ASSESSMENT OF GROUNDWATER POTENTIAL ZONES: THE CASE OF WOGAYI WATERSHED IN THE OMO-GIBE RIVER BASIN, ETHIOPIA.

M.Sc. THESIS

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ADVISORS' APPROVAL SHEET

This is to certify that, the thesis entitled **"Assessment of Groundwater Potential Zones: The Case of Wogayi Watershed In The Omo-Gibe River Basin, Ethiopia"** submitted in partial fulfillment of the requirements for the degree of Master's with specialization in Hydraulic Engineering, the Graduate Program of Hydraulic and Water resource Engineering and it has been carried out by **Wubishet Sisay Woldeyes** Id. No: **(GPHYdrR/0018/13)**, under my/our supervision. Therefore I/we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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We, the undersigned, members of the Board of Examiners of the final open defense by Wubishet Sisay Woldeyes have read and evaluated his/her thesis entitled "**Assessment of Groundwater Potential Zones: The Case of Wogayi Watershed In The Omo-Gibe River Basin, Ethiopia**, and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree.

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DECLARATION

I, the undersigned, declare that the thesis entitled with **"Assessment of Groundwater Potential Zones: The Case of Wogayi Watershed in the Omo-Gibe River Basin, Ethiopia"** is my original work, and has not been presented and submitted for any degree in any other university. It is submitted for the degree of Master of Science in Water Resources Engineering, and all sources of material used for this thesis have been fully acknowledged.

Name: Wubishet Sisay Woldeyes

Signature ___________________________

Date__________________________

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LIST OF ACRONYMS

AHP	Analytical hierarchy process
m.a.s.l	Meters Above Sea Level
BCM	Billion Cubic Meters
BH	Borehole
CI	Consistency Index
CR	Consistency Ratio
DD	Drainage Density
DEM	Digital Elevation Model
EMA	Ethiopian Mapping Agency
ERDAS	Earth Resources Data Analysis System
FAO	Food and Agricultural Organization
Ft/s	Feet per Second
HW	Hand Dag Well
GIS	Geographic Information System
GW	Groundwater
GWP	Groundwater Potential
IDW	Inverse Distance Weighted
ITCZ	Inter Tropical Convergence Zone
LD	Lineament density
LULC	Land Use / Land Cover

MCDA	Mulit Criteria Decision Analysis
MoA	Ministry of Agriculture
MoWE	Ministry of Water and Energy
M.Sc	Master of Science
MRAP	Missouri Resource Assessment Partnership
NMA	National Meteorological Agency
NASA	National Aeronautics and Space Administration
NGWA	National Groundwater Association
OLI	Operational Land Image
RF	Rainfall
RS	Remote Sensing
S.N.N.P.R	Southern Nations Nationalities and People Region
SRTM	Shuttle Radar Topography Mission
SW	Shallow well
UTM	Universal Traverse Mercator
USGS	United State Geological Survey
WOA	Weighted Overlay Analysis
WRCS	Water Resources Consulting Service

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDIXS

ABSTRACT

This study was aimed at assessing the groundwater potential of Wegayi watershed in the Omo-Gibe river basin. Secondary data: climate, topography, well log information and different thematic layers were used. The thematic layers considered in this study are geology, geomorphology, drainage density, lineament density, rainfall, soil types, slope and land use/cover. Arc GIS and Surfer 20 softwares were used to produce spatial maps of the different thematic layers and water table contours respectively. The geological formation of the catchment was evaluated using existing well logs data of the boreholes. The groundwater flow direction of the catchment was identified by using ground water level maps. The Saaty analytical hierarchy process (AHP) method was implemented to identify the groundwater potential zones based on their relative assigned weights. Eventually, the weights were normalized so as to indicating on their importance in groundwater occurrence. The major lithological units of the area are weathered and fractured basalts. These types of geological formation are recognized to be good groundwater formations. According to the groundwater flow lines and the ground water contour maps produced in the catchment, the groundwater flows from southern and eastern parts of the highlands of the catchment towards the plain areas of the northwestern parts of the catchment. The hydraulic characteristics are variable throughout the catchment. According to the result of groundwater potential map, the major recharge of groundwater occurs in the Easter and southwestern highlands of the catchment, which is said to be recharging zone. However, the area situated in the southeastern, northwestern and northeastern parts of the catchment is discharge zones. The results of AHP indicate that 58.12% moderate, 20.82% high, 21.03% low and 0.032% very low groundwater potential zones have been identified. 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-word: *Groundwater potential, Wogayi watershed, geological formation characterization; recharge and discharge zone.*

1. INTRODUCTION

1.1. Background

Groundwater is an important resource, accounting for a large portion of the total annual supply (Waikar & Aditya 2014). However, excessive use has significantly reduced groundwater supplies. Around 22% of the total fresh water resources projected to be available on the world are available as ground water sources, accounting for roughly 97% of all liquid fresh water suitable for human consumption (Abdul-Aziz et al., 2017). According to National Groundwater Association (NGWA) Report, Groundwater (GW) is the most widely used source of fresh water and extracted as raw materials with withdrawals rate currently in the estimate range of 982km^2 year in the world According to a recent study by (MacDonald et al., 2012), Africa possesses significant groundwater storage. Annual groundwater storage in Africa is estimated to be 100 times greater than annual renewable freshwater supplies, according to the researchers. Ground water supplies, accessed by hand dug wells and springs, have traditionally determined the growth and extent of human settlement outside the major riparian zones of Sub-Saharan Africa and across many other arid regions of the world. In recent years, ground water has been the primary method of meeting the growing demand for water in rural, dispersed populations, and small metropolitan areas across Sub-Saharan Africa (Pavelic et al., 2012). When compared to surface water resources, ground water is the safest and most reliable supply of water for residential, irrigation, industry, and municipalities (Abdul-Aziz et al., 2017). In Ethiopia, ground water is rarely used for agriculture, and 80% of the ground water resource is used for domestic water supply (Semu 2012). Ethiopia is renowned as Horn Africa's "water tower." This potential is not fully realized and transformed into development due to a variety of factors, including a lack of financial resources, technical issues, and a lack of good governance in the water sector (Kidanewold & Melesse 2014). According to (Belete et al., 2014), Ethiopia possesses 124.4 billion cubic meters (BCM) of river water, 70 billion cubic meters (BCM) of lake water, and 30 billion cubic meters (BCM) of ground water. Climate (rainfall), geomorphological (land feature, land use/cover), physiographical (topography), hydrological (drainage density, water bodies, etc.), geological factors, lineament density, and soil density all play a role in the occurrence, distribution, and movement of GW resources in any location (Murasingh et al., 2013). However, the level to which they have an impact varies by location and time. Because of the advancement of remote sensing and GIS methods, the approach to groundwater exploration has changed over time. When done with proper image processing and modeling approaches supported by field checking of parameters that will affect the availability of potential groundwater bearing zones in terms of quality and quantity of expected water for development, not only is the time required for delineating groundwater potential areas shortened, but also the quality of tracing potential areas has improved (WRCS 2013). In addition to GIS and RS approaches, the Analytic Hierarchy Process (AHP) method's multi-criteria decision analysis (MCDA) approach is utilized to assess the level of influence (importance) of each governing groundwater component and prioritize accordingly. Additionally, pairwise comparison can be used to assess the consistency of the weight allocated in order to avoid bias in the decision-making process (Manna et al., 2017).

Large parts of the study area residents are living under the rural areas. Water is basic for socio-economic development of the people whose income is primarily dependent on agriculture. However, with frequent poor water supply and sanitation services several socio-economic activities are reduced. Similarly most of the residents living in the study area are rural people whose livelihood is mainly dependent on agriculture with poor water supply and sanitation services. A large part of the watershed area is suitable for agricultural activities and settlement. Therefore, investigating the ground water potential of the study area is a main objective for improving the use of groundwater resource.

1.2. Statement of the problem

The mismanagement of groundwater resource to supply ever increasing demand finally leads to water shortages and pollution (Tsakiris 2004). Knowing Groundwater occurrences and distribution, and identifying a good site for groundwater exploration is one of the biggest challenges, and key concern for water resource development and management in the most countries today. Proper Groundwater Potential (GWP) and recharge investigation, and site selection done by using geophysical and hydrogeological method is still more difficult/laborious, time taking and cost ineffective. Improper groundwater potential site selection often leads an economic and time wastage for exploration, and unsustainable utilization resource is becoming increasingly an evident problem or challenging, and the key concern for many developing countries (Abdul-Aziz et al., 2017; Tesfaye 2015). Thus, using integrated approach geospatial tools (GIS and RS) with MCDA-AHP helps to evaluate the level of importance and consistence of weighted through pair wise comparison in order to reduce the bias on single factor on decision making process and to identify the main factor(s) responsible for groundwater resource development. In fact, the exponential growth of urban population, insufficient surface water due to irregular rain season and agricultural-led industrial development have resulted in greater attention to groundwater identification (Dessalegn & Worku 2018). However, using groundwater resource for such development potential studies always has less attention due to less information about the groundwater potential and distribution on the site in spatial, which leads much difficult to access, plan and manage groundwater resource and recharge potential on the site (Dereje et al., 2015). Also, the over-exploitation or excessive abstraction of groundwater exist in particular areas require replenishment capacity (artificial recharge) by identifying recharge potential site.

To solve such identified problems the current study is designed to provide groundwater information (database), distribution and map of potential site of GWP and recharge of the study areas by advanced geospatial techniques of GIS and RS. Therefore, it is better to understand spatial dynamics of groundwater resource and identifying the GWP areas even in large and inaccessible areas and to prepare proper plan and management for the sustainable utilization of water resource with short time and minimum cost.

1.3. Objective of the study

1.3.1. General objective

The general objective of this study was to assess the groundwater potential zones of Wogayi watershed in the Omo-Gibe river basin, Ethiopia.

1.3.2. Specific Objectives

The specific objectives of this study were:

- To characterize the geological formation in the study area;
- To prepare map of layers that affect groundwater potential in the study area
- To identifying the direction of groundwater flow in the study area;
- To spatially map the Wogayi watershed's groundwater recharge and discharge areas.

1.4. Research Questions

The following questions have been formulated to achieve the research objectives.

- How to identify the groundwater flow direction of the study area?

- What are the main factors affecting the occurrence and movements of groundwater in study area?
- How to identify the groundwater recharge and discharge of the study area?
- What is the dominant geological formation of the study area which affects the groundwater potential?

1.5. Scope of the study

This study attempted to assess the shallow groundwater potential zones using integrated GIS and remote sensing techniques in the case of Wogayi Watershed, Dawro zone, South west people's regional state, Ethiopia, which cover a total drainage area of 575.63 square kilometers. This study should be focused on the identifying the main factors that affect groundwater potential, identifying the groundwater flow direction, recharge and discharge areas identification and characterizing geological formation of the study area.

1.6. Significance of the study

Mapping groundwater potential and recharge zone is important to understand groundwater occurrence and distribution in space and time of the area, which used for proper plan, management and utilization and/or may give better information for the success in selecting the favorable sites for efficient exploration (boreholes/or hand dug wells/or tube well drilling), and for the construction of artificial recharge structure (check dam, recharge pit, recharge well, etc.) in efficient and effective (Badamasi et al., 2016). It is hoped that communities and private organization and/or individual in study area, and the government are the main beneficiary of the study. Specifically, the main beneficiary of this study includes (1) the communities are benefited from this study when the government or non-government bodies take action to develop and explore groundwater resource for community development without time and cost constraint. This enable them to get enough water for domestic use and agricultural (irrigation) purpose (2) the government, and any non-government organization are also benefited from this study, when they can take an action or decision-making on sustainable development, plan, management and utilization easily, and reduces the time and the cost for selecting potential sites. It is also essential for planning the location of new abstraction well to meet the increasing demand of water and providing a digital data set which serve as groundwater database for exploration, future monitoring programs and inventory GW resource of the selected sites (3) the study is also helpful for an individual who want to do more analysis on groundwater resource identification and evaluation, and modeling and one may get his own research ideas from this study as a reference material as well as for education. It also will helpful as bench mark for those who want to carry out further investigation for identification on groundwater resource identification on the study area and elsewhere.

2. LITERATURE REVIEW

2.1. Groundwater

At different times, different authors describe groundwater resources and potential. Groundwater is the most important natural resource discovered beneath the earth's surface, kept in a void space of geological stratum, and employed in economic development, home life, and any ecological diversity, according to (Rashman 2016). He also concluded that groundwater occurrence and flow systems are influenced by geological characteristics such as porosity and permeability, as well as the formation of landforms such as high mountains, rift valleys, and flat areas, as well as the role of landform on surface runoff and infiltration to the ground. According to (Adem 2019), groundwater potential refers to the possibility or likelihood of groundwater occurrence in a given area. Areas of good groundwater potential or productive water-bearing zones are referred to as good groundwater potential aquifers, and productive water-bearing zones are referred to as good groundwater potential aquifers. Groundwater is a valuable natural resource in many parts of the world for providing a more reliable and cost-effective water supply. Fresh water accounts for only 2.8 % of the total accessible water on the planet, with groundwater accounting for 97 % (Sekhri 2013).

2.2. Groundwater flow direction

Groundwater does not often remain stable, but rather moves or flows underground in response to natural slope (topography), geological formation, and external pressure caused by pumping wells and well drilling. The most direct technique of detecting the direction of groundwater migration is to measure the height of groundwater at several locations and map the contour line (which connects the points of equal elevation) as an equipotential line on the terrain. Groundwater flows perpendicular to the equipotential line in the direction of higher elevation to lower elevation, draining into streams, lakes, seas, ponds, and boreholes (Oborie et al., 2017).

The saturated zone's groundwater is always moving, and it flows in three dimensions. One or two-dimensional flow equations can be employed to simplify quantitative analysis when one or two flow directions appear to be dominant. Because three-dimensional analytical equations of groundwater flow are complex and frequently cannot be solved in a closed form, three-dimensional groundwater modeling may be the only practical quantitative tool when it is necessary to accurately analyze the entire flow field, as is frequently the case in contaminant fate and transport studies (Kresic 2009). Groundwater movement is extremely slow when compared to surface water. Groundwater flows "downhill" in the direction specified by the hydraulic head's slope, just like surface water. As a result, groundwater circulation changes from a high to a low hydraulic head (Buddemeier & Schloss 2000).

The flow of surface water is normally measured in feet per second (ft/s), while groundwater flow is measured in feet per year Moore (2011). Water that recharges at a high water table flows to a neighboring lowland in a local groundwater flow system. Local flow systems are the most active and shallowest flow systems; hence they have the most surface water exchange. Intermediate and regional flow systems can be found beneath local flow systems. Water in deeper flow systems travels a longer course and spends more time in contact with beneath elements. As a result, the water has a higher concentration of dissolved chemicals. Nonetheless, these deeper flow systems eventually discharge to surface water, and their chemical characteristics have a significant impact on the receiving surface water (USGS 2006). Because there is no hydraulic link between a river and a confined aquifer beneath it, the potentiometric surface of a confined aquifer is unaffected by surface topography and surface-water characteristics. Surface contours that are potentiometric can even be found above the land surface. This means that if a well were drilled at that site, the water would flow. Higher hydraulic conductivity or permeability is associated with areas with uniform groundwater flow because portions with wide water table contour spacing and, as a result, flat gradients have higher hydraulic conductivity or permeability (Tenalem and Tamiru 2001). Groundwater usually moves slowly, with an average horizontal velocity of one hundred meters per year and a vertical velocity of one meter per year. The quantities of water involved in groundwater flow are typically large when these velocities are multiplied by the cross-sectional areas through which the flows occur. As a result, the balance between inflows, outflows, and the amount of water stored is a critical component of an aquifer system. Because groundwater moves slowly, any man-made outflows, such as pumped boreholes, must be carefully placed to ensure that they gather water efficiently from the aquifer system. The identification of aquifer resources and the repercussions of changes in exploitation are both dependent on the water balance of the aquifer system.

The water balance is based on the continuity of flow idea (Kovalevsky et al., 2004). Water table contour maps are visual representations of the hydraulic head's gradient. Regarding the selection of initial circumstances, contouring of the hydraulic head data; this is the first and most critical phase not only geography, natural drainage patterns, underlying geology, and local recharge and discharge patterns must all be considered when interpreting a water table contour map. More particular, the spatial distribution of permeable and less permeable layers beneath the water table should be understood. A clay lens, for example, obstructs the downward flow of excess irrigation water or, if the land is not watered, excess rainfall (Hutti & Nijagunappa 2010). The majority of hydro-geologic investigations make contour maps of the water table (unconfined aquifers) or the piezometric surface (confined aquifers); it is a highly strong tool in aquifer research. Water table contour maps are frequently used to determine groundwater flow routes. Furthermore, the spacing and orientation of the contours, as well as their forms, directly reflect the presence of flow boundaries (Kresic 2009). Representative contour maps for the various types of aquifers within the hydrogeological basins can be constructed using field measurements of the water table or piezometric surface (Tenalem and Tamiru 2001). In the research area, the slope has a discernible change in elevation and is more or less of the same elevation.

