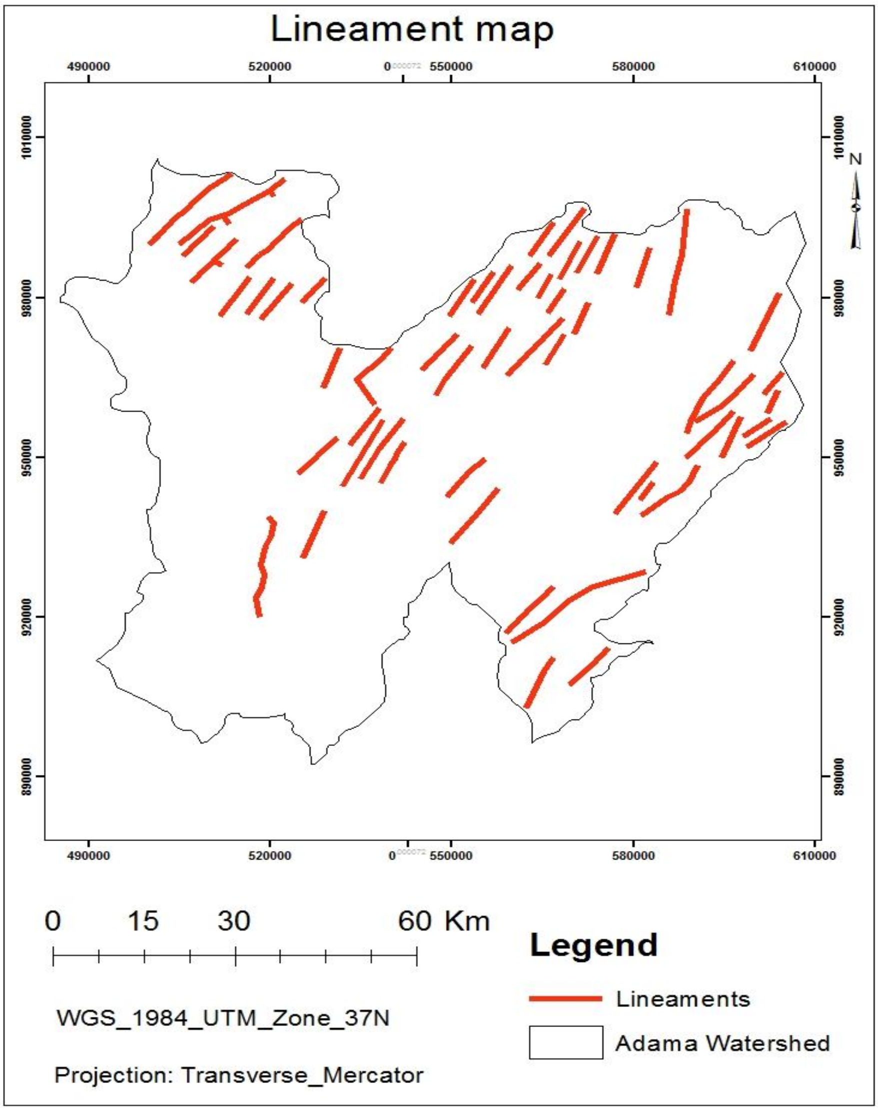


Figure 3.9. Lineament map of the study area.

The study area lineament features was generated from lithology map based on digitization method using GIS and have prepared the lineament map. Then, lineament density of the study area was calculated using kernel density analysis tool in GIS software and the area has been reclassified into five classes (0 - 0.04, 0.04 - 0.12, 0.12 - 0.21, 0.21 - 0.31, 0.31 - 0.53) were produced (Figure 3.10). Reclassified map of lineament was assigned weight based on the fact that areas closer to lineaments are the highest zone of increased porosity and permeability which intern have greater chance of accumulating groundwater.

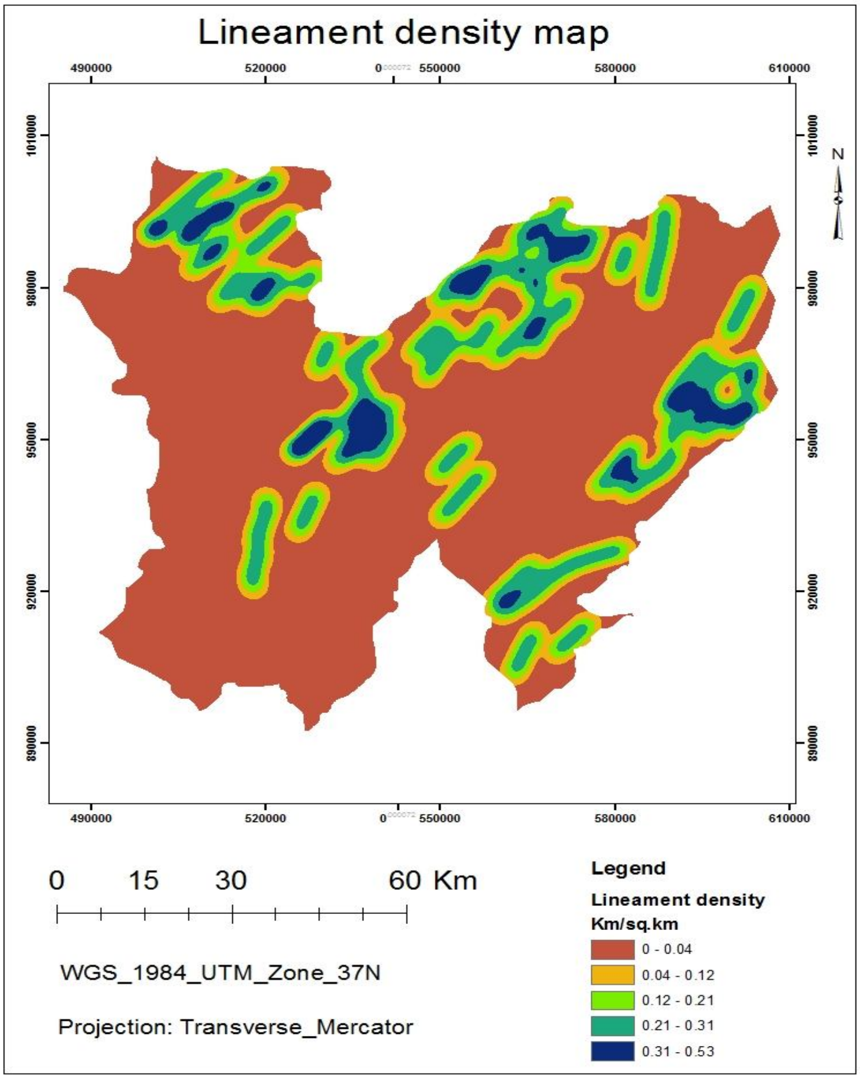


Figure 3.10. Reclassified Lineament density map of the study area.

