

JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR

**Evaluation of Groundwater Potential Zone Using Geospatial Techniques,
The Case of Muger Sub-Basin, Upper Blue Nile Basin, Ethiopia.**

By

Murtessa Kibret

A Thesis Submitted to the School of Graduate Studies of Jimma Institute of Technology, Faculty of Civil and Environmental Engineering, Hydrology and Hydraulic Engineering Chair for Partial Fulfillment of the Requirements for the Degree of Master of Science in Hydraulic Engineering

June, 2024

Jimma, Ethiopia

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Advisor: - Dr.Ing Wakjira Takala

Co-Advisor: - Chala Hailu (Assistant professor)

June,2024
Jimma, Ethiopia

Declaration

I declare that this research entitled Evaluation of Groundwater Potential Zone Using Geospatial Techniques, The Case of Muger Sub- Basin, Upper Blue Nile Basin, Ethiopia is my original work and has not been submitted as a requirement for the award of any degree in Jimma University or elsewhere.

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As research Adviser, I hereby certify that I have read and evaluated this thesis paper prepared under my guidance, by Murtessa Kibret entitled Evaluation of Groundwater Potential Zone Using Geospatial Techniques, The Case of Muger Sub- Basin, Upper Blue Nile Basin, Ethiopia. And recommend and would be accepted as a fulfilling requirement for the Degree Master of Science in Hydraulic Engineering.

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ABSTRACT

Groundwater potential assessment is the process of measuring, collecting, and analyzing relevant parameters on the quantity of groundwater resources for the better development and management of water resources. There is limited information about the occurrence, distribution, recharge, discharge, and factors that affect groundwater protection site selection. Finding a systematic approach is required to minimize this knowledge gap. Therefore, the main objective of this study is to evaluate and delineate the groundwater potential zone in Muger catchment, Upper Blue Nile, and evaluate the effect of the land management factor of the area on the distribution of groundwater potential, using geospatial techniques. Eight multi-influencing elements such as, land use land cover (LULC), DEM, rainfall, geology data, soil type, drainage density, slope, and lineament density, are used to develop groundwater potential. The land use land cover (LULC) image of 2022 was generated from a land satellite and classified using the ERDAS Imagine 2015. The Analytical Hierarchy Process (AHP) is used to estimate the weight of the parameters based on their relative value and percent of influence on groundwater potential and recharge. The consistency ratio for the weights assigned to each parameter was found to be 0.0785, which is less than 0.1, indicating that the weights assigned to each parameter are appropriate. A knowledge base ranking of 1 to 5 was assigned to each layer based on the importance of each layer for groundwater potential. Using the raster calculator feature of ArcGIS software, all the theme maps were combined to produce a composite groundwater potential map of the research area. Based on its groundwater potential availability rank and class, the created groundwater potential map has four ranks: 2, 3, 4, and 5. Its classes are Low, Moderate, High, and Very High, respectively. The groundwater potential zone (GWPZ) area coverage of the study area was identified as very high (2.79%, or 192.92 km²), high (73.79%, or 5114.08 km²), moderate (23.14%, or 1600.054 km²), and low (0.0867%, or 5.99 km²). The validity of the identified groundwater potential maps was done, by cross-checking with the existing borehole data collected from the catchment, as evidenced by the prediction accuracy was 71.42%. Reflects that the method applied for the present study produced significantly reliable and precise results. In addition to GWPZ evaluation the effect of land management factor on GWPZ was evaluated. Thus, based on the slope value (>30%) of LULC in the study area was changed from agricultural land to vegetation area (351 km²). Due to this change of LULC, the groundwater potential zone of the study area increased by (0.44% or 30.14 km²) to a good groundwater potential area. This implies that the groundwater potential zone of the catchment was influenced by land management practices, and the method is effective in doing such an investigation.