The slope has a direct relationship with rainfall and temperature variation, and slope angle affects water storage and transportation significantly (WRCS 2013).

2.3. Availability of Groundwater

Groundwater occurrence is determined by climatic, geological, hydrological, biological, and physiographical elements, as well as their interactions, rather than by (Arkoprovo et al. ,2012). Groundwater supply is influenced by the area's geology, geomorphology, tectonics, and climate. In Ethiopia, the fluctuation of these factors has a significant impact on the amount and quality of groundwater in various sections of the nation. The country's geology supplies usable groundwater as well as efficient rainfall transport to recharge aquifers, which produce springs and feed perennial rivers (Tamiru 2006).

Groundwater, according to (Rashman 2016), is the most important natural resource discovered beneath the earth's surface, held in the empty space of geological strata, and utilized in economic development, home life, and any ecological diversity. He also concludes that the occurrence and flow system of groundwater is influenced by geological characteristics such as porosity and permeability, as well as the formation of landforms such as high mountains, rift valleys, and flat areas, as well as the impact of landforms on surface runoff and infiltration to the ground.

Its identification and location are based on an indirect examination of some visible terrain features such as geologic, geomorphic, and landform characteristics, as well as their hydrologic characteristics (Lazarus and Yadav 2014).

Groundwater is held beneath the land surface in open spaces and fissures within geologic elements such as soil, sand, and rock. Aquifers are water-filled geologic layers capable of transmitting enough water to feed a well under normal hydraulic gradients (Kresic 2009). Relief, slope, weathering depth, type of weathered material, alluvium thickness, kind of deposited material, and the overall ensemble of varied landforms all play a role in determining the ground water regime, particularly in hard rocks and unconsolidated sediments. Delineation and mapping of diverse landforms, drainage characteristics, and structural features that could have a direct impact on the occurrence and movement of groundwater are all part of hydro geomorphological investigations. Many of these characteristics are conducive to the occurrence of groundwater and are characterized as poor, moderate, good, and very good prospecting zones in terms of groundwater potentiality (Lazarus and Yadav 2014). In the study area topography especially the slope angle has good contribution for the availability of water and emergence of springs in many places. Areas with slope angle between zeros to five degree and five to ten degrees were with less groundwater potential. Whereas the once with good contribution of water are those between 10 to 24 and those between 24 to 54 degrees. But in some cases where the role of faulting, geology and land use have higher role some of the sloppy lands have also good contribution. Similarly Groundwater availability is observed to benefit from areas with good vegetation cover, especially when they occur at a low angle or gently descending to flat plains. Water storage, as measured by spring discharge and borehole data, is particularly good in some parts of the rift (WRCS 2013).

2.4. Groundwater Mapping

A groundwater map is a pictorial representation of groundwater levels for a specific area. Complicated spatial information is much better presented on maps, than in tables or text; mapping also allows different types of information to be interpreted together. Increased and easy access to relevant information can therefore allow the decision making process to be better informed. Water mapping can be applied at different scales and contexts and used in various ways. Groundwater recharge zones are indicated by diverging contour lines, whereas groundwater discharge areas are indicated by converging contour lines.

The spacing of the contour lines can also be used to determine locations of good hydraulic conductivity. In fact, locations with uniform groundwater flow are characterized by higher hydraulic conductivity or permeability in areas with wide water table contour spacing and, as a result, flat gradients (Tenalem and Tamiru 2001). On a given date, a water table contour map depicts the elevation and shape of the water table. To build it, we must first convert the water level data from depth below the surface to water table elevation, or after level height above a datum plane, such as mean sea level. These data are then plotted on a topographic base map, with equivalent water table elevation lines created between them. Depending on the slope of the water table, a correct contour interval should be chosen. 0.25 to 0.50 m intervals may be sufficient for a flat water table; in steep water table areas, intervals of 1 to 5 m or even more may be required to avoid crowding the map with contour lines (Kumar 2006). The depth to the water table can be determined by installing wells that penetrate the top of the saturated zone just far enough to hold standing water. Preparation of a water table map requires that only wells that have their well screens placed near the water table be used. If the depth to water is measured at a number of such wells throughout an area of study, and if those water levels are referenced to a common datum such as sea level, the data can be contoured to indicate the configuration of the water table. In addition to various practical uses of a water-table map, such as estimating an approximate depth for a proposed well, the configuration of the water table provides an indication of the approximate direction of groundwater flow at any location on the water table. Lines drawn perpendicular to water-table contours usually indicates the direction of ground-water flow along the upper surface of the groundwater system. The water table is continually adjusting to changing recharge and discharge patterns. As a result, water-level measurements must be taken at roughly the same time to produce a water-table map, and the final map is only reflective of that exact period (USGS 2006).

A water table contour map is created using data from wells that access an unconfined aquifer. Hydro-geologists can use this map to characterize groundwater recharge, transport, and discharge. A low line is a path that groundwater takes that is roughly perpendicular to water table contours. A water-table contour or potentiometric-surface map is created by measuring head in wells accessing a limited aquifer. It's similar to a topographic map, but instead of land, it shows the slopes of a pressurized water surface. Groundwater potential zones are water-bearing formations in the earth's crust that serve as water transmission conduits and storage reservoirs.

Its identification and location are based on an indirect examination of some visible terrain elements such as geology, geomorphic, and landform properties, as well as their hydrologic characteristics (Lazarus and Yadav 2014).

The topographic base map should indicate all natural drainage channels and open water bodies, as well as contour lines of the ground surface. Water table contour lines can be constructed appropriately if the water levels of these surface waters are displayed on the map with these data and data on the land surface elevation for the given date. Not only must the terrain, natural drainage pattern, and local recharge and discharge patterns be considered when interpreting a water table contour map, but also the subsurface geology. More particular, the spatial distribution of permeable and less permeable layers beneath the water table should be understood.

A clay lens, for example, obstructs the downward flow of excess irrigation water or, if the land is not watered, excess rainfall. Above such a horizontal barrier, a groundwater mound will form (Kumar 2006). The use of remote sensing and GIS techniques is a fast emerging field in groundwater resource identification, mapping and planning. Remote sensing provides an opportunity for better observation and more systematic analysis of various geomorphic units, landforms, lineaments and drainages, due to its synoptic and multispectral coverage of a terrain. The techniques is increasingly used in prospecting for groundwater potential zones, because of their ability to identify and outline different ground features that may serve as direct or indirect indicators of the presence of groundwater resources (Lazarus and Yadav 2014).

When the groundwater basin is characterized by conspicuous drainages, a basin-wise approach produces the best results. A detailed examination of the geography, geology, and aquifer conditions is required. The topography of the groundwater basin is influenced by the location, structure, and permeability of rocks, as well as the water table's layout. Rainfall is the primary source of groundwater recharge. Rainwater that falls on the ground infiltrates into the soil in part. A portion of the infiltrated water is used to compensate for soil moisture deficiency, while the remainder percolates down to the water table, resulting in rainfall recharge to the aquifer. Rainfall recharge is determined by a variety of hydro meteorological and topographic parameters, as well as soil properties and water table depth. The methods for estimation of rainfall recharge involve the empirical relationships established between recharge and rainfall developed for different regions (Kumar 1997).

Groundwater flow direction and borehole water table elevation are calculated by subtracting surface elevation from borehole static water table elevation to get ground water elevation. On a given date, a water table contour map depicts the elevation and shape of the water table. Contour lines for the water table are comparable to topographic lines on a map. They essentially indicate subsurface elevations. The direction of groundwater movement in a specific region can be determined using water table contour lines. Many wells are drilled, and each one's hydraulic head is measured. Equipotential lines, often known as water table contours, are used to connect locations of equal head. Groundwater flow lines are drawn perpendicular to contour lines to depict the routes of groundwater down slope. A flow net is a map comprising groundwater contour lines and groundwater flow lines. Groundwater always flow perpendicular to equipotential lines, from a greater hydraulic head area to a lower hydraulic head area. Hydrological maps are created using existing data and extra data gathered from field surveys (Kumar 1997; Tenalem and Tamiru 2001). The depth of the water table varies greatly, ranging from zero at the land's surface to hundreds or even thousands of feet in some areas. Near permanent bodies of surface water like streams, lakes, and wetlands, the depth to the water table is usually shallow. Because ground-water recharge, which is the accretion of water to the upper surface of the saturated zone, is tied to wide variation in the quantity, distribution, and timing of precipitation, the water table's shape varies seasonally and from year to year (USGS 2006).

2.5. Groundwater recharges and discharge areas

Upstream, groundwater is refilled, and downstream, it is discharged. Near mountain peaks, where precipitation is likely to be higher than in the neighboring plains, recharge regions exist. Shallow groundwater discharges in the valleys and other low-lying zones of the Earth's crust. Artificial discharge, or the process of pumping groundwater from an aquifer to meet a socioeconomic need, occurs as a result of human involvement. Groundwater may also be subjected to artificial replenishment in some cases. To safeguard the groundwater resource, some progressive people are currently performing artificial recharge of their aquifers (Ponce 2006). Aquifer systems recycle water on a continuous basis. Groundwater recharge is the movement of water downward through the saturated zone by gravity or in a direction dictated by hydraulic conditions. Precipitation, stream flow, leaks (reservoirs, lakes, aqueducts), and artificial mechanisms all contribute to groundwater replenishment (injection wells). Rainwater that falls on the ground infiltrates into the soil in part.

Part of the infiltrated water is used to replenish the soil moisture deficiency, while the rest percolates down to the water table. The recharge from rainfall to the aquifer is the water that reaches the water table. Rainfall recharge is influenced by a variety of hydro meteorological and topographic parameters, as well as soil properties and water table depth (Rawat et al., 2012). Local changes in geology, structural connectedness, land use, and morphologic variables will all affect aquifer recharge. The evapotranspiration variance is higher in many places, which will have a substantial impact on groundwater net recharge or storage. This means that water is scarce in the area for many months of the year, with replenishment occurring mostly during the rainy season. Groundwater recharge will be variable due to rock variance; an average recharge of 75 to 112 mm might be anticipated for the area (Tamiru 2006; WRCS 2013) discussed the recharge of groundwater systems, which is excessively variable due to Ethiopia's great variability in terms of both place and time rainfall. Rainfall in the highlands is the primary source of recharge for the huge groundwater system. The northeastern and southern plateaus, where annual rainfall is substantial, receive the most recharging. Rapid infiltration occurs in cracked volcanic sites, as well as sedimentary rocks and thick permeable soils to a lesser extent. The Ethiopian rift serves as a discharge zone, with a plethora of perennial rivers, fresh and salt lakes, as well as cold and thermal springs. In unconfined aquifers, groundwater travels from topographically high to topographically low locations recharge and discharge.

The potential energy in a recharge region decreases with depth, causing water to flow downward. Groundwater flow is largely horizontal between the recharge and discharge sites. The potential energy increases with depth in a discharge area, resulting in upward groundwater flow (Moore 2011). Rainfall is the primary source of groundwater discharge in the study region, as it is in many other parts of Ethiopia. Local recharge from streams and nearby aquifers, particularly in the highlands, is also possible. Groundwater type mixing can be seen on the rift margins and parts of the rift floor where the morphology is steeply falling due to subsequent faults. Groundwater flows from locations with a greater gradient to areas with a lower gradient, and can be thought of as local recharge from nearby aquifers. Because of differences in geology, structural connectedness, land use, and morphologic variables, recharge to the aquifers will vary locally (WRCS 2013).

Groundwater recharge is also crucial for controlling groundwater availability during droughts. Groundwater recharge happens on a yearly basis and is influenced by a variety of elements, including total annual rainfall, rainfall distribution and intensity, connectivity to streams and rivers, soil type, and land use. Besides, the rate of infiltration is a function of soil type, rock type, antecedent water, and time. Aquifers react slowly to changes in rainfall and long term average rainfall is more important in controlling recharge to aquifers than short term variations. As a result, groundwater sources can compensate for surface water shortages. General water balances is subtracting of input and output, and give as change in storage (Tamiru 2006). Groundwater recharge is defined by (Rajaveni et al. ,2015) as the percolation/ infiltration of water from an unsaturated zone to a saturated zone through the porosity and permeability of earth materials above the water table, which culminates in precipitation, infiltration/ percolation of surface water to the subsurface influenced by geology and geomorphology. The hydraulic gradient, which is calculated from hydraulic head readings in wells and piezometers, can be multiplied by the permeability of the aquifer materials to determine the quantity of groundwater discharge or flux to and from surface water bodies for a known cross section of aquifer. The ease with which water moves through aquifer materials is measured in permeability. Because the pore spaces between sand grains are greater than the pore spaces between clay particles, sand is more permeable than clay (USGS 2006). The area's groundwater is discharged through springs, streams, and borehole abstraction. The main discharging means of groundwater in the area are springs on the hillside from which most streams originate the dry season flow of rivers, and annual water abstraction for town water supply services, agricultural, and other infrastructure developments. The wells discharge predominantly the local alluvial-colluvial sediment aquifer whereas the spring discharges mostly from the volcanic aquifer at hilly locations (Metaferia 2011). Continuous increased withdrawals from a groundwater reservoir in excess of replenish able recharge, on the other hand, may cause a consistent drop in the water table. A major problem arises as a result of this circumstance, resulting in the drying of shallow wells and an increase in pumping head for deeper wells and tube wells. As a result, emphasis has been placed on the planned and optimal development of water resources. The development of water resources with planning based on the combined use of surface and groundwater will be a suitable method (Kumar 1997). It is, without a doubt, one of the most poorly understood and quantified aspects of the hydrologic cycle. It's impossible to measure directly because it's very variable in space and time, thus measurements and estimates of associated geology and hydrologic features must suffice.

Local changes in geology, structural connectedness, land use, and morphologic variables will all affect aquifer recharge. The evapotranspiration variance is higher in many places, which will have a substantial impact on groundwater net recharge or storage (WRCS 2013).

2.6. Factors Influence Groundwater Potential and Recharge

The occurrence of groundwater potential and recharge zone is affected by many different geophysical and climatic factors like geology, topography and environmental condition.

As discussed by (Waikar and Aditya 2014) groundwater identification and zonation by using GIS and RS was mainly based the analysis of terrain feature like geological structures, landform, Land use/cover, Slope, Rainfall, drainage density, lineaments density and soil which they influence the occurrence and movement of groundwater. Some of major factors influence or responsible for groundwater resource identification and locate potential site are discussed below.

2.6.1. Land use/land covers (LULC)

Different land use/land cover has certain influence on groundwater potential and recharge directly through infiltration, runoff and evaporation (Fashae et al., 2014). Land cover is the human land use activities which involves built or modifies the natural environment as vegetation or plantation and others. This is influence or minimizes evaporation and runoff and increase the rate of water enter to the sub surface soil infiltration. Hence, the vegetation cover increases the chance of groundwater recharge and can be an indication for groundwater potential. On other hand, the land cover is the physical materials that cover the land surface by settlement, road/asphalt, grass and water. In settlement and built up area infiltration is low because of land covered by pavement and building, therefore in such area low recharge are expected.

2.6.2. Geomorphology

Geomorphology is the study of earth structures and also depicts the various landforms related to the groundwater occurrence and structural features (Ramu & Vinay 2010). Groundwater resources can be evaluated using a geomorphological terrain categorization that leads to hydro morphological delineation, which takes into account both morphological and lithological characteristics. Groundwater exploration relies on geomorphology to find interesting groundwater zones. Flood plains, alluvial fans, and valley fill, which are associated with thick alluvial and worn materials to provide high porosity and permeability, are more likely groundwater potential zones; however, pediments are not generally ideal for groundwater potential zones (Brunsden 1985).

2.6.3. Slope

The slope is one of the important factor which highly controlling the infiltration and runoff capacity of precipitation and surface water flow. Where steep slopes are present, groundwater potential is low because there is more surface runoff and decrease the infiltration rate of water into the ground by allowing less residence time for precipitation. In areas characterized by flatlands and/or valleys, groundwater potential and recharge is high because it is easier for the water to enter (infiltrate) to the ground and decrease the runoff on the surface by allowing more concentration time for precipitation to percolate (Venkateswaran et al., 2016). This so indicate high slope regions have high runoff and low infiltration rate that are not suitable for groundwater recharge, because of water cannot get enough time to infiltrate to the ground and vice versa. The slope map of the area is extracted from digital elevation model (DEM) using surface-spatial analysis tools in ArcGIS.

2.6.4. Soil

Soils are the most important factors for groundwater potential and its quality. Soil texture has a valuable role in groundwater potential. Soil permeability affects the pace at which water percolates or infiltrates into the water tables. The effective porosity of the soil is directly proportional to its permeability, which is highly impacted by grain form, size, adsorbed water, saturation level, and contaminants present. Gravels and coarse sand have the highest permeability, fine sand and loamy soils have intermediate permeability, while clay and silt soils have the lowest permeability (Saunders 2001). As a result, the soil's high permeability and poor water holding capacity should have resulted in substantial groundwater percolation.