Criteria	Classes	Ranking with word	Weight
Lineament density	0 - 0.04	Very low	1
	0.04 - 0.12	Low	2
	0.12 - 0.21	Moderate	3
	0.21 - 0.31	High	4
	0.31 - 0.53	Very high	5

Table 3.7. Weightage of Lineament density of the study area.

3.8.6. Rainfall

Rainfall is one of the major source for groundwater availability through the water cycle. The amount of rainfall is not the same all the places it varies based on the environmental conditions of the place. The high rainfall amounts imply the possibility of high groundwater recharge and vice versa. The area characterized by high rainfall amount shows high groundwater potential zones.

The relationship of rainfall to groundwater occurrence is governed by the rainfall distribution, topography, land use /land cover, soil and geology etc. all these factors affect the quantity of water that gets underground (Tesfaye, 2010). All the water that precipitated may be absorbed in a flat sand dune area. With respect to different surface condition which affect the amount of water that goes to the ground, annual rainfall should be taken in order to average the amount of water that infiltrates in to the ground regardless of surface condition. In general the high rainfall amounts imply the possibility of high groundwater potential zone (Sisay, 2007).

For analysis of rainfall effect in groundwater occurrences, the data were collected from National Meteorological Agency for last 10 year’s record data (2006-2015) at ten stations. Due to uneven distribution of the stations in the study area data were interpolated using IDW nearest neighbour interpolation techniques. After interpolation the study area raster map was clipped and reclassified in to five classes and final rainfall map was produced (Figure 3.11).

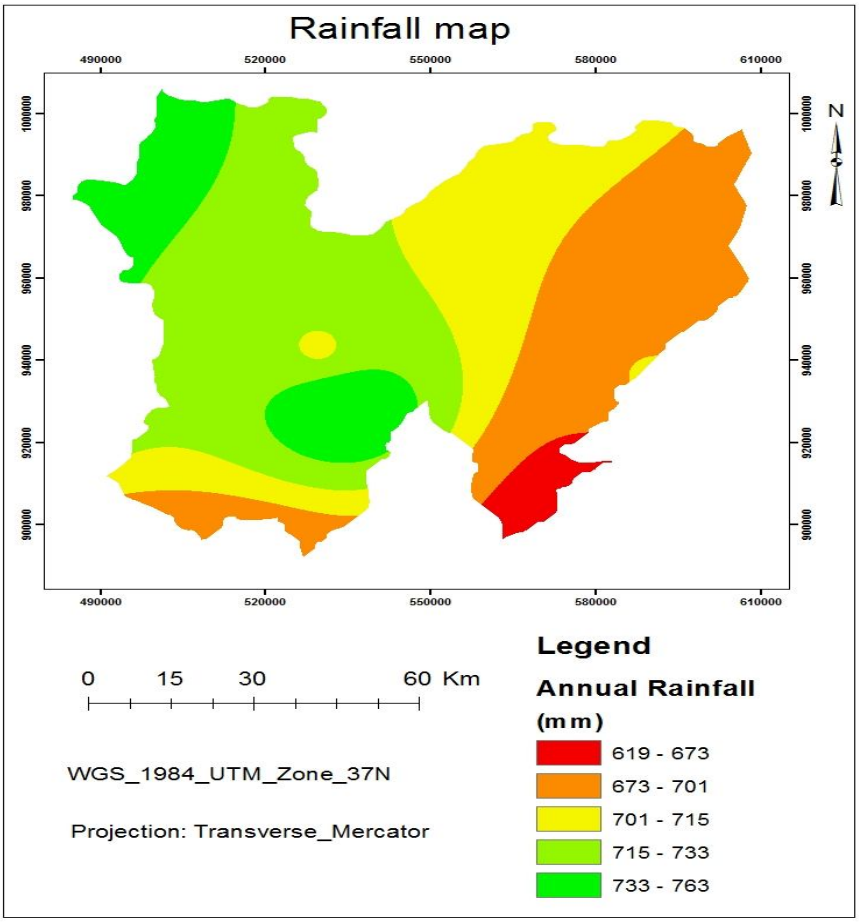


Figure 3.11. Reclassified Rainfall map of the study area.

Criteria	Classes	Ranking with word	Weight
Annual Rainfall (mm)	619 - 673	Very low	1
	673 - 701	Low	2
	701 - 715	Moderate	3
	715 - 733	High	4
	733 - 763	Very high	5

Table 3.8. Weightage of Rainfall of the study area.

3.8.7. Slope

Slope is an important factor for the identification of groundwater potential zones. Slope of any terrain is one of the factors allowing the infiltration of groundwater into subsurface or in other words groundwater recharge. In the gentle slope area, the surface runoff is slow allowing more time for rainwater to percolate, whereas, steep slope area facilitates high runoff allowing less residence time for rainwater to percolate and hence comparatively less infiltration (Sisay, 2007). The slope of the study area has been calculated in degrees based on the DEM model which was based on the ASTER data. The slope has been classified into five classes (Figure:3.12) and each class weightage has been assigned (Table:3.7).