Keywords: GIS, Groundwater potential, Mugar catchment, remote sense, Land use land cover

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ABBREVIATION AND ACRONYM

CI	Consistence Index
CR	Consistence Ratio
DEM	Digital Elevation Model
EMWE	Ethiopia Ministry of Water, and Energy
GWPI	Groundwater Potential Index
GIS	Geographic Information System
GPS	Global Positioning System
GWPZ	Groundwater Potential Zone
LULC	Land Use Land Cover
L/s	Liter per Second
Masl	Mean Sea level
Max Temp	Maximum Temperature
Min Temp	Minimum Temperature
NPEV	Normalised Principal Eigen Vector
NMA	National Meteorological Agency
OWWDSE	Oromia Water Work Design and Supervision Enterprise.
SRTM	Shuttle Radar Topography Mission
USGS	United States Geological Survey
WIOA	Weight Index Overlay Analysis
WWAP	World Water Assessment Program

1. INTRODUCTION

1.1 Background

Water is a unique natural resource, which has the power to change our world to be comfortable for life. The fact that water covers about 71% of Earth's surface, however, there is still a severe freshwater shortage for use in agriculture, industry, and drinking. Because 97% of the water on Earth is salt water in the form of seas and oceans, 2% of the water is in the form of glaciers in the polar regions, and the remaining 1% is in the form of stream channels and groundwater. (Wilson, 1983; Chow et al., 1998; Keith David Todd, 2005; Das & Pardeshi, 2018). The demand for freshwater is increasing as the world's population continues to grow in domestic, industrial, and agricultural activity over the past few years. (Barik et al., 2017). Today modern society exclusively depends on the presence of groundwater for irrigation and domestic, and industrial usage. Therefore, identifying ground sources also estimating their recharge and yield capacity is important, and needs to be evaluated in scientific studies dealing with groundwater prospecting, exploration, and management. (Nayak et al., 2017). As is the case in many other developing countries, most of the population of Ethiopia lives in rural areas, and urban depend directly on the groundwater for their livelihood.

Groundwater is water found below the surface of the ground in saturated zones, which is the largest available source of fresh water. Groundwater is considered one of the most valuable freshwater resources and it is a major supply of freshwater for humans where it is available (Fadhillah et al., 2021). Due to its lower level of contamination and wider distribution, groundwater is typically used to meet this increasing demand. It is one of the most important natural resources for supporting both human needs and economic growth (Arkoprovo et al., 2012). Increasing groundwater abstraction is becoming essential for economic growth and attaining many of Africa's Sustainable Development Goals (Bonsor et al., 2018). Additionally, it is a vital resource for human survival and economic growth in the vast, drought-prone regions of southern, eastern, and western Africa (Pavelic et al., 2012). Groundwater potential is primarily a hydrogeological and geophysical implication activity, and it depends on how well the hydrological indicators and evidence are interpreted (Kumari, 2018). In any location on earth, the presence of groundwater is not a matter of chance but rather the result of the interaction of climatic, geological, hydrological, physiographical, and ecological elements (Jhariya et al.,

2021). There are several factors, including lithology, geological structures, soil, lineament characteristics, slope, drainage pattern, geomorphology, land use/land cover, and the interactions between these elements, that control the presence and movement of groundwater in a given location (Abdulkerim et al., 2022; Andualem & Demeke, 2019b). The groundwater potential of an area depends on different facts, and it varies from place to place. According to its change variation of the groundwater potential within a short distance and the same geological formation has also been observed (Jhariya et al., 2021). Evaluation of potentiality in groundwater hydrology is crucial for the effective planning and management of groundwater resources in terms of their occurrences and accumulation (Kumar Pradhan et al., 2020). In the majority of Sub-Saharan African countries, groundwater resource management and protection lag far behind resource assessment and development. This is especially true in Ethiopia, which requires thorough planning, development, and implementation of water resource protection and management strategy involving local communities and other stakeholders (Mengistu et al., 2019).

In Ethiopia, groundwater is largely used for residential water use and sanitation services, and there is a strategic groundwater development plan that will be put into place from 2005 to 2025 the potential is also estimated as 2.6 - 6.5 BCM. (Yilma & Awulachew, 2009; Mengistu et al., 2019). As a result, a quantitative assessment, supported by scientific concepts, and existing procedures is required for the sustainable development and management of groundwater resources. (Rusia et al., 2018). So in developing nations like Ethiopia, rapid population growth and ineffective resource management have a direct or indirect impact on the quantity and quality of groundwater. (Mengistu et al., 2019). Therefore, unsuitable use of water policy and unscientific studied land management are also potential contributing reasons. So, groundwater resource evaluation with factors that impact the recharge zone is essential for sustainable management.