2.6.5. Drainage density

The other determinant factor controlling groundwater occurrence is drainage density. The drainage density is a metric that measures the length of a stream channel per unit area of a drainage watershed. The natural flow of water runoff to lowland/common sites is known as drainage density. It shows how surface and subsurface formations behave, as well as rock information, soil permeability, water infiltration, and surface runoff (Adem 2019).

It is calculated as the ratio of the total length of the stream network to the total area of the watershed, expressed in kilometers per square kilometer. Heavy drainage density values indicate high runoff and a low likelihood of groundwater availability; hence higher weights are assigned to the low drainage density area, and vice versa (Pinto et al., 2017).

2.6.6. Lineament density

Faults, foliations, joints, bedding planes, and a map of linear features on the earth's surface are all instances of structural discontinuities. It could be curved, straight, or slightly curved, but it is crucial for infiltration and water transfer to the earth (Morelli & Piana 2006). It is calculated as the ratio of the total length of all delineated lineaments to the total study area, expressed in km/km2. Groundwater recharge and discharge are better in places with a high lineament density, while groundwater recharge and discharge are severe in areas with a low lineament density. Because most faults or fracture systems serve as conduits for groundwater transport and storage, higher fault and lineament density can be utilized to predict secondary porosity (Yusuf 2013).

In general, the thickness of weathered rocks is greater along the lineaments hence; the lineaments are assumed to have control over the availability of groundwater.

2.6.7. Rainfall

Rainfall is one of the most important sources of groundwater, and it is recorded by a rain gauge for specific periods and expressed as the depth of precipitated water in inches. Topography, vegetation, and surface geology all affect the amount of water that gets underground, altering the link between rainfall and groundwater occurrence (Libasse 2007). In terms of varied surface conditions that affect the amount of water that percolates into the ground, regardless of surface condition, the average annual rainfall quantity of water that percolates into the ground should be considered. In general, increasing rainfall distribution increases the likelihood of groundwater potential zones forming. Zones with limited precipitation were assigned a low rating value, while zones with the most precipitation were given the highest rating value (Tolche 2021).

2.6.8. Lithology

Ground water flow, transport, and mineral composition are all dependent on the geologic formation and genetic type of the water. The nature of permeability, geological structure geomorphology, and the character of spatial heterogeneity of flow and transport parameters are all determined by the types of rocks (Lemessa 2017). Lithology plays a vital role in determining the groundwater potential of an area and it influences both the porosity and permeability of aquifer rocks for groundwater recharge. The porosity of rocks determines the storage capacity of rock formations, which means the sedimentary rocks, were considered as high potential for groundwater occurrence due to high porosity and permeability than igneous and metamorphic rocks (Saranya & Saravanan 2020). As a result, an area of rock with high permeability and porosity should be able to create a lot of groundwater. According to (Salwa 2015), GIS and remote sensing applications comprise groundwater delineation with other methods such as geospatial, numerical modeling, and geophysical methods and these methods are very expensive, laborious, time-consuming, and destructive. The investigation of remotely sensed data for drainage map, geological, geomorphological, and lineament characteristics of terrain in an integrated way was facilities effective evaluation of ground water potential zones (Arkoprovo et al., 2012). This technology is the most advanced and highly applicable in water resource development areas especially groundwater exploration.

2.7. Geological formation Characteristic

The geological history of the Omo-Gibe Basin constructed by previous workers indicates that the region is built up of >1000 meter, and perhaps as much as 2000 m, thick successions of volcanic lava flows, uncomfortably overlying scattered fluvio-lacustrine sediments and Precambrian crystalline basement rocks, as well as more widely distributed Tertiary flood basalts. Unlike conditions in northern and eastern Ethiopia, Mesozoic marine deposits have not, so far, been encountered in south-western Ethiopia including the Omo-Gibe (Basin Davidson 1983). According to (WRCS 2013) the geology of the Main Ethiopian Rift Valley contains basic to felsic volcanic, lacustrine sediments and recent to sub-recent Quaternary cover. The volcanic rock varies between Tertiary to Quaternary rocks of basalt, rhyolite, locally trachyte, trachyte basalt, and ignimbrite, tuff, with minor obsidian, nephrites, scoria, and other rocks. The sediments are lacustrine, pyroclastic or reworked volcano sedimentary sediments that vary in composition and thickness from place to place. The geologic formation in the upper soil profile has good primary and secondary porosity and permeability characteristics, which enables continuous recharge to the groundwater (Getachew 1998).

2.8. Application of RS and GIS in groundwater

2.8.1. Remote sensing and GIS in groundwater study

In addition to traditional surveys, modern technologies such as remote sensing and geographic information systems (GIS) have shown to be effective in analyzing geological, structural, and geomorphological conditions. As a result, combining the two technologies has shown to be a useful tool in groundwater research (Adem 2019). Remote sensing is an excellent tool for hydrologists and geologists in understanding the confusing problems of groundwater exploration. In recent years, Satellite remote sensing data has been widely used in locating groundwater potential zones. Satellite remote sensing data is not only cost-effective, reliable and timely but also meets the essential requirements of data in the geographical Information System (GIS). Integration of the information on the controlling parameters is best achieved through GIS which is an effective tool for storage, management and retrieval of spatial and non-spatial data as well as for integration and analysis of this information for meaningful solutions (Arkoprovo et al., 2012). GIS and remote sensing are the latest, time and cost effective technology for groundwater exploration by acquiring full information and access all parameters of factors which controls groundwater potentials and recharge zone areas by using different software easily. Groundwater potential zones are demarked with the help of remote sensing and Geographic Information System (GIS) techniques (Waikar and Aditya 2014).

2.8.2. Multi criteria decision analysis (MCDA)

Multi criteria decision analysis is a sub-discipline of operation research and a systematic procedure for combining layers of spatial data of criteria to analyze and select the best feasible option from a set of alternatives in the GIS framework. It was created in the 1960s to assist decision-makers in integrating numerous options. They analyze and support decision through formal analysis of alternative options, their attribute, evaluation criteria, goals or objectives, and constraints. Many researches have suggested that using MCDA approaches to assess structure decision problems and choose the optimum choice based on defined criteria for designating groundwater potential and recharge zone is an effective and selective tool. This research relies heavily on the Analytical Hierarchy Process (AHP) among the several MCDA methods (Malczewski 2006).

2.8.3. Analytical hierarchy process (AHP)

The Analytic Hierarchy Process (AHP), developed by Thomas Saaty in 1980, is a well-known and successful approach for dealing with complex decision-making. It can help the decision maker set priorities and make the best conclusion possible (judgment). When dimensions are independent, AHP is a knowledge-based method that is used. The AHP includes a valuable technique for assessing weightage based on its significance or interaction with groundwater storage and recharge, as well as checking the consistency of the decision maker's evaluations, decreasing decision-making bias (Malczewski 2006). The AHP helps to capture both subjective and objective components of a decision by reducing complex judgments to a series of pair wise comparisons and then synthesizing the results. According to the decision maker's pairwise comparisons of the criteria, the AHP creates a weight for each assessment criterion.

Hence, AHP allows for calculation of Consistency index (CI) and Consistency Ratios (CR) such that if the CR is less than or equal 0.1 (10%) then the inconsistency is acceptable otherwise reevaluated again.

3. MATERIAL AND METHODS

3.1. Description of the study area

3.1.1. Geographical location

Dawuro Zone is one of the 6 zones of the region and its center, Tarcha town is located about 240 km from Bonga town, Regional center of Southwest Ethiopia peoples.

The study area lies in five Woredas which are found in Dawuro zone viz. Mareqa woreda and Marimensa woreda in the South, Tocha woreda in the South west, Tarchazuria woreda in the west and Genebossa woreda in the east. The watershed lies within 7º2’0”to 7º15’0” North and 37º0’0” to 37º30’0” East. The total catchment area of the watershed is about 575.63 square kilometers and the topography of the watershed lies within 949-3011above mean sea level.

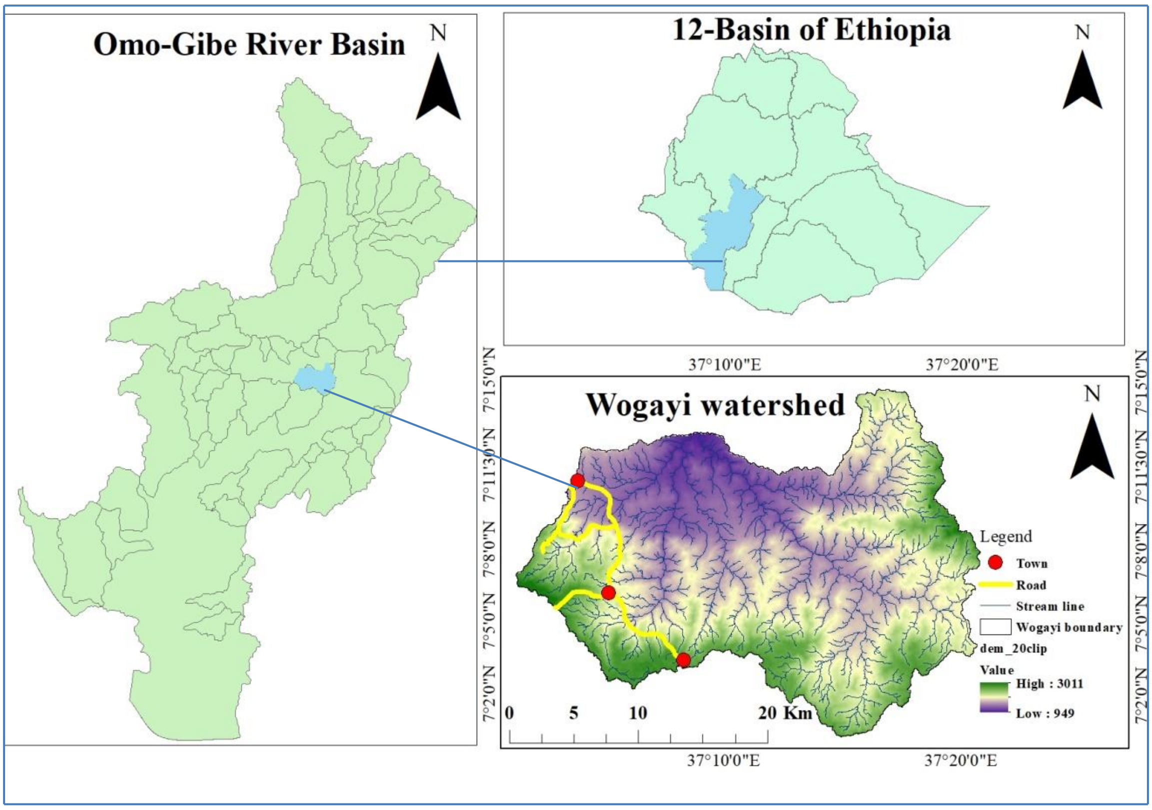

Figure 3.1: Location map of the study area.

3.1.2. Climate

In Ethiopia, the climate condition is highly influenced by altitude and an area having the highest altitude has the highest precipitation and vise-versa due to the orographic nature of the rainfall. The annual climate of the area is divided into rainy, minor rainy and dry seasons. In the area, a main rainy season is summer (kiremt), which is from the beginning of July to September, and above 70% of rain has occurred. The little rainy season (belg), is a small rain amount accounting for 20-30% of the annual amount and stays from March to June. Dry period (bega), which extends between October and February, occasional rains during this period bring 10-20% of the yearly average (Degefie 2007).

3.1.2.1. Rainfall characteristic of the study area

The meteorological parameters such as rainfall and temperature in the study area are practically governed by the climatic condition of the respected area and also by Inter Tropical Convergence Zone (ITCZ).

Table 3.1: Classification of climate zone based on Altitude and Temperature presented by (Ethiopian mapping Agency 1981) in the National Atlas of Ethiopia, p14.

No	Altitude (m.a.s.l)	Temperature (oc)	Climate Zone
1	Below 50	30-40	Desert (Bereha)
2	500-1500	About 30	Tropical (Kolla)
3	1500-2300	15-20	Sub-Tropical (WeinaDega)
4	2300 -3300	10-15	Temperate (Dega)
5	3300 & above	10 or Less	Alpine (Kur)

According to the above classification the study area is under climatic zones of Sub Tropical (WeinaDega).

The mean annual precipitation of the area calculated using arithmetic mean method from monthly long-term rainfall record of five stations (1999-2020), namely Chida, Tarcha, Gennabossa, Gessachere and Tocha obtained from National Meteorology Agency of Ethiopia (NMAE) amounts to 1837.09 mm.

Table 3.2: Selected meteorological stations in study area from 1999-2020 years

5-Wise meteorological Gauging Station					
S.No	Gauge station name	Elevation (m)	Latitude N (Decimal Degree)	Longitude E (Decimal Degree)	Annual RF(mm)
1	Tarcha	1335	6.58	37.2	1410.44
2	Chida	1659	7.1	36.47	1444.86
3	Gessachere	2251	7.05	37.54	1489.94
4	Genabossa	1741	7.15	37.2	1802.33
5	Tocha	2140	7.05	36.98	3037.88
Mean annual precipitation					1837.09

(Source: NMAE, 2022)

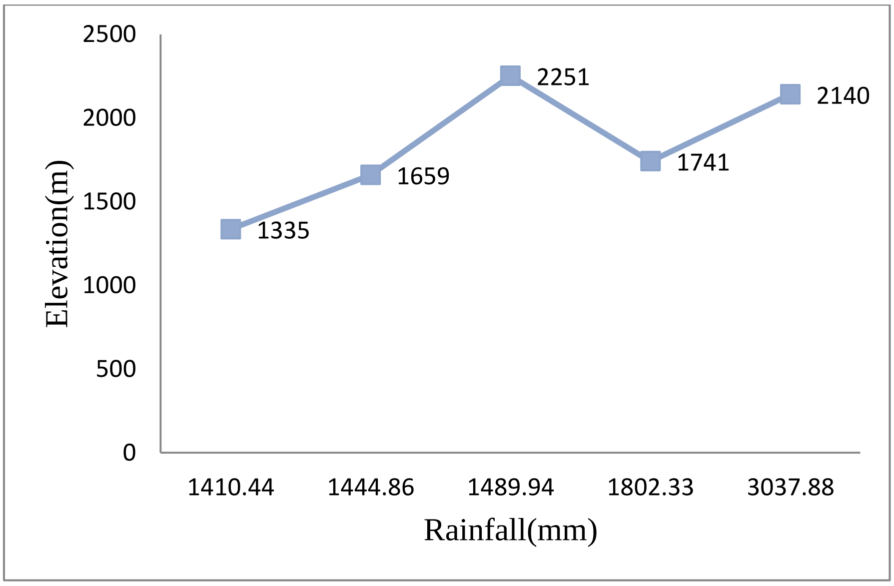

Figure 3.2 : Correlation of Rainfall with Elevation

3.1.2.2. Temperature Characteristic of the study area

According to the (National Atlas of Ethiopia 1981), the climatic conditions of the country are more influenced by their altitude and are classified into the following zones:

- “Kur” or Cool; 3300m a.s.l and above (annual mean temp. of <10oC).
- “Dega” or Temperate; 2300 – 3300m a.s.l (annual mean temp. of 10 to 15oC).
- “WeinaDega” Moderately Temperate; 1500–2300m a.s.l (15 to 20oC).

- “Kola” or Hot; <1500m.a.s.l. (annual mean temp. of >15oC).

The lowest and highest elevations recorded in the study area vary between 1139m and 2625m. According to the prevailing topographic setup the project area generally falls under “WeinaDega”. The effective mean annual temperature of “WeinaDega” climatic zone is in the order of $15^{o}C$ - 20 ^{o}C are characterized by moderate cold and hot weather condition.

3.2. Data Collection and Analysis

In order to achieve the objective of this study and to complete this research work the following materials were used: Computer (Laptop): To Run all software and process the data inside because all work is started and completed in computer after appropriate data was collected by hardware and software. Handheld GPS receiver (Garmin 78): In order to taking geographical coordinate (latitude, longitude, and altitude) and to check (verify) the accuracy of sample point such as water source inventory point and land use/cover in the study area. Hardware and Software: Hardware like external hard disk (1 TB storage disk) and software like GIS (ArcGIS 10.8), ERDAS 14, SURFER 20. Published and Unpublished literature and Maps: Such as Topographic map, geological map, etc. as a reference.

3.3. Data Description and Source

Different types of Primary and Secondary data on hydrological, geological and conventional exist were identified as parameter factor were collected and used for this study in the process of mapping and analysis. In order to map and process the analysis various software were also used. The types of data and software used in this study are mentioned and described in the Table 3.3 and 3.4.