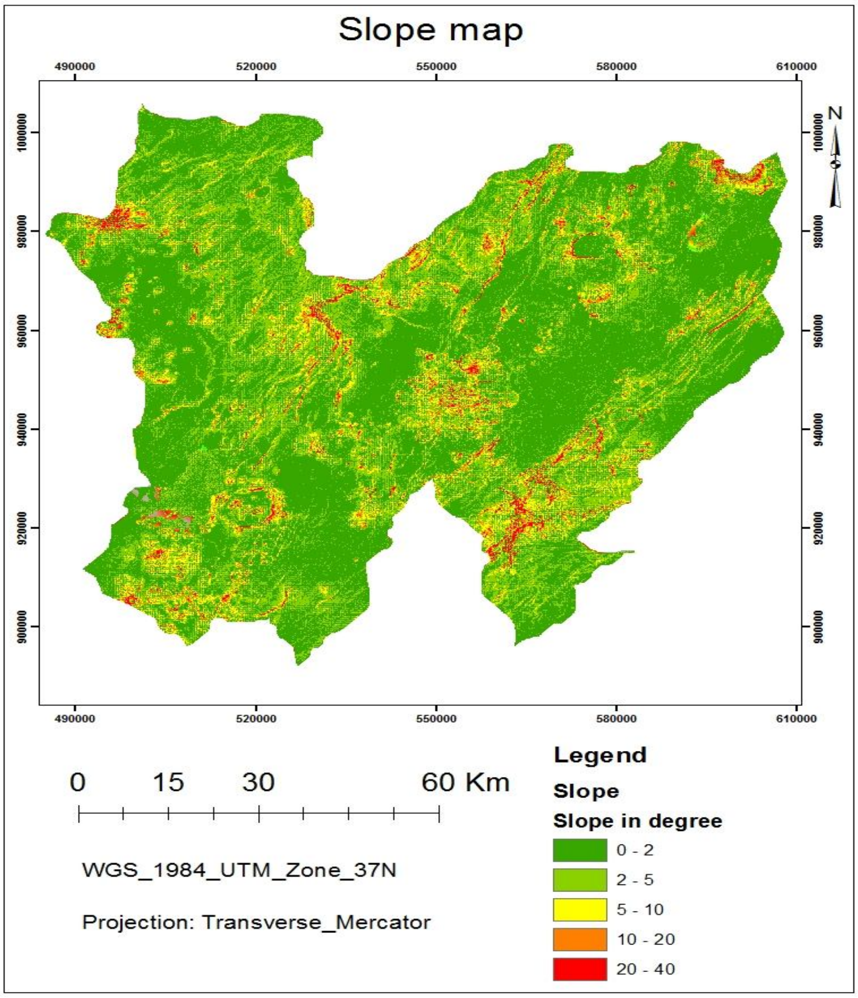


Figure 3.12. Reclassified slope map of the study area.

Criteria	Classes	Ranking with word	Weight
Slope	0 - 2	Very high	5
	2 - 5	High	4
	5 - 10	Moderate	3
	10 - 20	Low	2
	20 - 40	Very low	1

Table 3.9. Weightage of slope of the study area.

3.8.8. Soil type

Soil is the one of the primary factor which determines the amount of groundwater, the study of soil helps to find out the types and as its properties. The movement of ground water and infiltration of surface water into ground is based on the porosity and permeability of soil. Therefore the study of soil is important to determine the amount of ground water of any place.

Soil properties influence the relationship between runoff and infiltration rates which in turn control the degree of permeability, the principal factor in hydrogeology that determines the groundwater potential(Tesfaye, 2010). The soil forming factors, climate, parent rock, vegetation and other factors are responsible for the type of soil formed and plays an important role on groundwater recharge through infiltration and loss through run off (Tewodros, 2005). The soil classes used for the groundwater investigation are based on the hydrologic property of soil classification of FAO, (2001). Based on (FAO, 2001) soil classification, the study areas are entirely covered by the following types of major soil classes such as, Andosols, Cambisols, Luvisols, Phaeozems and Vertisols. The movement and infiltration of water in these types of soil is not the same so based on its property the weightages have been assigned (Table:3.8).

Andosols

Andosols accommodate the soils that develop in volcanic eject or glasses under almost any climate (except under hyperarid climate conditions). However, Andosols may also develop in other silicate-rich materials under acid weathering in humid and perhumid climates. They are typically black soils of volcanic landscapes parent material, volcanic glasses and eject (mainly ash, but also tuff, pumice, cinders and others) or other silicate-rich material. Andosols are easy to cultivate and have good water storage properties. Strongly hydrated Andosols are difficult to till because of their low bearing capacity and their stickiness.

Phaeozems

Phaeozems accommodate soils of relatively wet grassland and forest regions in moderately continental climates. They have dark, humus rich surface horizon and are porous, fertile soils that make excellent farmland. Phaeozems are in use for the production of soybean and wheat and other small grains. Phaeozems in the temperate belt are planted with wheat, barley and vegetables alongside other crops. Vast areas of Phaeozems are used for cattle rearing and fattening on improved pastures. Wind and water erosion are serious hazards to these soil types.

Luvisols

Luvisols have distinct clay accumulation horizon. Most Luvisols are well drained but Luvisols in depression areas with shallow groundwater may develop gleyic soil properties in and below the argic horizon. Stagnic properties are found where a dense illuviation horizon obstructs downward percolation and the surface soil becomes saturated with water for extended periods of time. Soils in which clay is washed down from the surface soil to an accumulation horizon at some depth.

Cambisols

Most Cambisols are medium textured and have a good structural stability, a high porosity, and good water holding capacity and good internal drainage. Most Cambisols also contain at least some weatherable minerals in the silt and sand fractions. Based on these characteristics, Cambisols have good infiltration capacity to recharge groundwater.

Vertisols

Commonly known as black cotton soil containing smectite clay that characterize sticky nature and have high water holding capacity and low infiltration capacity. Vertisols become very hard in the dry season and are sticky in the wet season. Tillage is difficult, except for a short period at the transition between the wet and dry seasons.

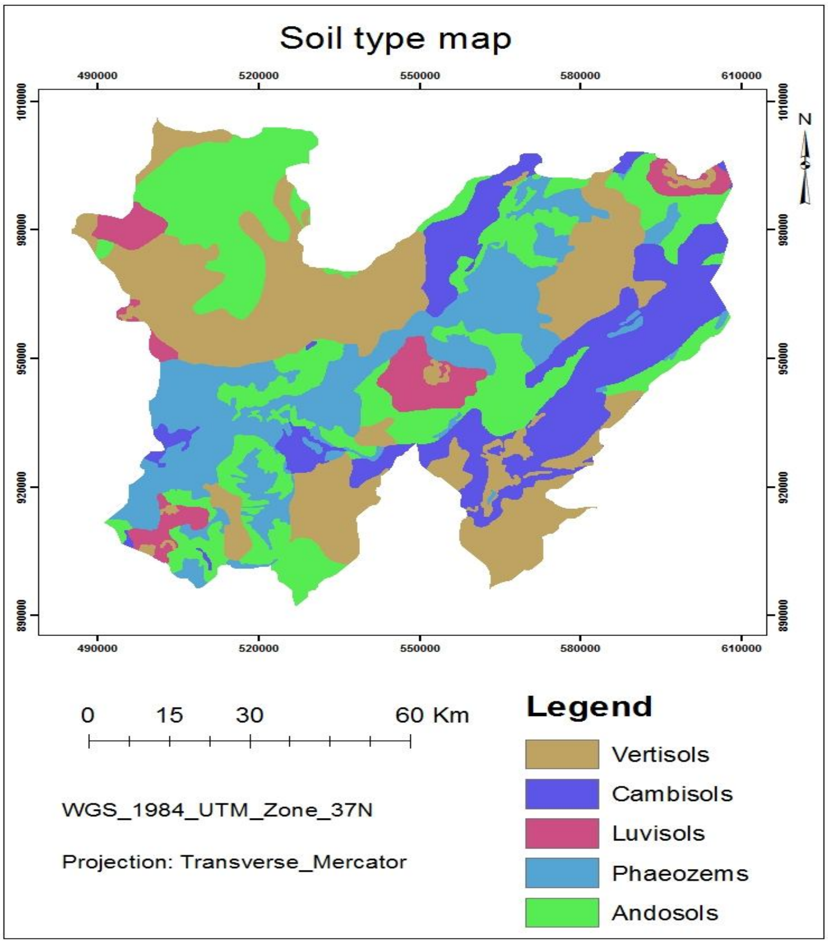


Figure 3.13. Soil map of the study area.