Groundwater potential assessment is the process of measuring, collecting, and analyzing relevant parameters on the quantity and quality of groundwater resources for the better development and management of water resources (Todd & Mays, 2004; Herrmann & Bucksch, 2014). There are several methods of groundwater potential investigation techniques: surface investigation, sub-surface investigation, ground-based survey, geophysical method, and drilling tests are used which are expensive take long periods and require large data sets (Todd & Mays,

2004; Nampak et al., 2014). Among these, tools remote sensing (RS) and geographic informatics systems (GIS) are regarded as the most beneficial and affordable tools with less mechanical and physical labor requirements. The study conducted on groundwater potential, using GIS and remote sensing methods of investigation, shows that delineating groundwater potential zones by integrating different thematic layers, which have direct control of groundwater occurrence, is preferable (Hasibuan et al., 2021). GIS and remote sensing can generate information in the geographical and temporal domain, essential for successful analysis, prediction, and validation. One of the most time and economic benefits of using remote sensing data for hydrogeological research and monitoring (Nampak et al., 2014; Hussein et al., 2017). Most of the methods used to investigate groundwater potential areas are expensive and take a long period to complete as a result, in this study, groundwater potential zones are evaluated using GIS and remote sensing techniques. Which was the best choice for quickly determining the existence of groundwater and mapping groundwater potential.

When groundwater exploration is conducted, the impact of land management factors on groundwater potential is often overlooked. (Murmu et al., 2019). However, only a small number of researchers have undertaken studies to examine possible changes in groundwater recharge resulting from Land Use Land Cover (LULC) changes. (Khan & Jhariya, 2018, Lamichhane & Shakya, 2019a) And have stated that groundwater potential zones might be affected by land misuse. This poses a risk to the sustainable use of groundwater. In the current research, based on this perspective, the effect of land management factors in the study area on the distribution of groundwater recharge was analyzed. Such an evaluation provides an advantage for land-use planning and proper management for the sustainable use of groundwater.

This study explores the need for a detailed study and survey to estimate groundwater resources with better accuracy. So, the validation of the research was done by collecting the borehole data from the catchment and overlaid with the map of the groundwater potential zone generated by ArcGIS software. Therefore, the present study evaluates the groundwater potential zones of the Muger catchment by developing a thematic map and delineating the parameters that influence groundwater potential zones using GIS and remote sensing techniques. In addition to groundwater potential zones evaluation, the study also evaluated the effects of land management factors on groundwater potential zones. This presents an opportunity for sustainable development and the responsible use of groundwater.

1.2 Statement of the problem

According to the World Economic Forum (UNESCO, 2007), there will be a global issue with freshwater shortages in the future. Currently, groundwater provides around 40% of the water humans use, and over the coming decades, this percentage is expected to rise. (Biswas et al., 2020). In addition, increasing hydro-ecological degradation, global warming, and a scarcity of fresh groundwater resources are all major issues facing humanity. (Melesse et al., 2013). The processes of change in groundwater systems are influenced by a variety of factors, including physical, policy, legal, climate variability, and natural Hazards. (hariya et al., 2021). In Ethiopia and at present study area population growth occurs from time to time and most of them use surface and groundwater for domestic, agricultural, and industrial purposes. The Muger Sub-basin, one of the main sub-basins of the Upper Blue Nile Basin, often experiences severe famine due to drought and a lack of good water infrastructure. (Adeba & Tafese, 2021).

Before, the people and animals living in the Muger catchment area used sources of water from rainfall, surface, and groundwater for multi-purpose. However, there have been recent hydrological and geological changes in the study area because of factors such as climate change, which include decreases in stream flow of surface water, drying perennial springs, and the destruction of wetlands. (Roth et al., 2018). These changes are manifestations of a decrease in water quantity, and they encourage researchers to look for alternative sources of water to meet water demand. There is limited information about the occurrence, distribution, recharge, and factors that affect groundwater potential site selection. Also, most of the investigations before assessing groundwater potential zones missed the effect of land management factors on the groundwater potential zones. (Lamichhane & Shakya, 2019a). So, finding a methodical approach is required to minimize this knowledge gap. The techniques and technology used for the investigation of groundwater potential zone determination are also tedious. In the past time field surveys took a lot of time and resources to complete (Hussein et al., 2017). Therefore, the purpose of this study is to evaluate groundwater potential zones, by preparing a groundwater potential district map for multi-criteria influence factors. That is used as decision-making for quantifying groundwater potential zones using geospatial techniques in the Muger catchment. In addition, this research attempts to evaluate the influence of land management factors (LUCL change) on GWPZ in the Muger catchment of upper Blue Nile, Ethiopia.