Table 3.3: Types of data used and their source

No	Data used	Source	Purpose
1	Meteorological Data	National Meteorological Agency of Ethiopia	To create rainfall map
2	Soil data(1:1000,000)	Ministry of Agriculture	To create soil type and texture map
3	Satellite data	htt://earthexplorer.usgs.gov /or from EMA	To create land use/cove map
4	Geological data	Ethiopia Geological Survey	To create lithological

	(1:250,000)		map
5	Digital-Elevation Model (20m×20m) resolution	Geospatial information Institute (former name: Ethiopia Mapping Agency)	To create drainage density, slope and Lineament density map
6	Ground truth (water source inventory) data	Dawuro zone water, mines and energy department	To validate the groundwater potential zone of the study area
7	Geomorphological data (1:1000,000)	Ministry of Agriculture	To create geomorphology map of the study area

Table 3.4: Types of software used and their purpose

No	Software Used	Purpose
1	ArcGIS 10.8	To create the thematic map of parameter affect groundwater occurrence and delineate the groundwater potential and recharge zone map of the study area
2	ERDAS 14	By layer stacking, mosaic and classifying land use land cover
3	Surfer 20	For generation groundwater contour map and flow direction and also used for 3-D visualization of groundwater flow or the land surface
4	Google Earth 7.2	For verification of ground

3.3.1. Study area delineation

The Preparations of boundary shape for the study area was the first stage. The study area shape was prepared through different stages in the ArcGIS platform from SRTM-DEM data of 20mx20m resolution. In this process, the SRTM-DEM was imported to Arc map, and the area was delineated use a spatial analysis tool. The hydrology tools in the spatial analysis tool take place to delineate watershed through the following steps: - Project DEM to fill to flow direction to flow accumulation to the basin to polygon and finally, Wogayi watershed was extracted.

3.3.2. Thematic map preparation

After the delineation and identification of the boundary shape of the study area, the preparation of different thematic maps for each factor that influences the occurrence of groundwater potential would be carried out from collected data in the Arc map. These maps were firstly projected into the WGS_1984_ UTM zone_ 37N in the ArcGIS platform and different thematic maps were prepared and reclassified using a spatial analysis tool. The method of thematic map preparation for each parameter was described in detail as follows.

3.3.2.1. Rainfall map

The twenty two-year daily rainfall data were obtained from five meteorological stations namely Tarcha, Chida, Genabossa, Tocha and Gessachare which were located in and around the study area. The missed rainfall data was filled before analysis because the precipitation data was consistent, the total study area's rainfall distribution was analyzed using the mean arithmetic approach due to the rain gauge stations utilized in the area were very close to on other and had similar topography. Then, the average annual rainfall data was prepared and the Inverse Distance Weighting (IDW) interpolation method in ArcGIS spatial analysis tool was used to prepare a spatial rainfall map by converting the point rainfall to areal rainfall in the watershed. Finally, the rainfall map for evaluation of groundwater potential zone was prepared from long-term annual average rainfall data using spatial analysis tool by IDW interpolation.

3.3.2.2. Drainage density map

Shutter Radar Topography Mission of Digital Elevation Model (SRTM-DEM) from remote sensing data was used derived the slope and drainage density maps of the study area. The 20m x 20m resolution of the DEM geo tiff file was data obtained Geospatial information Institute (Ethiopia Mapping Agency). Then, this file was imported into Arc map and projected to WGS_1984_ UTM zone_ 37N. The development of drainage density involves filling sinks, flow direction, flow accumulation, and stream network extraction. Finally, a drainage density map was produced and calculated using a line density analysis tool through dividing the total length of the stream channel in watershed to total area of the watershed and reclassified using spatial analysis tools.

3.3.2.3. Slope map

A slope map of the area was prepared from DEM with 20mx20m spatial resolution. The projected DEM data was used as an input for slope extraction in the Arc Map of ArcGIS spatial analysis tool. Finally, a slope map of the study area was prepared for study using the surface tool in the spatial analysis tools and reclassified using the reclassify tool in spatial analysis tools based on their importance.

3.3.2.4. Geomorphology map

Geomorphology map was prepared from of land feature (Geomorphic) map of Ethiopia at 20m resolution taken from Ministry of Agriculture and clipped to the study area by shape file of watershed by using clip option found in reprocessing in ArcGIS. The clipped geomorphology map was in polygon format (vector format) which needs to convert to raster. The clipped feature geomorphology map was converted to raster by using polygon to raster window by selecting from conversion tools. The raster geomorphology map was reclassified by using reclass command in spatial analysis tools.

3.3.2.5. LULC map

Land use/cover of Wogayi watershed was generated from mosaic Landsat image (SPOT 5) obtained from Geospatial Information Institute (Former name Ethiopia Mapping agency (EMA)) acquired in 2021 through for supervised classifications. Land use land cover map was prepared using satellite land image (SPOT 5) converted from Raster data type Landsat image.

3.3.2.6. Lineament density map

Lineament map of the study area was also prepared from DEM data in a 20m resolution. This data was imported to ArcGIS software platform and line extraction of the area was done use algorithm tools in the software. Then, import the automatic line extract shape file into Arc map platform. Because the generated lineament was made up of several lines, it was splitting into single lines use the splitting command in ArcGIS. The result lineament raster was called a lineament map, and it was used to generate lineament density which was calculated by the ratio of total length of all the lineaments demarcated to total study area. Finally, the Lineament density map of the study area was prepared used the line density tool and reclassified using the spatial analysis tool.

3.3.2.7. Soil map

The convectional data was used to prepare the soil map of the study area. Soil data of the Omo-Gibe River basin was obtained from Minster of Agriculture. This data was imported into Arc map and project to WGS_1984_ UTM zone_ 37N. After projection, the soil map of the study area was clipped from the Omo-Gibe River basin. The description and classification of the soil physical properties were done based on the FAO guidelines. The study area is composed of five soil types (Figure 3.8): eutric cambisols, dystric fluvisols, dystric gleysols, eutric nitisols, and orithic acrisols. Finally, the soil types were papered using the ArcGIS platform.

3.3.2.8. Geologic map

Geologic map of the study area was prepared by digitizing and clipped from the geological map of jimma taken from Geological Survey of Ethiopia. This data was imported into Arc map and project to WGS_1984_ UTM zone_ 37N. The clipped lithology map was in polygon format, the clipped feature was converted to raster by using polygon to raster window by selecting from conversion tools. The raster lithology map was reclassified by using reclass command in spatial analysis tools in ArcGIS.

3.4. Method of data analysis

After the collection of relevant data for groundwater potential assessment, the successful analysis of information in the spatially and temporally is significantly required to identify the suitable zone. These suitability zones were prepared and identified based on the influence of different factors and integrating of them. Before the integration of data sets, the class weights and map scores were assessed based on AHP and analyzed through pair-wise comparison of the significance matrixes.

3.4.1. Estimating and filling of rainfall missing data

Following the identification of significant factors that influence groundwater potential, the missing data of the rainfall factor was filled. The missing rainfall data of stations that occur at a specific rain gauge station for a specific period due to the absence of an observer or instrumental error were calculated using data from surrounding stations. Inverse Distance Weighting (IDW) was chosen as the method to fill in missing rainfall data because it has the potential to estimate missing rainfall values with the 10% above of error to compare with other methods. In particular, it assumes that each measured point has a local influence that reduces with distance, and that weights change in proportion to the linear distance between the samples and the un-sampled point (Lixin & Revesz 2004). The weights are unaffected by the spatial arrangement of the samples, and the weighting function is the inverse of the distance to the specified exponent, therefore the projected value for a site is given by:

$$PX = \sum_{i=1}^{N} pi * wj \; ; wi = \frac{\frac{1}{di^{\wedge}2}}{\sum_{i=1}^{N}\left(\frac{1}{d}\right)^{\wedge}2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where: PX denotes missed rainfall data at station X; Pi denotes rainfall of surrounding station; N denotes the number of nearest known points surrounding (x, y); Wi denotes the weight assigned to each known point value Wi at location (xi, yi); di denotes the Euclidean distance between each (xi, yi) and (x, y) (Lixin & Revesz 2004).

To generate a rainfall map, the rainfall gauges measure point data at each station in the research area, which should be converted to averaged aerial rainfall using the interpolation method. Because rainfall measurement is a single-point observation, it cannot be utilized as a representative value for the entire area. As a result, the representative aerial depth of rainfall over the entire area is analyzed utilizing varied rainfall depth of different stations identified in the study location. For uniformly dispersed gauges and closely and evenly spaced gauging stations, the arithmetic mean method is the easiest and most reliable way to determine average rainfall. The following Equation can be used to compute it.

$$P_A = \frac{\sum_{i=1}^{n} P}{N} = \frac{P1+P2+\cdots+Pn}{N} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where, PX: missed rainfall data at station X; P1, P2, and Pn rainfall at station 1, 2, and n; n: total number of rainfall station watershed. According to this method the average annual RF depth in the watershed 1837.1mm (Table 3.5).

Table 3.5: Average areal rainfall depth of the study area by arithmetic mean method

Gauge station name	Elevation (m)	Longitude(DD)	Latitude (DD)	Mean Annual Rainfall (mm)
Tarcha	1335	37.2	6.58	1410.44
Chida	1659	36.47	7.1	1444.86
Gessachere	2251	37.54	7.05	1489.94
Genabossa	1741	37.2	7.15	1802.33
Tocha	2140	36.98	7.05	3037.88
Average annual rainfall				1837.1

3.4.2. AHP techniques and weight assignments

After the preparation of all the different thematic maps, the multi-criteria decision analysis (MCDA) method was applied to enables us to assign the criteria weights to produce the potential groundwater. 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). According to Saaty's, for a good decision there must be $CR \leq 0.1$. Here CR shows that the assigning weights for each factor were consistency and the relative weight were appropriate and acceptable for decision making. However, if $CR > 0.1$ there is an indicator of error when assigning ranks to the criteria/factors. Due to this, it should reevaluate the assigning relative importance of the factors or the assessment of CR should be revised the pairwise weight.

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 9are given for those factors having an "extreme importance" over another factor.

WEIGHT - AHP weight derivation								
Pairwise comparison 9 Point Continuous Rating Scale								
1⁄9	1⁄7	1⁄5	1⁄3	1	3	5	7	9
Extreme	Very Strong	Strong	Moderate	Equal	Moderate	Strong	Very Strong	Extreme

Less Important	Equal Important	More Important

Table 3.6: Ratings on Satty's 9 – point continues scale

Note: 2, 4, 6 and 8 - are intermediate values denoting compromise.

: Reciprocal no (1/9, 1/7, 1/5 and 1/3) - indicate Values for inverse comparison.

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

3.5. Mapping of ground water flow direction

Because ground water is typically hidden from physical observation, many people struggle to visualize its occurrence and movement. This difficulty hinders their ability to comprehend and effectively address groundwater-related issues. Ground equipotential lines and flow directions or lines can help address the problem to some extent (Zelalem 2009). The significance in advance of groundwater flow direction was analyzed used Arc GIS 10.8 and Surfer 20program.

Surfer was developed as the industry standard contour mapping software used by geologists, hydrologists and engineers to rapidly and easily change XYZ data into clear surface, contour, wireframe, image, shaded relief and vector maps. Three D (3D) maps generated with Surfer are known for their clarity, color and accuracy (ECUC 2001).

The most common application of Surfer is to generate a contour map or surface plot from an XYZ data file. The Data command from the Grid menu uses an XYZ data file to produce a grid. To determine the flow direction of groundwater in the study area, a contour map of the watershed was generated using 52 XYZ data of boreholes, and hand dug wells XYZ data of the well are given in (Appendix 1).

3.6. Groundwater recharges and discharge area identification

For appropriate land-use planning and management methods, an analysis of the groundwater flow system connecting recharge and discharge areas is essential. This information can be obtained through a variety of methods, including hydrological mapping, vegetation mapping, and groundwater flow modeling (Batelaan et al., 2003).

The recharge and discharging zone of the watershed was identified with the help of Surfer 20 program, Geographic Information system (GIS) and integration of thematic map of the catchment. The groundwater recharge and discharge zones of the study area was developed by using the weighted overlay analysis (WOA) of the eight reclassified of thematic layers (lithology, geomorphology, slope, lineament density, LULC, rainfall, drainage density and soil) with their percentage of influence in ArcGIS. GIS and RS technologies were used for the analysis and integrate surface feature of factor influence that are used to indicate groundwater recharge and discharge zone. In order to delineate the groundwater and recharge for this study area all thematic maps were reclassified and changed into raster format and superimposed by weighted overlay method.

The water table contour map was done used Surfer 20 program. Based on the groundwater flow direction in a contour map, the convergence and divergence zone of the watershed was identified.

A water table contour map was used to categorize groundwater recharge and discharge areas. The flow line on a flow net tends to diverge from recharge areas and converges towards to discharge areas. High land areas are an indicator of recharge areas, and topography is a major factor to consider when delineating the recharge and discharge zones. In general, the divergence and convergence of vector flow lines are indicators of the recharge and discharge areas. Groundwater recharge and discharge regions were also located using a water-table contour map (Fetter 2001).

3.7. Characterize the geological formation

Geological formation of the study area was analyzed by using the secondary data of borehole lithological log data (geological description). Borehole lithological units were taken from the well completion reports, which was to characterize geological formation (Appendix 2).

A borehole geological log is constructed from sampling and inspection of well cuttings collected at frequent intervals during drilling the well or test holes. Such logs provided a picture of the geological character and thickness of each stratum encountered as a function of depth thereby allowing aquifers to be defined.

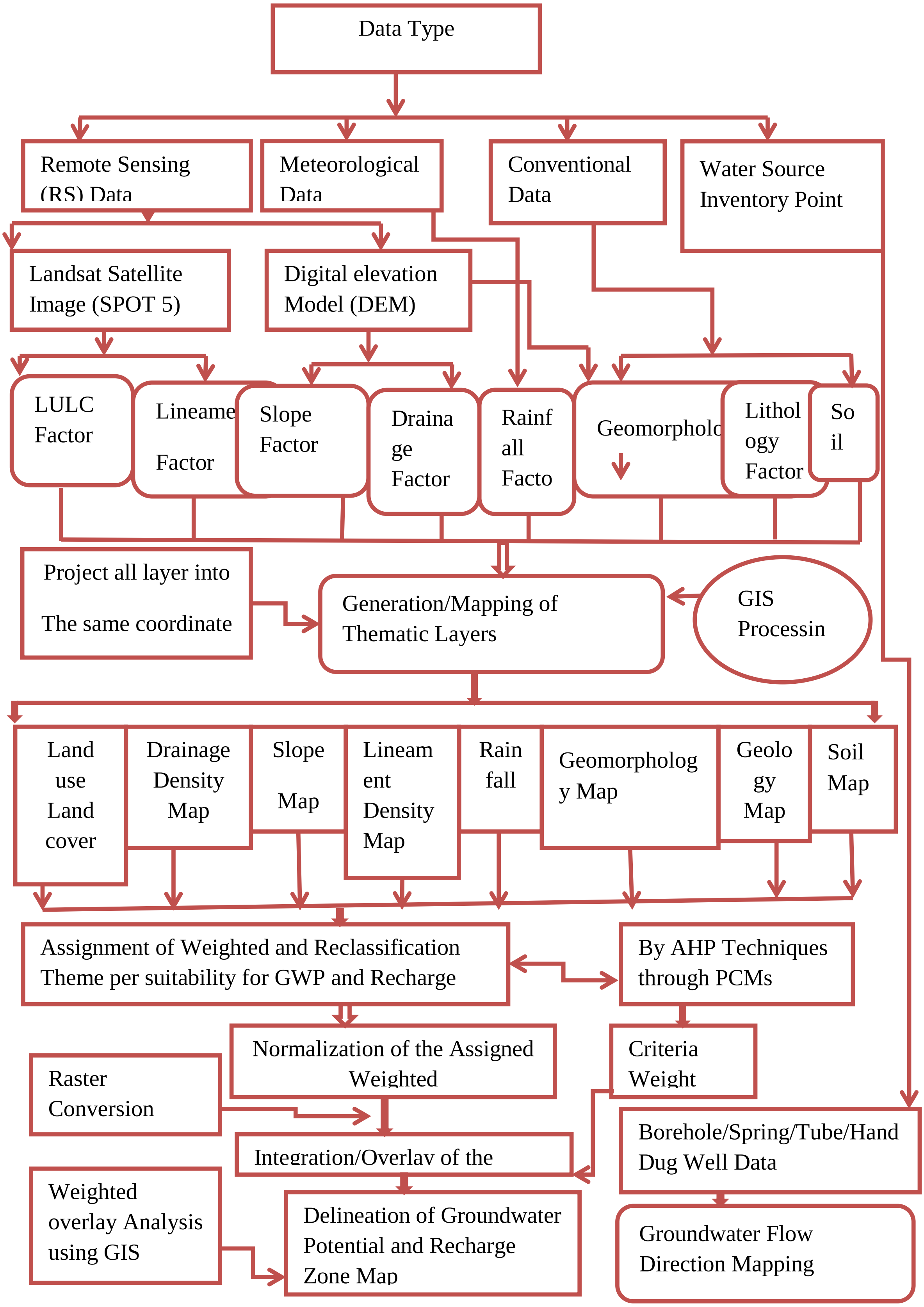

Figure 3.3: Conceptual framework of the general methodology was used for the study

4. RESULTS AND DISCUSSIONS

These chapters describe the results of the application of GIS and remote sensing methods in mapping groundwater potential and recharge zones in Wogayi Watershed area. The result of AHP process used to assign weights for each factor considered to be influence GWP occurrence were discussed. Suitability class and reclassified thematic maps produced for each factor were also discussed her. Finally, Weighted overlay analysis carried out to map groundwater potential and recharge zone and validation of the final result that reveal the capability of GIS and RS in delineation of GWP and recharge zone was done.