Criteria	Classes	Ranking with word	Weight
Soil type	Andosols	Very high	5
	Phaeozems	High	4
	Cambisols	Moderate	3
	Luvisols	Low	2
	Vertisols	Very low	1

Table 3.10. Weightage of soil type of the study area.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1. Data Integration Analysis in GIS Environment

To evaluate the different ground water potential zones, essential parameters were considered, and the maps were prepared for each layer. These maps were converted to raster data sets having the same pixel size and different weightage were assigned as per their groundwater potential controlling capacity within the study area and reclassification of each map was done based on the weight values produced. Accordingly, the value 5 was given for very highly controlling units, 4 for high controlling units, 3 for moderately controlling units, 2 for low controlling units and 1 for very low controlling reclassified units. Finally the maps integrated using GIS software with the purpose intended to delineate the groundwater potential areas for the study region. All the weighted thematic maps were integrated and defined criteria weight using the IDRIS software and overlay analysis done using ArcGIS software and groundwater potential prospect zones were identified (Figure 4.3).

4.2. Criteria weights and Map Scores

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 0.03 which is accepted (Figure 4.1). 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:

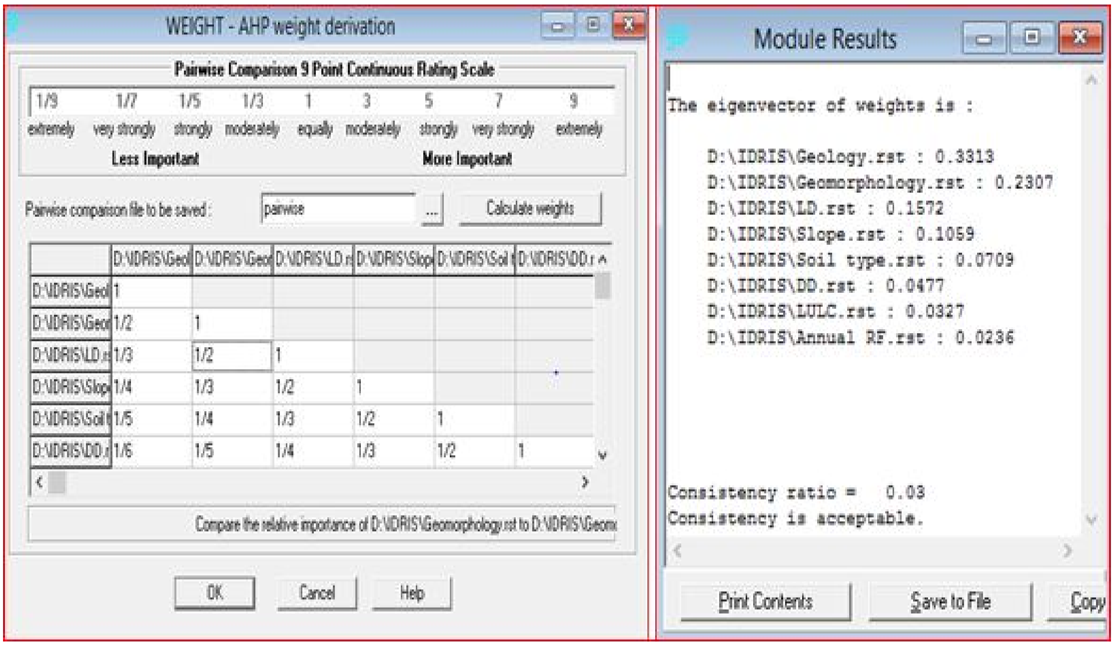


Figure 4.1. Weights of parameters determined using Analytical hierarchy (AHP).

Table 4.1. Paired comparison matrix.

	Geol.	Geom.	Lin.	Slope	Soil	DD	LULC	RF	Weight	Weight(%)
Geol.	1								0.3313	33
Geom.	1/2	1							0.2307	23
Lin.	1/3	1/2	1						0.1572	16
Slope	1/4	1/3	1/2	1					0.1069	11
Soil	1/5	1/4	1/3	1/2	1				0.0709	7
DD	1/6	1/5	1/4	1/3	1/2	1			0.0477	5
LULC	1/7	1/6	1/5	1/4	1/3	1/2	1		0.0327	3
RF	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	0.0236	2

Consistency ratio = 0.03, acceptable.

4.3. Groundwater potential zoning

By integration of all the thematic maps, groundwater potential zones were delineated and classified as: very high potential, high potential, moderate potential, low potential and very low potential zones (Figure 4.3). The thematic layers include Drainage density, Slope, Land use/cover, Rainfall, Soil, Geology, Rainfall and Lineament density . Each of the class in the thematic layers was qualitatively described and reclassified by assigning numbers starting from 1 up to 6. Numbers were assigned based on groundwater potentiality of each class in layers. The higher the number the better groundwater potentiality or availability. After assigning weight the integration of all layers were carried out applying raster overlay analysis in a GIS environment using the following formula:

GWPZM = 33 * lithology map+23 *geomorphology map + 16* lineament density map + 11* slope map + 7* soil map+5* drainage density map + 3* Land use/ Land cover map + 2*rainfall map.

No.	Parameters	Weight (%)	Class	Rank
1.	Geology	33	Rhyolitic volcanic centers(Qr)	1
			Tranchites(Nqtb)	2
			Alluvia and lacustrine deposits(Q)	3
			Alkaline basalt(Qb)	4
			Ignimbrites(Qd)	5
			Naziret seties(Nn)	6
2.	Geomorphology	23	Undulating high plateau	1
			Low plateau	2
			Lava platforms and plains	3
			Alluvial Plains- Awash	4
			Lakes	5
3.	Lineament density	16	0 -0.04	1
			0.04 - 0.12	2
			0.12 -0.21	3
			0.21 - 0.31	4
			0.31 - 0.53	5
			0 - 2	5

4.	Slope	11	2 - 5	4
			5 - 10	3
			10 - 20	2
			20 - 40	1
5.	Soil type	7	Andosols	5
			Phaeozems	4
			Luvisols	3
			Cambisols	2
			Vertislos	1
6.	Drainage density	5	0 - 0.48	5
			0.48 - 0.73	4
			0.73 -0.97	3
			0.97 - 1.27	2
			1.27 - 2.01	1
7.	Land use/Land cover	3	Water body	5
			Vegetation	4
			Agricultural land	3
			Bare land	2
			Built up	1
8.	Annual mean Rainfall	2	619 - 673	1
			673 - 701	2
			701 - 715	3
			715 - 733	4
			733 - 763	5

Table 4.2. Rank and % influence of different thematic layers.

From the composite layer, the identification of groundwater prospect zones was made by grouping the polygons into different prospect zones: Very high, High, moderate, Low and Very low.

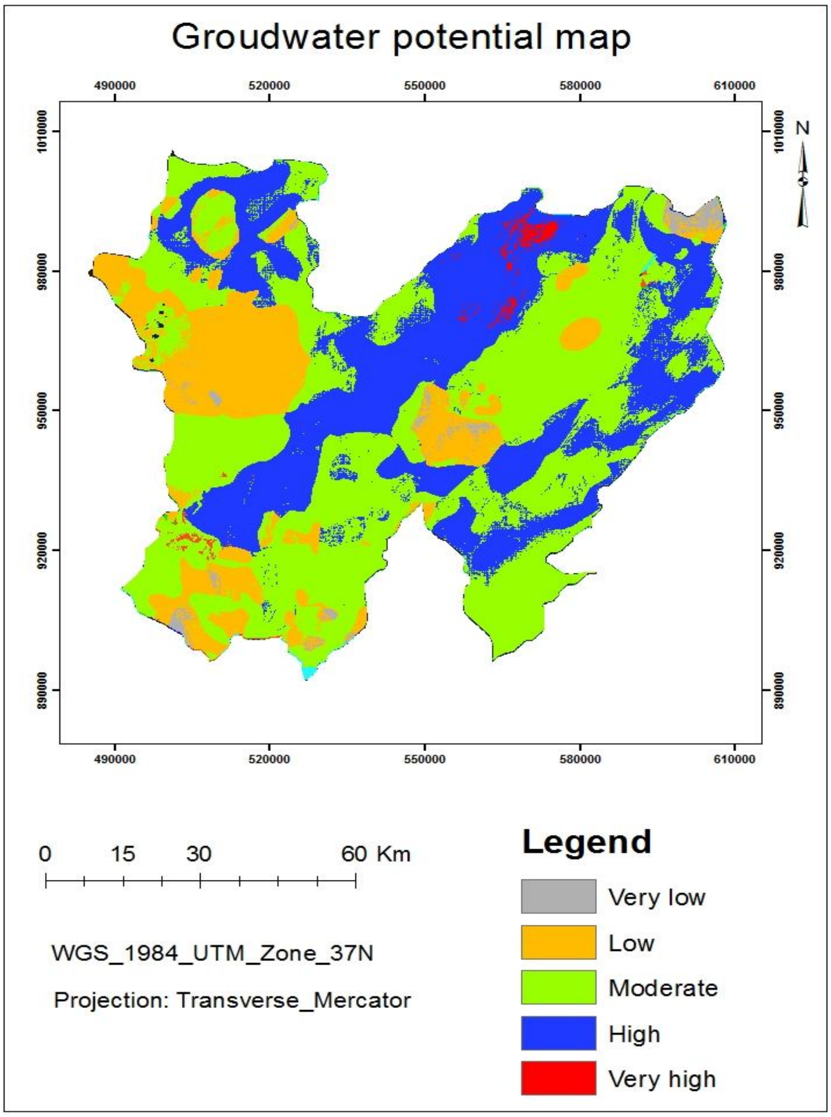


Figure 4.3. Groundwater potential zones map of the study area.

Spatially the very high and high categories are distributed along areas near to lineaments and less drainage density and where the geology is affected by secondary structure and having interconnected pore spaces. This highlights the importance of lineaments, geology and geomorphologic units for groundwater investigations. Areas with moderate groundwater prospects are attributed to contributions from combinations of the land use/cover, geology, slope, geomorphology and soil types. The low to very low categories of groundwater potential zones are spatially distributed mainly along ridges where slope class is very high, the geology is compact, clay soil composition and far from lineaments. In this study area, 6292.67hect. moderate, 4398.2hect. high, 2196.48hect. low, 161.96hect. very low and 77.63hect. very high groundwater potential zones have been identified(Table 4.3).

No.	Ground water potential zones	Area coverage (hectare)	Percentage(%)
1	Very low	161.96	1.23
2	Low	2196.48	16.73
3	Moderate	6292.67	47.94
4	High	4398.2	33.51
5	Very high	77.63	0.59

Table 4.3. Area coverage of each ground water potential zones.

4.4. Result Validation

The validity of the model result was checked with borehole data which reflects the actual groundwater potential. Accordingly the result showed that the groundwater potential zones prepared through this model matches quite well with borehole data. Interestingly out of 55 boreholes 35 falls on the high, 20 boreholes are overlaid properly on moderate class of groundwater potential zone. Moreover no boreholes were found under low groundwater potential zones which reflects the accuracy of results(Figure. 4.4).

The model will help as a guideline for designing a suitable groundwater exploration plan in the future. The spatial distributions of the various groundwater potential zones obtained from the model generally show regional patterns of lineaments, drainage, geomorphology and geology. In general the result of the model is found to be in good agreement with the information on the ground. Hence the finding of this work demonstrated that the methodology has merits to be replicated in groundwater exploration in other areas with appropriate modification of factors.