4.1. Characterization of factors affecting groundwater potential

Table 4.1: presents the paired comparison matrix to assess the relative importance of the different factors. The higher the weights are the more its relative importance among other factors towards telling the groundwater potential.

Factors	RF	Geol.	Geom.	Slope	DD	LD	LULC	Soil	Weight	Weight (%)
RF	1	3	3	3	4	4	5	5	0.309	31
Geol.	0.333	1	3	3	3	3	3	3	0.199	20
Geom.	0.333	0.333	1	1	1	3	3	3	0.112	11
Slope	0.333	0.333	1	1	1	3	5	3	0.122	12
DD	0.25	0.333	1	1	1	3	3	3	0.108	11
LD	0.25	0.333	0.333	0.333	0.333	1	3	3	0.07	7
LULC	0.2	0.333	0.333	0.2	0.333	0.333	1	1	0.039	4
Soil	0.2	0.333	0.333	0.333	0.333	0.333	1	1	0.041	4

Weights of parameters determined using Analytical hierarchy process (AHP) Appendix 3. The result of the CR in this study is 0.0566 which is accepted based on previous work of Analytical Hierarchy Process. 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 includes a valuable technique for assessing weightage based on its significance or interaction with groundwater storage and recharge, as well as checking the consistency of the decision maker's evaluations, decreasing decision-making bias (Malczewski 2006).

4.2. Analysis of different input thematic layers for groundwater potential

The selection of indicators influencing groundwater potential mainly depends on the objective of the study and their relative importance was taken from previous literature. For the analysis of the potential groundwater zone, a total of eight parameters were considered for the study, such as lineaments density, lithology, soil, slope, drainage density, geomorphology, land use/land cover, and rainfall. The classification, weight assignment, and suitability level of each thematic map were agreed upon and in the acceptable condition with other related studies such as (Adem 2019; Lemessa 2017; Libasse 2007; Tolche 2021; Yusuf 2013). Thus, the analysis of the eight different thematic layers for each groundwater influencing factor in detail was presented as follows.

4.2.1. Lineament density

The result shows that a very high lineament density was observed in the near center to the upper part of the area with values ranging from 1.04 to 1.58 km/km^2 having good groundwater potential whereas areas with very low (0 to 0.172) have poor groundwater potential which was mainly observed at southern, west southern and north eastern (Table 4.2 and Figure 4.2). The intermediate values were classified as highly suitable (0.738 to 0.1.04), moderately suitable (0.474 to 0738), and poorly suitable, which ranged the values between 0.172 to 0.474 km/km^2.

Table 4.2: The assigned weights and classes for lineament density

Factor	Lineament density Km/km^2	Description	Area (Km^2)	Area (%)	Suitability classification	Rank
Lineament Density	(0-0.172)	very low density	289.04	50.5	Very Low	1
	(0,172-0.474)	Low density	70.62	12.3	Low	2
	(0.474-0.738)	Medium density	82.75	14.4	Medium	3
	(0.738-1.04)	High density	121.14	21.2	High	4
	(1.04-1.58)	Very high density	9.18	1.6	Very High	5

It is expected that the thickness of weathered rocks is greater along the lineaments. Hence, they are assumed to enhance the availability of groundwater. The higher groundwater potential was estimated in an area where there is a high thickness of lineament. The direction of the lineament of the study area is towards the direction of the tributaries, which suggests that the direction of the aquifers mostly tends to be aligned with the surface water (Figure 4.1). Generally, about 50.5% of an area was very poor, 12.3% of the area was poor, 14.4% of the area was moderate, 21.2% of the area was highly suitable and only1.6 % of the area was excellent for groundwater potential occurrences based on the influence of lineament density factor in the study area. Lineaments are the simple and complex linear properties of geological structures such as faults, cleavages, fractures, and the various surface of discontinuities (terraces and ridges) arranged in a straight line or a curved that are identified by remote sensing (Agumase et al., 2019).

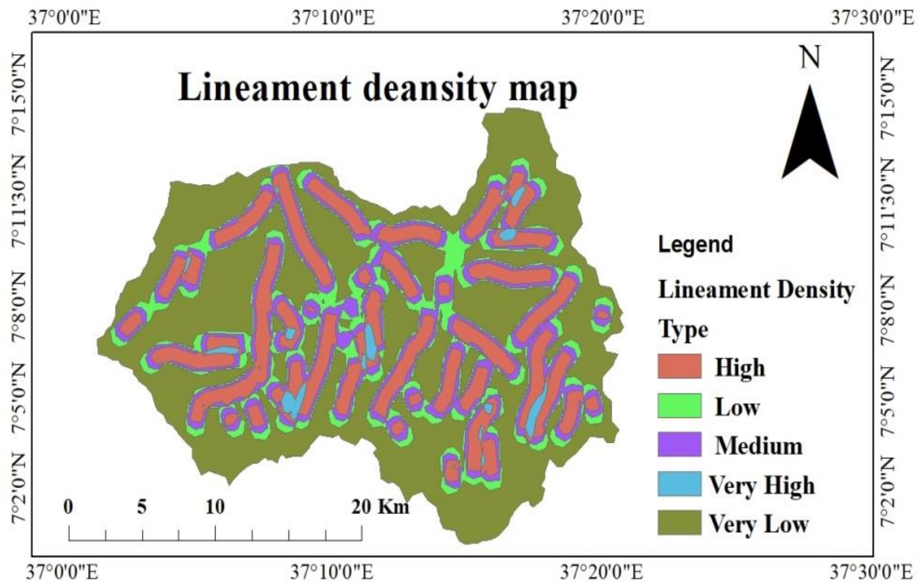

Figure 4.1: Lineament density map

4.2.2. Drainage density

The results showed that, high drainage density was found at the western, north western and eastern, north eastern part of the watershed around the mountains area which results less groundwater potential. An area that has a curved ridge or steep slope causes the larger runoff rather than the infiltration of water to the ground system. Due to this the areas with lower class (0 to 0.87 km/km^2) have highly suitable while the higher class (2.41 to 3.58 km/km^2) has very less suitable for the occurrence of groundwater potential and further their details with rates are presented in Table 4.3.

Table 4.3: The assigned weights and classes for drainage density

Factor	Drainage density (km/km$^{2)}$	Description	Area (Km^2)	Area (%)	Suitability classification	Rank
Drainage Density	(0-0.87)	Very low density	92.56	16.18	Very high	5
	(0.87-1.38)	Low density	139.44	24.37	High	4
	(1.38-1.88)	Moderate density	140.99	24.64	Moderate	3
	(1.88-2.41)	High density	130.85	22.87	Low	2
	(2.41-3.58)	Very high density	68.4	11.95	Very low	1

As shown in Table 4.3, the structural drainage network was employed to explain the characteristics of the groundwater potential zone. In the present study, the higher drainage density was seen in the southern, north western and eastern, north eastern area around the mountains area and assigned with a very low rank of suitability for groundwater potential occurrence and vice versa (Figure 4.2), and the classification are agreed with these findings. Around the16.18% of an area covered was an excellent, 24.37% of the area was highly suitable, 24.64% of the area was moderate, and 22.87% of the area was poor and only 11.95% of an area was very poor based on the influence of drainage density factor on the occurrence of groundwater potential. An area where high drainage density values have high runoff and indicate a low possibility of groundwater availability and hence higher weighs are assigning to the lower drainage density area and vice versa (Dar et al., 2020; Tolche 2021).

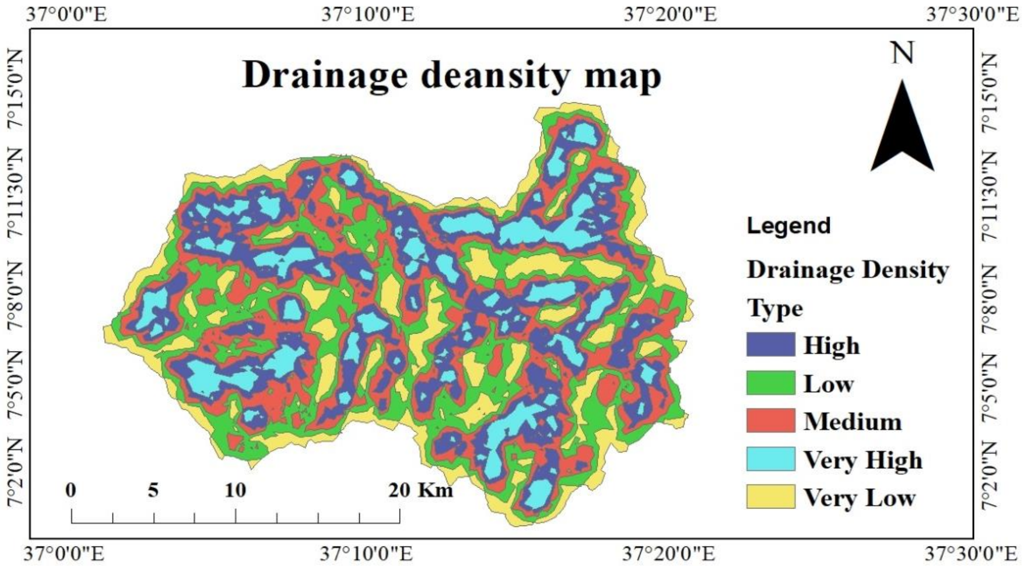

Figure 4.2: Drainage density map

4.2.3. Land use land cover

The land use land cover pattern of the study area was categorized into crop land, forest land, water body, shrub land and bare soil. Crop land was mostly dominated at central to western, northwestern and southeastern part of the region, forest land was mostly dominated at south, southwestern and northeastern part, water body was found in central, north and northeastern, southwestern and west part of the study region, open shrub land was found in southwestern and north and bare soil was found in central, west and north and northeastern part of the region (Figure 4.3). Different types of LULC have a different rate of groundwater occurrence due to different rate of infiltration capacity. Considering this, LULC of the study area was reclassified based the suitability rank as shown on Table 4.3. Lower rank (2) was given for bare soil areas because it cause high runoff and low infiltration which result in low groundwater potential and recharge zone whereas higher rank (5) was given for wetland and water bodies because it cause high recharge may exist over a long period of time due to low runoff and high infiltration which result in very high groundwater potential and recharge zone (Figure 4.3). The reclassified LULC map result on Figure 4.3 showed that highest area of coverage (67.90%) of the total study area is highly suitable for identification of groundwater potential zones.

Table 4.4: The assigned weights and classes for LULC

Factor	LULC Types	Area (Km^2)	Area (%)	Suitability classification	Rank
LULC	Water body/Wet land	14.3	2.49	Very high	5
	Rock out crop/Annual crop/ Perennial crop	390.5	67.90	High	4
	Spares forest/Moderate forest/Dens forest/ Wood land	169.6	29.49	Moderate	3
	Open shrub land	0.7	0.12	Low	2
	Bare land	0.001	0.0002	Very low	1

Even an area is covered by vegetation and trees for the forest land and other land; the given rate was less than that of agricultural land because they are located in and around high slope areas such that it made the higher runoff and the less infiltration rate on the area. The ability of dense forest areas and agricultural land to recharge and hold groundwater is high, whereas exposed bare rock and built-up areas are least favorable for infiltration and recharging groundwater (Dar et al., 2020). Land use land cover describes the surface of the earth cover. The land cover is the natural layer which includes features like water bodies, vegetation, mountain, and bare soil while land use is the modified natural environment by human operation and comprising parameters like croplands, industry, plantations, built-up lands, and so on. Information on soil moisture, permeability, percolation, and amount of runoff is decided based on the land use type of the study. Therefore, land use/ cover influences either directly or indirectly or/and have a positive or negative impact on groundwater recharge. Trees may increase water loss by evapotranspiration or they may facilitate recharge by reducing runoff and by intercepting water and infiltrating its droplet slowly (Murthy 2000). For the issue being talked about, regardless of whether evapotranspiration and interception are accepted consistent and just constructive outcomes of vegetation are considered given a large portion of the vegetation's are involved in the ledge region and sloppy. From a water asset perspective, it has high runoff and a low likelihood to penetrate subsurface except especially along with the geographical constructions (Yusuf 2013). In this way, vegetation covers are given as least position and agricultural terrains have the most noteworthy position for this study when compared them to each other.

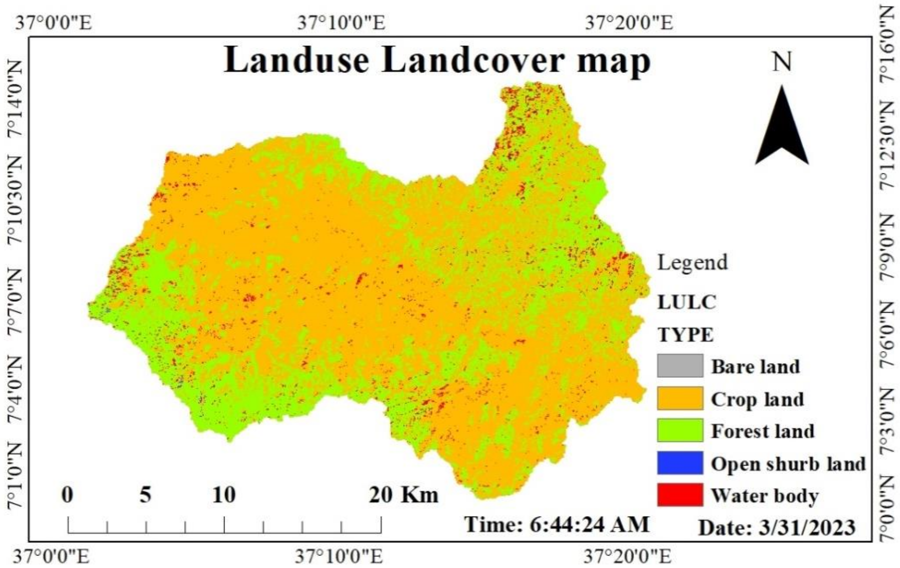

Figure 4.3: LULC Map

4.2.4. Slope

The results showed that, the highest rank was given to flat slope (0 to 2%) because it holds water to infiltrate into the ground whereas the lowest rank was assigned for very steep slope (> 30 %) because they result in high runoff and low infiltration which cause low groundwater recharge. The nearly flat slope was mainly found in north western area and steep slope was located around mountains and main stream drainage area of the study region. Further, the class, rate, and rank are given for each slope class based on the groundwater perspective is summarized in Table 4.5.

Table 4.5: The assigned weights and classes for the slope gradient

Factor	Slope (%)	Description	Area (Km^2)	Area (%)	Suitability classification	Rank
Slope	0-2	Flat to gentle	161.7	28.4	Very High	5
	2-8	Gentle to high slope	179.7	31.5	High	4
	8-15	High to hill slope	129.3	22.7	Medium	3
	15-30	Steep	71.4	12.5	Low	2

	>30	Very Steep	27.7	4.9	Very Low	1

Based on their influences, the remaining classes were taken as high (2%-8%), moderate (8%-15%) and low (15%-30%) suitability for groundwater potential which covers an area of 31.5%, 22.7% and 12.5% from the total area respectively. This indicates that a major portion of the area was highly suitable and around 17% of the area was poor and very poor suitable for the occurrence groundwater potential based on the slope factor influence. The slope is an important factor for the identification of groundwater potential zones in any region. The gentile slope zones have moderate surface runoff which permits more opportunity for water to penetrate the ground while zones with steep slopes work with high runoff along these lines allowing less time for water and thus sensibly less infiltration. The nearly flat slope has been an excellent category for groundwater potential because flat terrain is appropriate for more infiltration and recharge, and the steep slope area was categorized as poor groundwater potential (Siva et al., 2017).

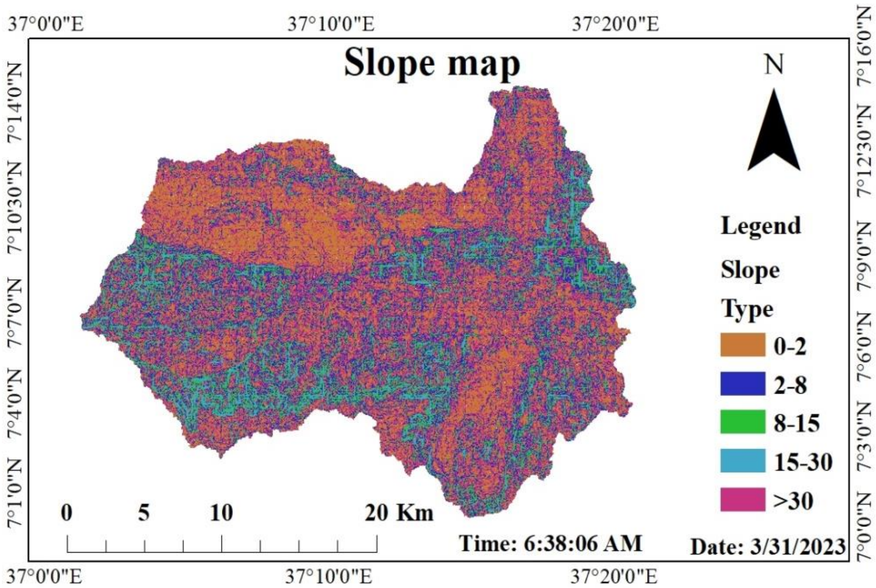

Figure 4.4: Slope Map

4.2.5. Geomorphology

The results showed that a summit landform is the surface form that rises prominently above its surroundings and generally has a steep slope, located at the south, south western and east, north eastern part of the study. The reverse is true for bottom land for this study because the main drainage (high gorge) area was considered as a bottom that was found at north to west and north to east edge of the watershed. Flat is a relatively plain area of earth surface exhibiting gentle slope and small local relief which covers the largest area of the watershed (Figure 4.5) Whereas, the slope is usually rounded natural elevation of land which have much less steep and lower than a summit form, and have also lower in altitude.