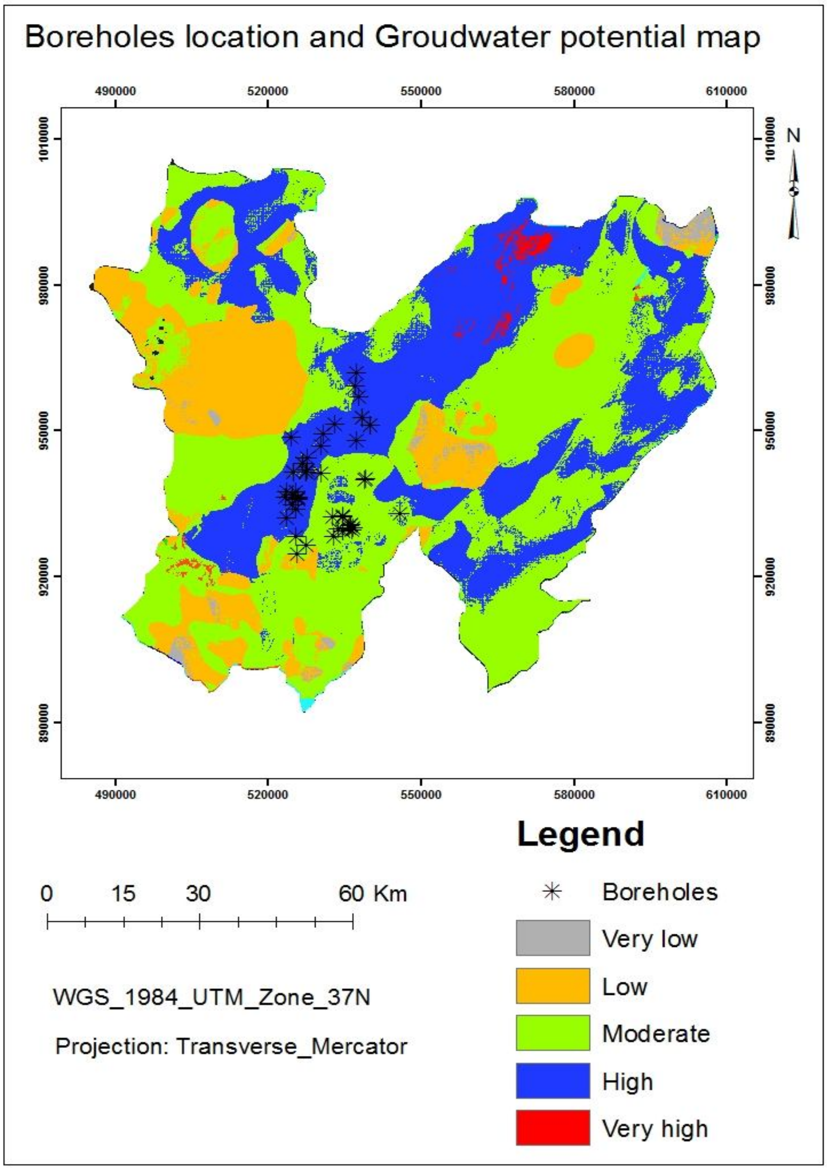


Figure 4.4. Comparison of boreholes location and groundwater potential zones.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Geographical Information System and remote sensing has proved to be powerful and cost effective method for determining groundwater potential in Adama Watershed. The study reveals that integration of eight thematic maps such as drainage density, slope, geology, geomorphology, lineament density, Annual mean rainfall, soil types and land use/land cover gives first hand information to local authorities and planners about the areas suitable for groundwater exploration. In this study area, five categories of groundwater potential zones have been delineated based on remote sensing and GIS techniques which are very high, high, moderate, low and very low.

The study of identification of ground water potential zone in Adama Watershed depicts that, vast area has been covered by moderate potential zone followed by high, low, very low and very high potential zone respectively. To validate the result of present study fifty five sample boreholes location data have been collected, then these data have been correlated with the result of study. The resulted groundwater potential zoning map validated by using 55 borehole data. Interestingly out of 55 boreholes 35 falls on the high, 20 boreholes are overlaid properly on moderate class of groundwater potential zone. Moreover no boreholes were found under low groundwater potential zones which reflects the accuracy of results.

The result of correlation between study result and sample data showed that the groundwater potential zones prepared through this model are generally in agreement with borehole data. Therefore based on the result and accuracy of the study suggest these method would be suitable for exploring groundwater potential zones. The accuracy of study's result with the sample data proves Satty's Analytical Hierarchical Process is one of the suitable method for assigning the weightage for the groundwater studies. Finally, it is concluded that the integrated GIS and Remote Sensing techniques are very efficient and useful for the identification of groundwater potential zones.

5.2 Recommendation

Based on the present study the following recommendations are made.

- Satellite image processing provides important groundwater indicator parameters in shorter time and lesser cost. Therefore integration of these data with ground based information in GIS environment is recommended for groundwater development projects.
- For more realistic result detailed ground verification of thematic layers generated from satellite images and GIS model output needs to be done.
- In future assessment adequate planning of samples collection, handling, storage and analysis should be made. Sufficient samples should be collected for mapping spatial distribution of water quality parameters.
- Frequent monitoring of ground water levels and providing essential background data for efficient ground water management. It assumes greater significance with competing demands for water in the area.
- Results obtained from the present study work are very good. Therefore, more study should be done such as Groundwater Quality for the study area should be included in order to protect the groundwater potential zone.
- . The concerned body have to use the result of the study as guideline for the drilling of boreholes.
- The study also recommends the use of GIS technology with RS data for the further study of ground water, which can minimize the cost, time, human power with higher accuracy.

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7. Appendixes

Monthly Rainfall in mm recorded at different stations.

Station Name: Abomsa, Long: 39.83 Lat: 8.46 Elevation: 1630m												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	0.0	38.8	165.8	47.4	22.4	51.8	220.9	175.6	95.5	93.0	1.4	50.1
2007	16.8	40.9	0.0	104.9	85.9	0.0	121.8	221.5	124.5	24.4	13.7	0.0
2008	5.4	2.4	1.1	74.6	85.5	42.1	193.9	176.4	102.0	143.1	48.6	0.0
2009	67.7	0.0	49.3	56.3	28.7	22.4	147.8	181.9	54.5	165.0	14.5	5.2
2010	19.9	148.2	44.1	76.2	152.0	73.0	152.3	167.8	130.3	0.0	65.0	1.7
2011	0.0	18.2	61.2	27.3	130.1	106.6	56.7	176.6	218.7	3.8	108.7	0.0
2012	0.0	0.0	38.0	83.6	47.4	37.2	249.6	285.4	76.7	11.4	7.0	5.8
2013	40.5	2.1	33.6	123.2	72.5	57.3	208.5	135.8	97.3	34.0	45.1	0.0
2014	0.0	0.0	79.5	46.9	82.7	9.6	94.4	107.2	119.5	153.0	13.9	0.0
2015	0.0	0.0	10.6		102.8	126.4	72.5	154.0	77.4	5.5	66.8	4.9
Station Name : Adama, Long: 39.2, Lat: 8.53												
2006	72.5	6.3	90.1	41.3	71.1	50.2	144.3	165.0	68.4	6.0	5.3	0.0
2007	17.6	88.4	64.6	88.7	27.8	58.7	173.5	225.0	128.8	10.1	0.5	28.5
2008	23.1	31.6	82.1	101.7	64.7	62.8	225.7	344.4	138.0	25.4	6.7	0.0
2009	34.6	0.0	0.0	79.9	69.2	58.7	353.1	302.2	100.3	37.5	69.5	0.0
2010	111.1	0.0	4.5	17.2	18.7	7.5	114.6	125.3	23.1	50.5	0.0	20.0
2011	0.0	97.3	88.8	27.4	68.1	100.6	227.8	242.9	164.7	0.0	17.6	0.3
2012	22.0	0.0	10.4	17.6	68.7	54.8	215.1	155.8	192.1	0.0	0.0	0.0
2013	4.4	0.2	69.2	35.1	36.0	38.9	443.2	105.2	132.8	34.0	5.2	0.0
2014	0.0	4.8	123.0	7.1	62.3	7.7	211.7	180.0	150.6	91.7	8.9	0.0
2015	0.0	0.0	11.0	3.6	180.4	74.9	131.3	207.9	78.6	2.3	47.0	1.5
Station Name : Addis Ababa, Long: 38.75, Lat: 9.03, Elevation: 2354m												
2006	2.0	36.6	107.8	93.9	37.8	115.1	313.2	331.1	132.5	35.9	0.0	0.0
2007	9.9	21.3	61.1	86.8	134.0	157.6	191.3	305.4	130.9	37.2	0.1	0.0
2008	0.0	0.0	0.0	34.0	75.3	73.1	295.1	259.1	192.7	22.2	53.1	0.0
2009	40.9	0.0	12.4	46.1	52.0	77.5	238.2	269.5	86.1	42.4	2.0	79.9
2010	0.4	115.2	75.6	159.5	94.7	107.2	320.2	138.8	105.0	0.0	13.8	15.7
2011	3.4	13.6	27.9	0.0	86.0	148.0	183.1	296.5	141.3	0.0	11.9	0.0
2012	0.0	0.0	34.5	75.1	58.5	72.8	228.8	281.6	176.9	1.2	0.0	0.0
2013	0.0	0.0	63.5	114.4	78.5	101.4	157.6	270.2	126.7	45.3	3.2	0.0
2014	0.0	41.7	29.7	33.7	62.1	41.8	179.7	253.6	95.1	34.8	0.0	0.0
2015	0.0	0.0	21.3	0.0	0.0	0.0	163.0	203.0	0.0	0.0	1.3	1.8
Station Name: Bui, Long: 38.55,Lat: 8.33, Elevation: 2054m												
2006	59.3	4.7	23.1	158.1	2.6	114.3	211.0	193.9	117.9	26.8	9.5	0.0
2007	0.0	17.4	143.9	103.3	158.9	122.8	146.8	353.9	90.0	34.8	36.7	0.0
2008	14.5	33.7	206.2	161.8	95.9	76.0	298.6	0.0	74.6	33.2	0.0	12.5

2009	17.7	243.5	31.5	70.2	97.3	174.2	286.6	154.4	98.2	21.2	3.5	0.0
2010	0.0	0.0	0.0	0.0	86.2	186.2	332.4	187.1	0.0	17.8	147.8	0.0
2011	19.2	0.0	68.7	74.9	0.0	22.2	244.4	140.7	116.8	140.7	0.0	11.0
2012	0.0	152.3	141.1	262.4	114.4	209.1	205.5	269.4	154.4	0.0	9.2	0.0
2013	0.0	0.0	50.6	49.0	403.7	149.4	218.2	179.9	85.5	0.0	14.0	0.0
2014	0.0	0.0	20.1	111.4	66.9	110.6	221.1	95.0	99.7	0.0	0.0	2.5
2015	0.0	0.0	136.2	88.5	54.1	156.9	210.8	190.0	57.4	47.5	0.6	0.0
Station Name: Kulumsa, Long: 39.15, Lat: 8.009, Elevation: 2211m												
2006	5.0	16.0	82.7	131.4	61.9	80.6	161.6	99.7	81.3	77.0	2.0	6.5
2007	27.2	59.6	49.4	89.9	155.3	120.6	130.9	96.4	79.8	20.2	6.6	0.0
2008	0.5	2.3	0.2	41.5	81.2		158.7	232.8	101.6	78.9	65.6	0.0
2009	20.3	10.8	35.5	50.2	61.7	57.5	158.5	202.4	95.0	68.3	0.9	26.8
2010	4.5	127.4	101.1	107.2	94.7	115.9	147.5	85.7	123.5	3.3	3.5	3.5
2011	8.4	25.6	133.3	58.3	120.5	64.7	113.9	153.6	167.4	0.0	4.0	0.0
2012	1.4	2.5	28.3	101.3	72.7	75.7	198.2	187.9	272.1	3.8	4.0	13.3
2013	7.5	0.0	82.7	36.1	130.3	56.1	203.5	76.4	114.9	36.0	6.3	0.0
2014	0.0	29.7	75.3	65.5	110.7	40.8	40.8	128.0	158.7	214.7	1.5	0.0
2015	0.0	0.0	0.0	17.9	136.8	140.2	59.0	72.8	115.2	12.7	28.4	0.0
Station Name: Melkasa, Long: 39.31, Lat: 8.4, Elevation: 1540m.												
2006	17.5	24.2	128.1	75.3	5.8	51.6	190.2	187.5	161.2	1.8	1.8	54.0
2007	51.6	1.8	93.7	72.8	1.8	54.2	203.5	140.0	110.4	67.9	20.3	4.5
2008	23.0	2.4	85.0	100.0	95.1	80.6	117.8	232.2	129.5	4.7	12.1	0.0
2009	11.0	44.5	59.4	94.7	34.7	60.9	209.4	217.0	138.5	24.2	0.0	34.3
2010	48.5	40.7	74.8	88.2	100.2	62.1	171.2	238.7	200.1	30.5	9.7	0.0
2011	0.0	0.0	0.7	73.7	98.4	45.8	334.3	210.9	121.7	92.5	74.7	0.0
2012	53.0	0.0	0.0	47.9	52.9	51.9	151.9	138.8	34.0	99.8	1.3	47.9
2013	0.0	122.8	89.9	31.5	115.2	107.1	210.2	294.4	113.9	0.0	4.9	3.2
2014	0.0	1.5	37.9	45.6	38.2	102.0	126.4	218.2	188.1	0.0	52.2	0.0
2015	0.0	0.0	47.5	36.8	18.3	22.4	430.8	209.9	155.4	3.0	0.6	0.0
Station Name : Nuraera, Long: 39.9, Lat: 8.08, Elevation: 1140m												
2006	3.3	30.9	127.2	53.4	8.4	28.0	180.2	81.2	59.6	25.7	0.0	28.6
2007	56.0	27.5	80.8	45.5	18.4	17.2	141.1	169.4	58.3	18.0	1.4	0.0
2008	2.0	2.0	0.0	55.5	0.0	41.2	249.2	103.0	40.5	58.4	8.7	0.0
2009	111.1	0.0	4.5	17.2	18.7	7.5	114.6	125.3	23.1	50.5	0.0	19.0
2010	0.0	0.0	120.3	3.1	0.0	23.1	153.7	145.3	94.8	0.0	13.5	0.0
2011	0.0	7.5	86.3	8.7	78.0	43.0	95.1	164.0	110.7	0.0	34.5	0.0
2012	0.0	0.0	0.0	19.6	0.0	22.3	286.0	143.7	81.5	7.0	0.0	0.0
2013	18.3	0.0	32.4	0.0	6.1	14.7	332.0	78.1	99.5	21.2	14.6	0.0
2014	0.0	32.8	28.7	33.0	28.9	4.7	93.2	28.0	93.4	66.5	19.9	0.0
2015	0.0	0.0	2.7	0.0	90.6	63.0	71.1	116.9	63.8	0.0	35.5	0.0
Station Name: Robe, Long: 40.05, Lat: 7.13, Elevation: 2480m												
2006	22.2	10.9	118.1	63.6	72.5	77.4	118.7	111.2	123.8	66.8	26.7	7.2
2007	29.6	2.3	89.8	46.4	54.3	35.7	67.6	69.9	120.2	45.7	3.5	83.9