Table 4.6: The assigned weights and classes for Landform

Factor	Geomorphic type	Area (Km^2)	Area (%)	Suitability classification	Rank
Geomorphology	Flat	252.27	44.0	High	4
	Bottom	30.50	5.3	Moderate	3
	Slope	248.23	43.3	Low	2
	Summit	42.09	7.3	Very Low	1

The given rating values of geomorphological classes varied in terms of characteristics and spatial distribution for groundwater potential. For this study, the flat area was more promising for groundwater potential due to the large recharge rate occurs at the plain slope and given the high weightage than others. And the gorge shape of the main drainage stream area was considered as bottom for the study and has enabled to produce the moderate rate of groundwater potential whereas slope and summit areas produce low and very low respectively which results in the poor potential for groundwater perspective due to less infiltration rate. About 44% of the area was highly suitable, 5.3% of the area was moderate 43.3% of the area was poor and 7.3% of the area was very poor based on the area coverage of landform factor which influences groundwater potential (Table 4.6). (Hussein et al., 2017) reported that groundwater occurrence is more influenced by alluvial plains and plateaus which promote high potential while groundwater control is highly influenced by mountainous and residual hills locations which result in low groundwater potential. From the geomorphologic study point of view, identification and investigation of various landforms and structural features in the study region are very important. Landform simply describes the shape and topography of the region and plays a vital role in groundwater availability and distribution. Integrating geomorphological background with hydrological characteristics of an area provides a simple way to understand the groundwater behavior Siva et al. (2017). The volcanic terrain of Ethiopia comes in a variety of landforms that is of significant importance to groundwater occurrence and movement (Kebede 2013).

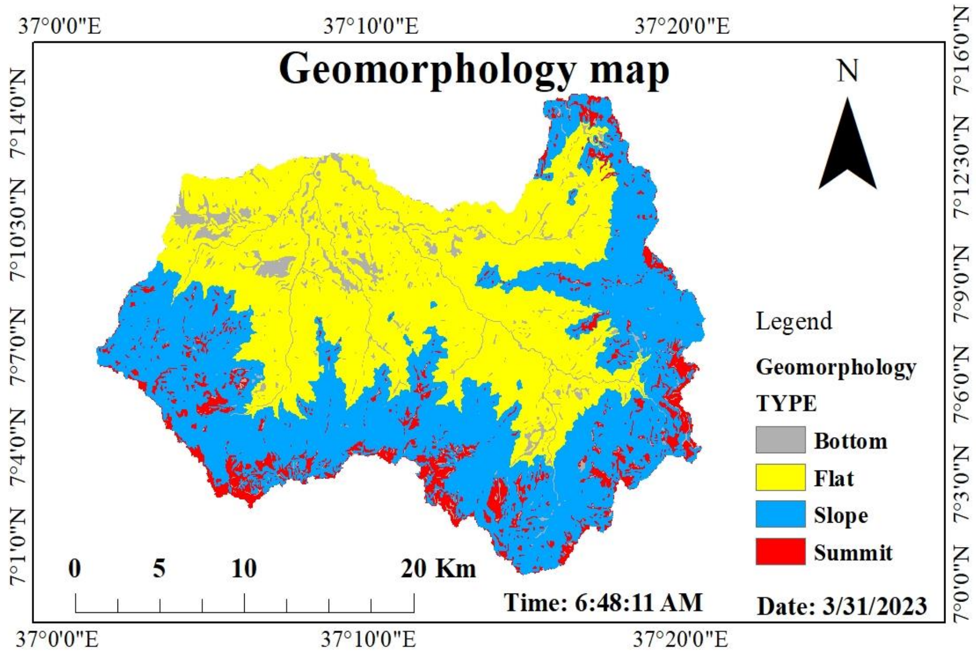

Figure 4.5: Geomorphology Map

4.2.6. Rainfall

The amount of water that percolates into the ground, annual rainfall should be taken into account with varied surface conditions that determine the amount of water that flows to the ground system. The long-term mean annual rainfall map of the study area was prepared by IDW interpolation from five meteorological stations. For the cause, an area where high mean annual rainfall has a greater tendency to occur high groundwater potential due to high infiltration rate rather than a low rainfall area. Based on the rainfall factor, most parts of the study area were suitable (6.61% in a very high and 7.21% in high suitability range) in which the high amount of rainfall can recharge into the groundwater system, whereas 9.16% was moderate and 32.84 was poor and 44.18% of the total area was very poor suitable for groundwater potential.

Table 4.7: The assigned weights and classes for Rainfall

Factor	Mean Annual RF (mm)	Area (Km^2)	Area (%)	Suitability classification	Rank
	<1600	252.9	44.18	Very Low	1
	1600-1900	188.0	32.84	Low	2

Rainfall	1900-2500	52.4	9.16	Medium	3
	2500-3000	41.3	7.21	High	4
	>3000	37.8	6.61	Very High	5

The results showed that, the weights of rainfall factors were given based on the contribution to groundwater recharge, the high rate was assigned for high rainfall and low rainfall areas were assigned the lowest rate for low groundwater potential. The higher the rainfall, the more the volume available for percolating the soil and has been assigned a large weight and vice versa (Saranya and Saravanan 2020; Yusuf 2013). It was identified that an area having high mean annual rainfall was observed around the lower part whereas less rainfall was observed at the upper part of the watershed due to the altitude and, also the range of their classification were based on the above findings and agreed with them. Rainfall is another factor that governs the amount of water that would be available to infiltrate and joins into groundwater zones. Factors such as terrain, vegetation, and surface geology alter the link between rainfall and groundwater occurrence; all of these factors influence the amount of water that gets underground (Libasse 2007).

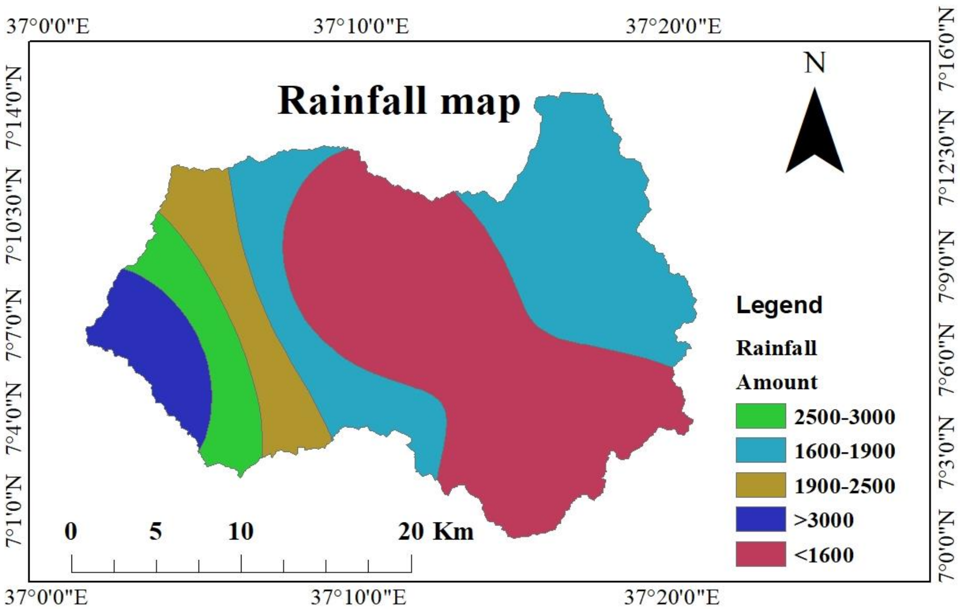

Figure 4.6: Rainfall Map

4.2.7. Geology

The results showed that TV1(Omo trachyte): mainly of massive trachyte was found at east southern, TV2(Lower basalt flow); strafed basalt flow with rare pyroclastic was found at south, northeastern and central part , TV3(Lower trachyte flow); strafed massive trachyte's with rare pyroclastic and coal bed at place was found at northwestern , TV5(Middle basalt flow); mainly basalts with rare intercalation of trachyte was found at south and southwestern and TV6(Middle trachyte flow);mainly intercalated with minor ignimbrite and rare basalt was found at southeastern, northwestern and northeastern part of the region. In general, Cenozoic lithological units such as tertiary volcanic and quaternary groups were found in the study area. According to the data, there are five major lithological units founds in the study region, and from these, the lower basalt flow are most dominant whereas middle trachyte and middle basalt flow are less dominated one. In the study, lower basal flow has a very high rank to form groundwater potential whereas lower trachyte has very low rank. Further, the classes, the area coverage from the total, assigned weights with consistency ratio of each lithological unit were presented in Table 4.8 and Figure 4.7.

Table 4.8: The assigned weights and classes for geology

Factor	Geological type	Description	Area (Km^2)	Area (%)	Suitability classification	Rank
Geology	TV2	Lower basalt flow	243.69	43.68	Very high	5
	TV6	Middle trachyte flow	103.4	18.53	High	4
	TV5	Middle basalt flow	121.2	21.72	Medium	3
	TV1	Omo trachyte	59.91	10.74	Low	2
	TV3	Lower trachyte flow	29.76	5.33	Very low	1

Lithology plays a major role in the availability and occurrence of groundwater and their types affect the recharge of groundwater as it controls the percolation. The storage of groundwater depends upon the type and porosity of rock formation. Types of rocks determine peculiarities of geological cross-section structure, type of porosity values, the nature of permeability, geological structure geomorphology, and character of spatial heterogeneity of flow and transport parameters (Lemessa 2017). According to (WRCS 2013) the geology of the Main Ethiopian Rift Valley contains basic to felsic volcanic, lacustrine sediments and recent to sub-recent Quaternary cover. The volcanic rock varies between Tertiary to Quaternary rocks of basalt, rhyolite, locally trachyte, trachyte basalt, and ignimbrite, tuff, with minor obsidian, nephrites, scoria, and other rocks. The sediments are lacustrine, pyroclastic or reworked volcano sedimentary sediments that vary in composition and thickness from place to place. The geologic formation in the upper soil profile has good primary and secondary porosity and permeability characteristics, which enables continuous recharge to the groundwater (Getachew 1998).

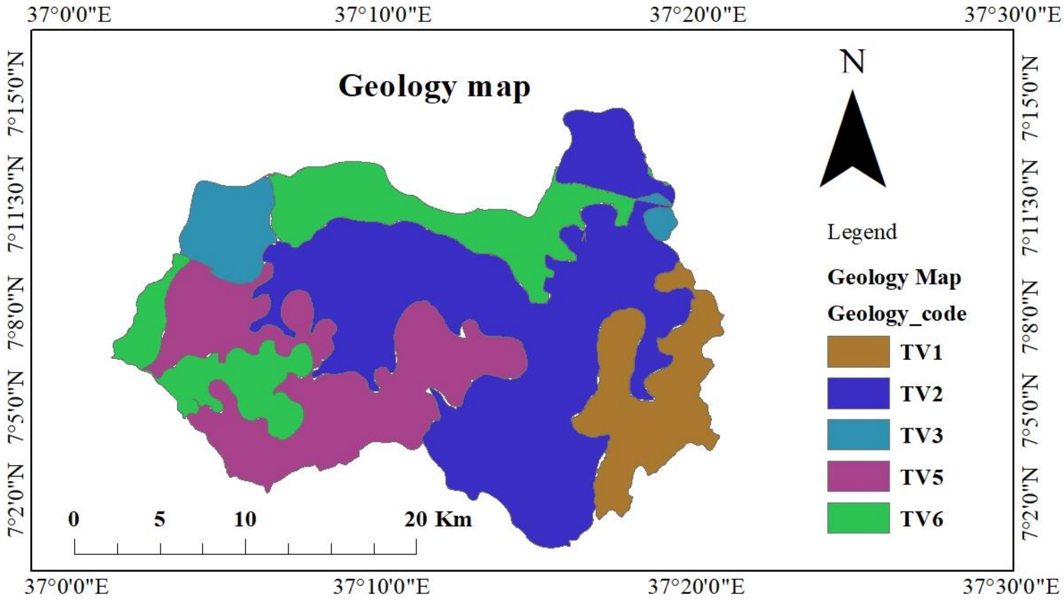

Figure 4.7: Geology Map

4.2.8 Soil

The results showed that ,soil types and texture map was found around northern, northeastern, southwestern and southeastern part of the area have a coarse grain soil type (sandy loam and loam) with nitisols and cambisols soil types, which is suitable for water infiltration (groundwater recharge). The clay soils texture and nitisols soil types in the south, southwestern and middle part of the study area are poor and moderately suitable for groundwater recharge. But there is high groundwater potential here due to ground flow from sloped areas because of geological characteristics, high lineament density and other factor. As described in Table 4.8 from the total study area the moderate zone has highest area of coverage which is cover around 64.75% and the very low, low and high classes which cover 21.93%, 1.11% and 11.94% of the total study area as classified as suitability class for groundwater recharge respectively.

Table 4.9: Soil types and texture suitability class

Factor	Soil types	Soil texture	Area (Km^2)	Area (%)	Suitability classification	Rank
Soil types and texture	Orthic acrisols	Clay	125.6	21.93	Very low	1
	Dystric fluvisols	Sandy clay loam	6.4	1.11	Low	2
	Dystric gleysols	Clay loam	1.6	0.27		
	Dystric nitisols	Loam	370.9	64.75	Moderate	3
	Eutric cambisols	Sandy loam	68.4	11.94	High	4

Soil is the loose surface material that consists of organic matter and inorganic particles through some natural process whether internal or external process as weathering and decomposition of parent materials, climate change, organisms, and human activities. It is one of the major important parameters that affect the occurrence and distribution of groundwater and plays a significant role in the infiltration of water into the ground. The rate of infiltration depends on the permeability and water holding capacity of the soil. The permeable area containing a large amount of sand or gravel permits high percent precipitation to infiltrate the ground and contribute to groundwater whereas less permeable areas have a little percent of water seeping in. The amount of water reaching the water table depends on the extent of the unconsolidated zone lying beneath the soil (Arivalagan et al., 2014). Soil property influences the relationship between runoff and infiltration rates of the soil. It determines the water storage capacity and affects the resistance of water flowing into the deeper layers. The development of soils depends primarily on geologic and climatic conditions. Cultivation and deforestation have considerably changed the natural vegetation cover over the area. They have accelerated the rate of weathering and erosion problem (Habtamu & Rapprich 2014).

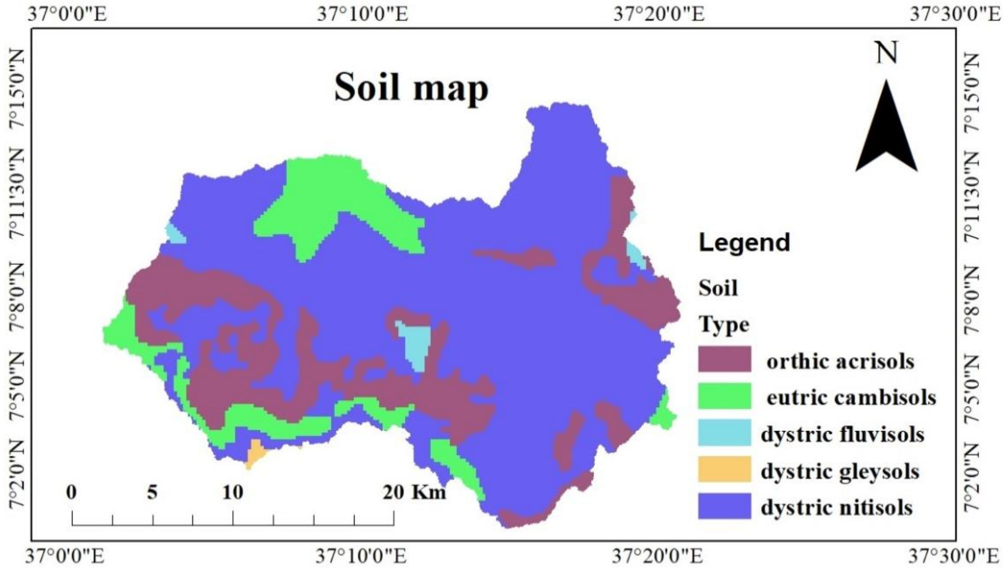

Figure 4.8: Soil Map

4.2. Groundwater Flow Direction

Groundwater flow is controlled by geological structures and lithology. Water table maps were constructed to determine horizontal groundwater flow directions. The 3D map presented below show the flow directions (Figure 4.10). In three dimensional groundwater contour and flow direction map abrupt change in flow direction is observed by convergence and divergence of the flow lines. Also view provides a visible picture and displays the controlling factors which affect the flow pattern (Figure 4.10). The water table elevation in the catchment along the southern escarpments of the catchment is defined by 2600m a.m.s.l; however the lowest water table elevation is about 1200m in central TarchaZuria woreda. The groundwater contour map (Figure 4.9) revealed that the groundwater flows downwards from the Southern in a higher hydraulic head (elevation) towards to west located within the locations close to TarchaZuria woreda. Likewise, groundwater flows from southern and eastern parts of the highlands of the catchment towards the plain areas of the northwestern parts of the catchment. It was realized by employing the idea that groundwater flows from topographically higher elevation to lower elevation. Groundwater is driven by lateral variation in water table or phreatic aquifers. Local relief in topography causes local system of groundwater flow. Due to pronounced local relief, various condition of groundwater flow in local and intermediate flow systems possibly exists. In the study area the flow system generally follows the topographic variation. It is important to determine the position of the water level and the direction in which groundwater moves because many water related projects and constructions are highly influenced by groundwater flow system. According to (Buddemeier & Schloss 2000) groundwater flows from the highest values of the contour elevation to the lowest values in the direction perpendicular to the contour line.