2008	7.7	0.0	55.6	163.0	68.2	103.5	98.6	152.2	92.0	49.2	37.2	64.2
2009	55.5	11.2	44.5	110.7	22.7	69.0	124.8			60.7	14.5	13.8
2010	5.1	0.0	41.0	105.8	77.4	71.7	78.2	179.5	80.0	82.7	106.3	0.0
2011	30.1	8.3	31.6	107.4	53.1	35.4	66.4	134.9	106.5	100.2	36.2	38.3
2012	4.4	136.8	193.9	136.3	101.0	70.1	108.8	160.0		71.2	0.0	0.2
2013	0.0	0.2	20.0	70.9	126.7	37.9	133.5	133.0	152.9	36.9	57.2	0.0
2014	0.0	0.0	8.8	158.6	59.4	34.1	150.6	222.9	136.7	68.7	3.2	12.3
2015	12.4	0.0	115.2	81.7	104.4	79.5	153.7	183.0	60.7	102.5	116.4	0.0
Station Name: Shola Gebeya, Long: 39.55, Lat: 9.22, Elevation: 2500m												
2006	5.4	7.9	21.8	56.1	25.0	75.6	295.6	239.3	92.8	46.8	0.0	32.3
2007	5.8	9.7	9.3	53.6	23.3	120.8	282.5	342.3	151.2	3.1	6.1	0.0
2008	2.0	2.6	0.0	42.2	75.1	80.0	322.5	247.2	131.2	7.8	34.4	0.7
2009	25.8	0.0	17.9	32.1	15.3	30.7	280.0	259.0	67.1	96.6	4.7	
2010	1.6	78.6	72.0	97.3	75.5	39.2	222.5	75.5	102.4	0.0	2.3	3.6
2011	0.0	1.4	64.6	24.2	48.2	88.1	216.0	289.1	110.7	0.0	3.1	0.0
2012	0.0	0.0	5.0	83.4	20.8	81.9	342.0	278.0	70.0	1.1	0.0	3.5
2013	3.7	0.0	26.1	66.2	46.2	56.1	410.7	215.3	99.6	55.0	10.7	0.0
2014	0.0	20.9	60.9	31.6	52.8	31.8	219.0	229.5	88.5	67.8	12.0	0.0
2015	0.0	0.0	18.6	0.0	91.6	85.3	106.8	288.9				
Station Name: Ziway, Long: 38.7, Lat: 7.93, Elevation: 1640m												
2006	20.0	0.0	70.4	229.5	4.7	150.4	161.7	57.4	45.8	108.4	0.3	0.0
2007	6.1	22.3	43.4	48.7	57.7	44.9	166.5	177.8	98.0	90.8	0.0	0.0
2008	5.5	0.0	28.5	2.4	44.2	110.3	85.0	63.8	72.0	133.8	0.0	0.0
2009	0.0	0.0	3.0	65.2	97.3	34.0	215.5	95.7	106.9	31.1	31.4	24.2
2010	21.2	0.3	98.0	127.1	21.3	82.9	221.7	156.7	101.0	0.0	3.2	17.4
2011	92.0	0.8	23.8	150.3	0.0	94.1	176.7	129.6	92.7	10.9	2.7	0.0
2012	48.5	14.3	85.4	100.8	197.0	55.4	103.0	91.5	140.2	4.6	1.4	0.0
2013	1.0		39.1	197.5	45.0	137.9	185.6	65.0	72.8	9.5	0.0	7.3
2014	10.5	46.1	22.7	59.6	166.1	136.6	195.1	83.3	59.3	22.7	1.6	0.0
2015	0.0	0.4	8.7	2.2	80.3	112.2	292.3	194.2	62.6	65.0	224.2	0.0

Location of Boreholes used for Result validation.

No.	Zone	District	Water_type	E	N
1	East Shewa	Adama	BH42	527667	941523
2	East Shewa	Adama	BH33	527524	926601
3	East Shewa	Adama	BH	526928	943518
4	East Shewa	Adama	BH	526928	943518
5	East Shewa	Adama	BH43	526928	943518
6	East Shewa	Adama	HDW	526093	936013
7	East Shewa	Adama	HDW	525977	936456
8	East Shewa	Adama	BH	525951	936324
9	East Shewa	Adama	BH32	525690	924757
10	East Shewa	Adama	BH31	525688	928442
11	East Shewa	Adama	BH14	525685	933969
12	East Shewa	Adama	HDW	525663	937529
13	East Shewa	Adama	BH	525135	941567
14	East Shewa	Adama	BH	525135	941567
15	East Shewa	Adama	BH18	525000	937000
16	East Shewa	Adama	BH19	525000	937000
17	East Shewa	Adama	BH20	525000	935000
18	East Shewa	Adama	BH	545947	933003
19	East Shewa	Adama	BH	540248	951358
20	East Shewa	Adama	BH	540248	951358
21	East Shewa	Adama	BH29	539213	940271
22	East Shewa	Adama	BH	539121	940043
23	East Shewa	Adama	BH	538684	952916
24	East Shewa	Adama	BH	538684	952916
25	East Shewa	Adama	BH	537831	957213
26	East Shewa	Adama	BH	537560	948216
27	East Shewa	Adama	DW	537496	962107
28	East Shewa	Adama	BH	537174	959450
29	East Shewa	Adama	BH27	536813	930293
30	East Shewa	Adama	BH26	536580	929743
31	East Shewa	Adama	BH	536348	930881
32	East Shewa	Adama	BH5	536248	930836
33	East Shewa	Adama	BH6	536178	930736
34	East Shewa	Adama	BH	535994	930146
35	East Shewa	Adama	BH24	534890	932712
36	East Shewa	Adama	BH	534851	932498
37	East Shewa	Adama	BH	534851	932498
38	East Shewa	Adama	BH	534805	929527
39	East Shewa	Adama	BH	534805	929527
40	East Shewa	Adama	BH	533854	929852
41	East Shewa	Adama	BH	533250	951511

42	East Shewa	Adama	BH11	533027	928447
43	East Shewa	Adama	BH25	532673	932328
44	East Shewa	Adama	BH	530861	949490
45	East Shewa	Adama	BH4	530609	947065
46	East Shewa	Adama	TCK65	530429	941358
47	East Shewa	Adama	BH	527845	942127
48	East Shewa	Adama	BH1	527786	944511
49	East Shewa	Adama	TCK66	527667	941523
50	East Shewa	Adama	BH	527667	941523
51	East Shewa	Adama	BH	527667	941523
52	East Shewa	Adama	BH3	524648	948746
53	East Shewa	Adama	BH34	523851	932126
54	East Shewa	Adama	BH36	523848	937653
55	East Shewa	Adama	BH	523583	936462