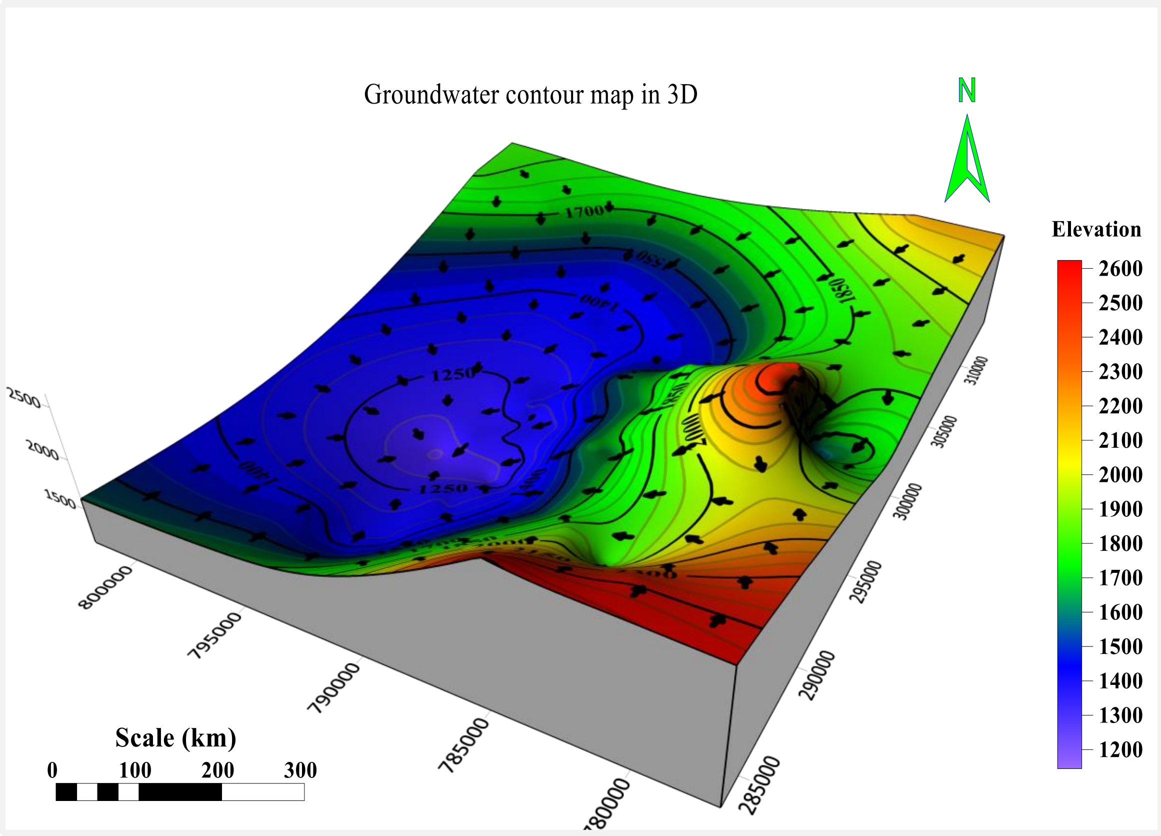

Figure 4.9: Groundwater contour map of Wogayi catchment in three dimensions

4.3. Groundwater recharges and discharge identification

The results showed that groundwater is recharged by springs in highland areas mainly around Mareka woreda and Marimensa woreda in southwestern and Gennabosa woreda in eastern. Likewise, discharge is originated in low land areas in the form of seepage.

A discharge in natural from groundwater system is not only from the flow of water into Rivers, wetlands and springs, but also evaporation from upper parts of capillary fringes where groundwater is close to the surface. The situation is likely suited in the low lands of the catchment area where groundwater level is close to the surface. The results of AHP indicate that 58.12% moderate, 20.82% high, 21.03% low and 0.032% very low groundwater potential zones have been identified. Figure 4.10 and 4.11 shows the groundwater recharge and discharge areas of the study area.

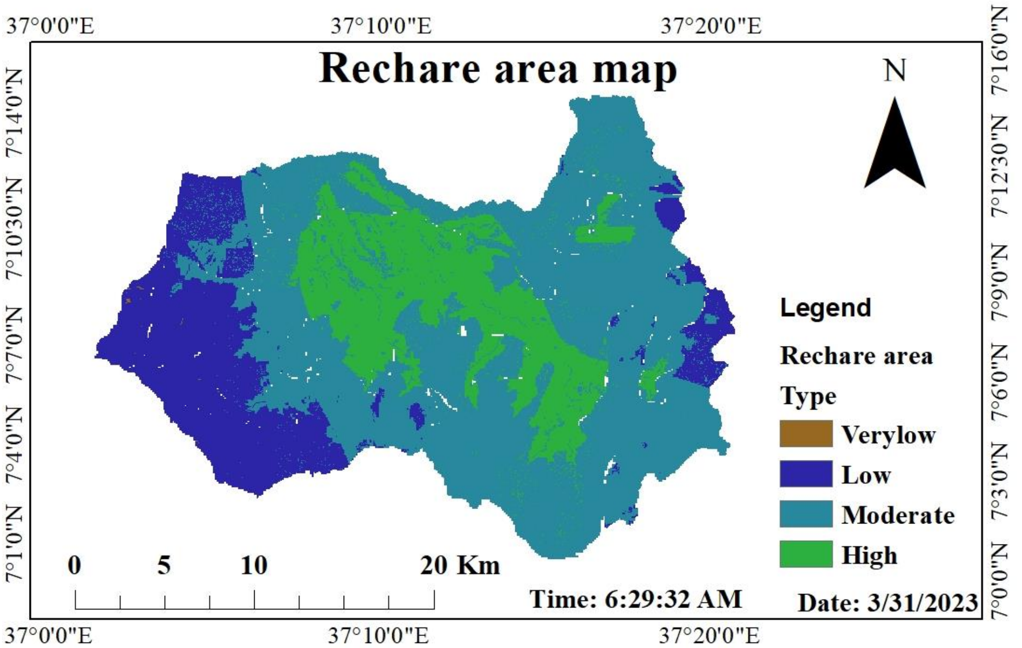

Figure4.10: The recharge area map

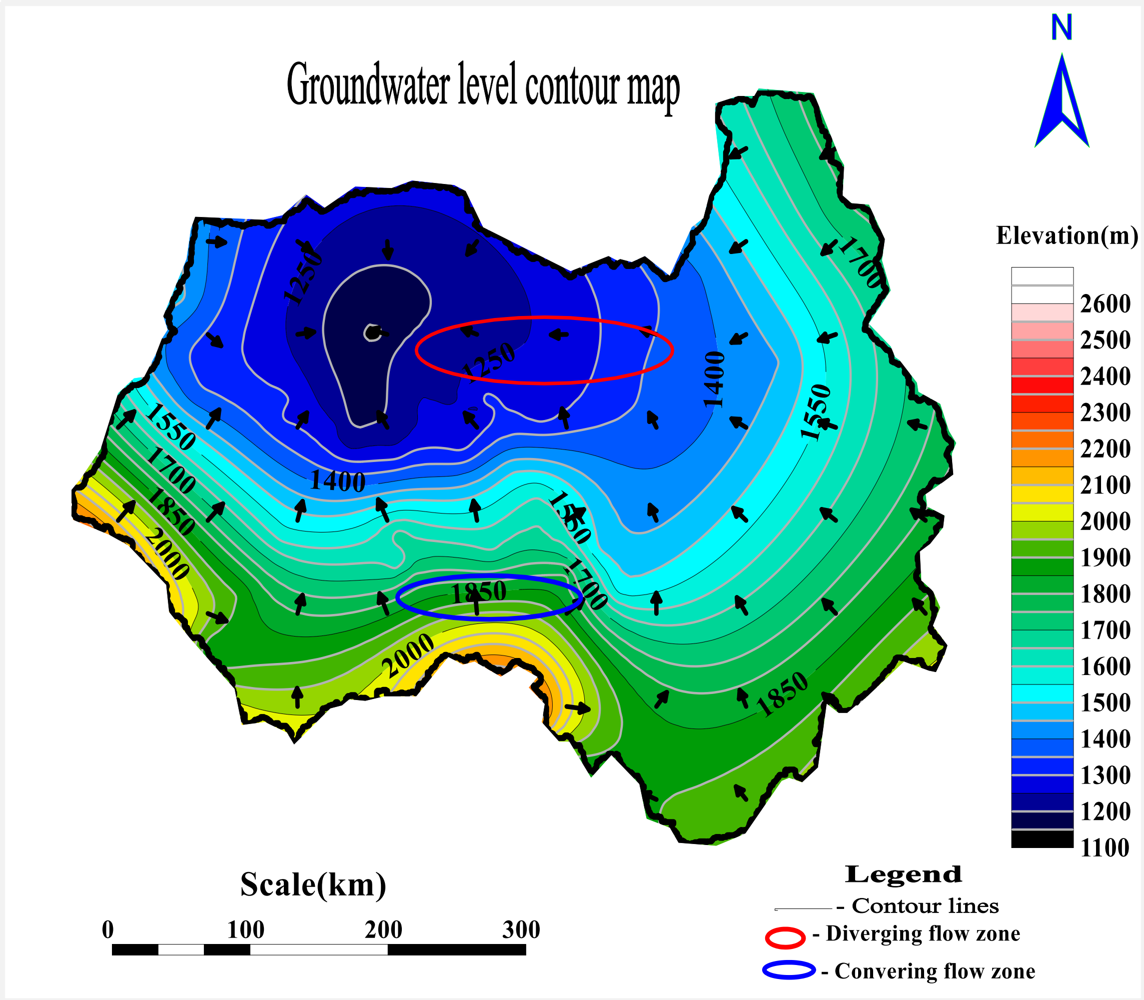

Figure 4.11: Groundwater level contour lines, converging and diverging flow zones

The recharge to the aquifer varies in different locations due to variation in geology, slope, hydraulic connectivity, land use, morphologic variations. The evapotranspiration variation in many places is higher, which have significant effects on the recharge of groundwater. According to (Habtamu & Rapprich 2014), the potential evapotranspiration is nearly 750mm per year and the annual average precipitation is about 700mm per year in the rift areas. As it can be seen from Figure 4.11, the diverging groundwater flow lines are suited from the north eastern high land parts towards the western part of the study area of discharging zones. However, recharging zone is located in the eastern plateaus of the catchment area. The major recharge occurs in the south western and eastern annual rainfall is highland of the catchment where slope is high. Rapid infiltration occurs in areas covered by fractured volcanic and to a lesser extent in sedimentary rocks and thick permeable soils, in somewhat dry lands, due to the fact that the area located in the northwestern Gessabale, in the northeastern TarchaZuria woreda and Mareka woreda southeastern part of the catchment are discharge area. Topographic setting relates to the local relief circumstance gives an idea about the general direction of groundwater flow and its effect on groundwater recharge and discharge. The results showed that 0 to 2 (very gentle), 2 to 8 (gentle), 8 to 15 (moderate), 15 to 30 (steep) and >30 (very steep) slopes Figure (3.4). The southwestern and eastern parts of the catchment area have higher slope value; which are dominantly steep slope, it resulted greater runoff and thus lesser groundwater discharge. However, the southeastern, central north and northwestern parts of the catchment are gentle slopes, which considered as lesser runoff; hence groundwater recharge is lesser (Figure 4.11). Therefore, with regarding to the slopes of the catchment area, the upper parts of the catchment are considered as high groundwater potential zone. Whereas, the slope of lower catchment area(eastern and south western parts) is greater than the surface runoff is high allowing less time for rainwater to percolate and consider to be poor groundwater potential zone. It flows rapidly on the surface keeping other factors constant. In order to formulate a sound water resource planning and management strategy, analysis of the groundwater flow system regarding recharge and discharge areas are required. According to (Winter 1999) the groundwater flow system are supposed that groundwater recharge occurs in topographically higher areas and groundwater discharge in topographically lower areas. Water enters in the ground water systems is in recharge areas and moves through them as dictated by hydraulic gradients and hydraulic conductivities to discharge areas (Zelalem 2009).

4.4. Characterize the geological formation by using borehole lithological log

The results of borehole lithological log data indicate that the occurrence of volcanic rocks particularly fractured and weathered basalt (Appendix2). These volcanic rocks that cover largest surface of the study area are extrusive origin with enormous groundwater potential on most part of the study area. The extrusive volcanic rocks that have erupted and formed on the land surface have a greater capacity for water transmission and storage than do intrusive rocks that formed and cooled beneath the earth's surface. The aquifers associated with volcanic formations related with a combined effect of during and after rock formations porosity and permeability. The highly weathered volcanic rocks of the area hold the shallow ground water system of the study area with water table that follow geomorphology. This type of formation also plays key role on recharging the deep aquifer system of the fractured zones and feeding the perennial streams.

The highly productive bore wells of the area are also drilled aligning the same geological structures. This indicates how the groundwater flow controlled with the prevailing geological structures. In principle, Groundwater in volcanic aquifer reside in weak zone of a consolidated masses usually with fracture , contacts and lava tunnels that form the groundwater occurrence complex even with a difference at small distance.

Hence, it is very essential to find out the weak zones of the middle basalt to locate borehole source. According to the borehole lithological log data of the study area, the main geologic formation type of most of the wells are weathered and fractured basalts (Figure 4.12 and 4.13). The weathered and fractured zone thickness in basaltic formation determines groundwater storage and flow.

The basalts range from fresh type to highly fractured, fissured, jointed or vesicular type. The basalt varieties with joints fracture and fissures form good productive aquifer.

Lithology plays a major role in the availability and occurrence of groundwater and their types affect the recharge of groundwater as it controls the percolation. The storage of groundwater depends upon the type and porosity of rock formation. Types of rocks determine peculiarities of geological cross-section structure, type of porosity values, the nature of permeability, geological structure geomorphology, and character of spatial heterogeneity of flow and transport parameters (Lemessa 2017).

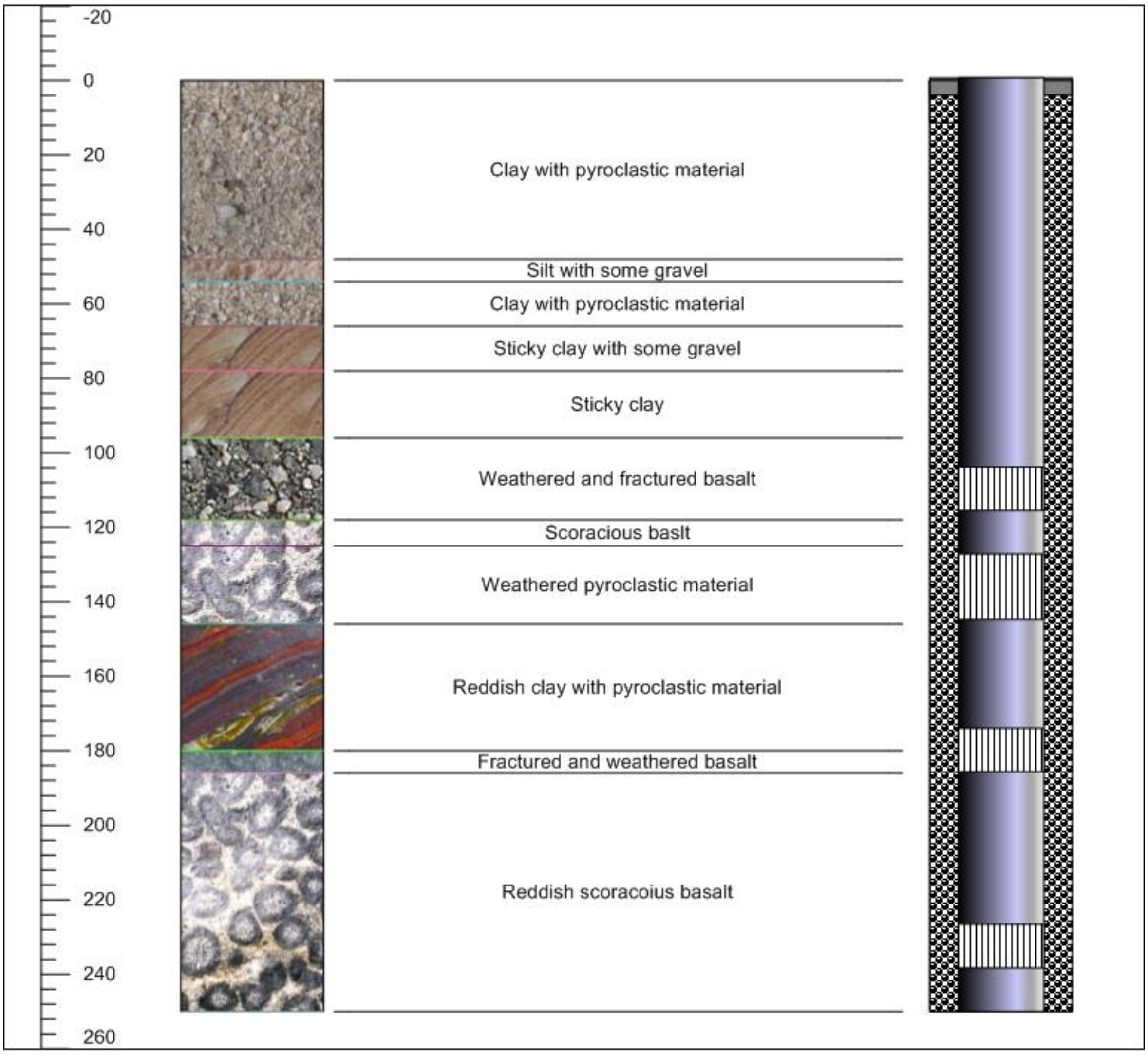

Figure 4.12: Geological well log of the Tarcha 01 well

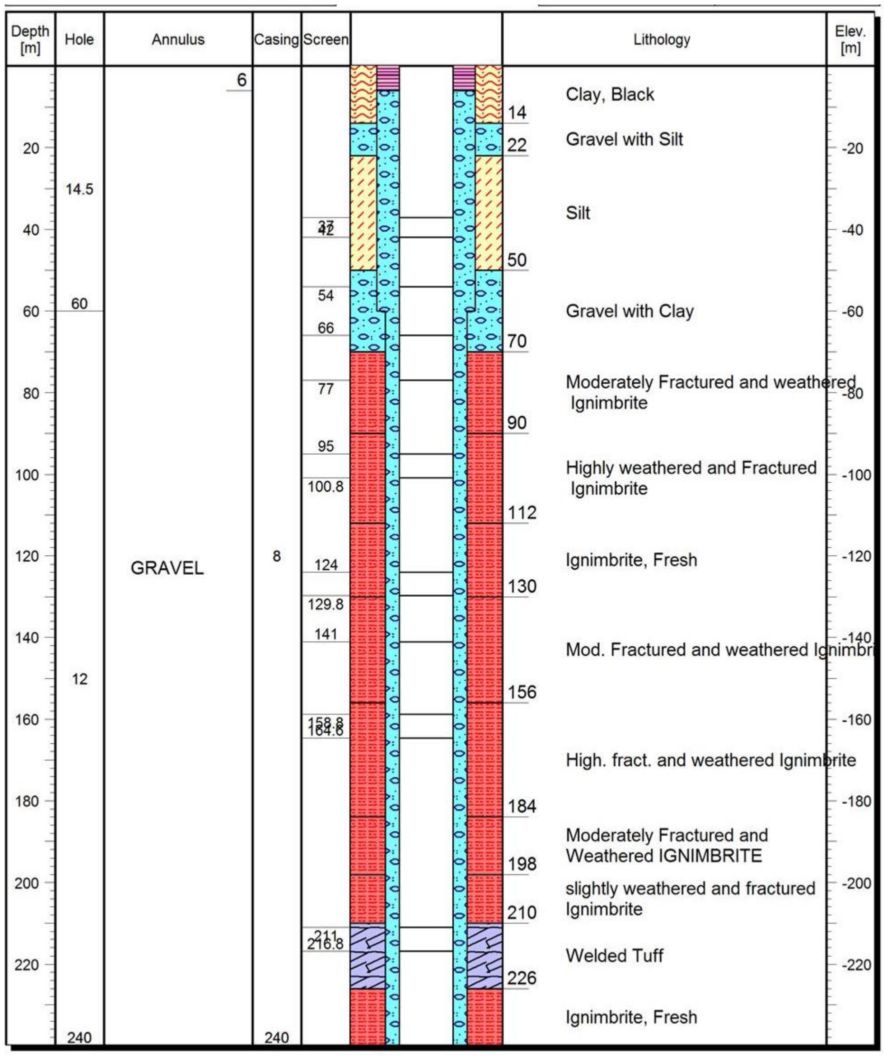

Figure 4.13: Geological well log of the Tarcha campus well

5. SUMMMAER AND RECONCLUSOIN

5.1 Summary

Groundwater is the most valuable natural resources for sustainable development of the country. The identification, delineation and evaluation of these resources have paramount importance for planning and management of water resources in the region. The identified and delineated groundwater potential and recharge zones of the present study area was the result of integrated GIS and remote sensing techniques with multi-criteria decision analysis (MCDA)–analytic hierarchy process (AHP) method. In this study GIS is the most appropriate tool for the mapping of groundwater potential and recharge zones effectively with more accurate, low cost and short period. The thematic map of the factors were prepared after identifying the main factors influence groundwater potential and recharge based on appropriate selection criteria set. The identified factors for this study area was include geology, geomorphology, slope, lineament density, land use/land cover, rainfall, drainage density and soil. These eight parameters were weighted and ranked by AHP method in pair-wise comparison matrix (PCM) based on their influence on groundwater potential and recharge zone. The weighted comparison analysis by AHP was accepted after consistency ratio are checked by normalization and become less than 0.1, otherwise reevaluated. For this study, the consistency ratio is 0.0566. The eight thematic layers were overlaid by weighted overlay analysis in ArcGIS after extract/export raw data from reclassified each thematic layers, converted vector data to raster, resample to the same cell size, and projected all layer on the same projected coordinate system. In addition to groundwater discharge and the groundwater recharge area were identified based the thematic layers prepared from factor influencing groundwater recharge because all factors has no equal significant for delineating groundwater recharge area.

Groundwater recharge zone highly influenced by rainfall coincide with high lineament density. The high groundwater recharge zone is found in high lineament density. According to the result AHP, the major recharge of groundwater occurs in the Easter and southwestern highlands of the catchment, which is said to be recharging zone. However, the area situated in the southeastern, northwestern and northeastern parts of the catchment is discharge zones. Groundwater flow directions in the catchment are generally flows from southern and eastern parts of the highlands of the catchment towards the plain areas of the northwestern parts of the catchment based on the contour map and the ground water flow lines generated. There is also the contribution of tectonic structures mainly fractures and basalts from eastern to the western parts of the catchment which could have significant role in the descendent movements of water from the adjacent water bodies. The results of AHP indicate that 58.12% moderate, 20.82% high, 21.03% low and 0.032% very low groundwater potential zones have been identified. Finally, it can be concluded that integration of GIS and remote sensing techniques are very efficient and useful, time and cost effective tools for identification and mapping of groundwater discharge and recharge area.

5.2. Conclusion

Based on the results of the study the following recommendations are given.

- For future development of the well, provision of geophysical assessment should have to be done on the potential areas of ground water.
- So far there are many boreholes; shallow wells and hand dug wells in the study area, but most of them lack proper well completion report (well history). Hence, further appropriate database organization of the wells should have to be done.
- Detail study on hydrogeological condition of the area in such study is recommended to further study.
- The integration of GIS and RS techniques with MCDA-AHP method is a very powerful tool in mapping of assess of groundwater potential.

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Appendixes

Appendix 1: Locations of boreholes and shallow wells analyzed to construct contours

No	Zone	District	Water Type	X (UTM)	Y (UTM)	Z (m)	Depth (m)	S.W.L(m)	G.W.L (m
1	Dawuro	Tarcha	BH	296969	789998	1295	193	23.6	1271.4
2	Dawuro	Tarcha	BH	295505	791516	1256	174	5	1251
3	Dawuro	Tarcha	BH	294959	790687	1233	145	64	1169
4	Dawuro	Tarcha	BH	294142	790706	1212	125	63	1149
5	Dawuro	Tarcha	BH	297731	791572	1311	115	14	1297
6	Dawuro	Tarcha	BH	297490	791370	1247	103	5	1242
7	Dawuro	Tarcha	BH	293674	790798	1204	175	55	1149
8	Dawuro	Tarcha	BH	293177	790322	1217	172	31	1186
9	Dawuro	Tarcha	BH	293896	790229	1245	189	15.3	1229.7
10	Dawuro	Tarcha	BH	294688	790009	1261	159	47	1204
11	Dawuro	Tarcha	BH	296131	791843	1241	123	22.3	1218.7
12	Dawuro	Tarcha	BH	297097	790403	1281	184	41.65	1239.35
13	Dawuro	TarchaZuria	BH	299856	786992	1661	151	11.7	1649.3
14	Dawu	Tarcha	BH	2934	7910	1171	156	40	1131
15	Dawu	TarchaZur	BH	2925	7908	1260	191	80	1180

	ro	ia		57	14				
16	Dawuro	TarchaZuria	BH	293995	793788	1139	180	20	1119
17	Dawuro	Tarcha	BH	296000	791310	1261	170	30.6	1230.4
18	Dawuro	Tarcha	BH	291130	791209	1297	186	55.4	1241.6
19	Dawuro	Mareka	HW	295111	792994	1238	93	46.1	1191.6
20	Dawuro	Mareka	HW	295989	794028	1209	84	41.65	1167.4
21	Dawuro	Mareka	HW	297588	792186	1285	79	30	1228
22	Dawuro	Mareka	HW	299513	788620	1590	62	41.03	1549
23	Dawuro	Mareka	HW	300528	785946	1798	84	49.7	1748.3
24	Dawuro	Mareka	HW	302365	785460	1521	83	147.7	1374
25	Dawuro	Mareka	HW	289037	777009	2287	93	35	2252
26	Dawuro	Mareka	HW	293762	784176	1861	86	66.79	1794.3
27	Dawuro	Tocha	HW	294794	787269	1673	90	48	1625
28	Dawuro	Tocha	SW	293408	790414	1221	87	72	1149
29	Dawuro	Tocha	SW	295207	785916	1749	89	57.3	1691.7
30	Dawuro	Tocha	HW	297518	781105	2380	80	15.81	2364.2
31	Dawu	Mareka	HW	2976	7812	2344	91	10	2334

	ro			84	99				
32	Dawuro	Mareka	HW	297643	781195	2367	75	30	2337
33	Dawuro	Mareka	HW	298857	780705	2368	73	35.2	2332.81875
34	Dawuro	Tocha	HW	289297	785307	1896	72	21	1875
35	Dawuro	Tarchazuria	HW	290944	791102	1290	72	22	1268
36	Dawuro	Tarchazuria	HW	286595	792472	1426	92	35.9	1390.1
37	Dawuro	Tarchazuria	HW	287041	793526	1383	75	44.01	1339
38	Dawuro	Mareka	HW	298677	780688	2378	97	21	2357
39	Dawuro	Marimenssa	HW	287332	795043	1462	72	57.43	1404.6
40	Dawuro	Tarchazuria	HW	290948	791813	1305	93	23	1282
41	Dawuro	Genabossa	HW	286635	792437	1435	87	62	1373
42	Dawuro	Genabossa	HW	287904	793074	1338	97	34	1304
43	Dawuro	Tarchazuria	BH	299662	791224	1269	167	51	1218
44	Dawuro	Genabossa	HW	307842	792922	1451	87	45.1	1405.9
45	Dawuro	Genabossa	HW	310530	802052	1866	100	35	1831
46	Dawuro	Genabossa	HW	314011	780948	2126	88	27	2099

47	Dawuro	Genabossa	HW	311968	798826	1807	97	45.21	1761.79
48	Dawuro	Genabossa	HW	309917	797892	1739	87	25	1714
49	Dawuro	Genabossa	HW	304421	791504	1365	90	71	1294
50	Dawuro	Genabossa	HW	305511	795540	1420	78	18	1402
51	Dawuro	Genabossa	HW	304065	778069	1911	92	46	1865
52	Dawuro	Genabossa	HW	304807	778069	1912	89	39	1873

Appendix 2: Well completion report Tarcha 01well completion report

FROM (M)	TO (M)	LITHOLOGY
0.00	2	Clay
2	8	Fractured Trachyte Light in Color
8	22	Moderately fractured trachyte yellowish in color
22	42	Moderately fractured basalt
42	66	Slightly fractured basalt
66	118	Slightly fracture & Moderately weathered basalt
118	150	Highly weathered & fractured Basalt (altered basalt) brown in color
150	180	Moderately weathered & slightly fractured basalt
180	212	Highly weathered basalt brown in color
212	240	Moderately fractured & slightly weathered basalt
240	268	Slightly fractured & moderately weathered basalt
268	284	Slightly fractured & weathered basalt
286	288.3	Fresh basalt , Hard basalt

Ermmana well completion report

From	To(m)	
0	14	Clay, Black
14	22	Gravel with silt
22	50	Silt
50	70	Gravel with Clay
70	90	Moderately Fractured Ignimbrite
90	112	Highly weathered Ignimbrite
112	130	Ignimbrite, Fresh
130	156	Moderately fractured and weathered Ignimbrite
156	184	Highly fractured and weathered Ignimbrite
184	198	Moderately Fractured and Weathered Ignimbrite
198	210	Slightly Fractured and Weathered ignimbrite
210	226	Welded Tuff
226	240	Ignimbrite, Fresh

Tarcha campus well completion report

No.	Depth range, (m)	Geologic description		Lithology	Water-bearing
	From	to			
1	0	48	Clay with pyroclastic material	Pyroclastic material	
2	48	54	Silt with some gravel	Silt	
3	54	66	Clay with pyroclastic material	pyroclastic material	
4	66	78	Sticky clay with some gravel	clay	
5	78	96	Sticky clay	clay	
6	96	118	Weathered and fractured basalt	Basalt	**Water-bearing**
7	118	125	Scoracious baslt	Scoracious baslt	
8	125	146	Weathered pyroclastic material	pyroclastic material	**Water-bearing**
9	146	180	Reddish clay with pyroclastic material	clay with pyroclastic material	

10	180	186	Fractured and weathered basalt	basalt	**Water-bearing**
11	186	250	Reddish scoracoius basalt	scoracoius basalt	

Wozozuria well completion report

Depth (m)		Litho Logical Description
From	To	
0	4	Clay , Black
4	14	Clay + Gravel
14	24	Highly Weathered Basalt
24	88	Moderately Fractured Basalt
88	106	Slightly weathered and fractured Basalt
106	120	Moderately Fractured & weathered Basalt
120	128	Highly Weathered and Fractured Basalt
128	148	Moderately Fractured and weathered Basalt
148	170	Moderately weathered and Slightly Fractured Basalt
170	174	Slightly weathered and fractured Basalt
174	202	Moderately Fractured and Weathered Basalt
202	232	Slightly lo Moderately Fractured and Weathered basalt
232	234	Slightly Fractured Basalt

Lala well completion report

No.	Depth range, (m)		**Geologic description**
	From	To	
1	0	6	Clay
2	6	30	Fresh basalt
3	30	36	Fractured and weathered basalt
4	36	84	Weathered basalt intercalated with partial and sand gravel

5	84	105	Fresh basalt
6	105	148	Fractured basalt and partial gravel
7	148	153	Fresh basalt

Tarcha 02 well completion report

Depth (m)		Litho Logical Description
From	To	
0	10	Highly weathered trachyte
10	18	Clay
18	28	Sand
28	66	Massive trachyte
66	78	Moderately weathered trachyte
78	82	Highly weathered basalt
82	96	Slightly weathered and slightly fractured basalt
96	126	Massive basalt
126	168	Moderately fractured and slightly weathered basalt
168	176	Highly fractured basalt
176	186	Moderately fractured and moderately weathered basalt
186	194	Highly fractured and slightly weathered basalt
194	202	Clay
202	210	Moderately fractured basalt
210	232	Moderately weathered and moderately fractured basalt
232	262	Slightly weathered basalt
262	290	Massive basalt

Appendix 3: Weights of parameters determined using Analytical hierarchy (AHP)