1.3 Objectives

1.3.1 General objective

The main objective of this study is to evaluate groundwater potential zones, of the Muger catchment, upper Blue Nile basin, using geospatial techniques.

1.3.2 Specific objectives

1. To identify and analyze key factors influencing groundwater potential zones.
2. Delineating groundwater potential zones in the catchment and identifying suitable areas for groundwater development using weighted overlay analysis techniques with AHP and ArcGIS.
3. Evaluating the effect of land management factors on groundwater potential.

1.4 Research questions

1. What are the factors that determine groundwater potential zones and how do the parameters vary spatially?
2. Where might zones of potential groundwater be found and how do the potential sites vary spatially?
3. What is the impact of land management factors on the groundwater potential or recharge regulating parameters?

1.5 Scope of the study

The study was focused on the evaluation of groundwater potential zones in the Muger catchment. To fulfill this task the activities were performed: Collecting information on groundwater potential assessment of the study area, related to the previous research around the world within groundwater potential delineation. Groundwater Potential zones were accessed by incorporating groundwater-related data, geology, LULC, drainage density, lineament density, elevation slope, soil, and rainfall data into Arc GIS software. After considering their attributes, giving each theme feature a weight. The final integrated polygon's total weights are derived by adding or multiplying the weights assigned to the various levels based on their suitability. A map of the potential zone for groundwater prospecting was created. In addition to groundwater potential identification, technically by converting some land use systems of the study area evaluating the effect of land management factors on groundwater potential within the Muger catchment was

analyzed. To inform water users and decision-makers about the sustainable use and management of groundwater resources, regions on the map are labeled as very good, good, poor, and very poor. Finally, for the justification of the outcome validation was done.

1.6 Significance of the study

Today modern society exclusively depends on the presence of water potential for domestic, irrigation, and industry usage. Therefore, identifying groundwater sources besides estimating their recharge and yield capacity is important. The result of the study was preparing a groundwater potential zone map, which may provide information about productive well location in the study area. This was reducing the extra labor and time required in siting well location for groundwater exploration. The provision of such maps may provide good information for well drillers and decision-makers. Additionally, it is important to reduce the effects of land change without recommending it by appreciating site selection, planning for land use, choosing a site, managing it, and keeping local expenditures to a minimum. Planners, decision-makers, and researchers can also use this information as input for further investigation.

2. LITERATURE REVIEW

2.1 Background

To fulfill this task, the relevant and related literature on this topic is discussed and presented in this chapter. It is anticipated that the chosen readings from a wide variety of literature will serve as the foundation for developing the conceptual framework of this study. Those documents and books that help to assess more about groundwater potential, surface topography, groundwater sources, geology, hydrology, hydrogeology, and intermittent and perennial rivers, were reviewed. (Abdulkerim et al., 2022; Haile, 2022).

Specifically, there are several studies conducted in the study area related to surface water and climate change, land management, and others however, groundwater potential is limited in this sub-basin, but several studies conducted in the upper Blue Nile River basin. (Adeba & Tafese, 2021). The research region is underutilized since it has enough surface and groundwater potential for a variety of water resource development projects to solve various problems across the nations. So, the literature study in this work focuses on previous research that has been done by various scholars that relate to groundwater characterization and potential evaluation.

2.2 Groundwater potential

Hydrogeology is a science that studies groundwater occurrence, movement, and distribution and is known as groundwater hydrology, Water found underground in voids and fissures in rock, sand, and soil is known as groundwater. (Todd & Mays, 2004). Aquifers are geologic formations of soil, sand, and rocks where it is stored and slowly circulates. (Schmidt & Hahn, 2012).

Groundwater is also referred to as subsurface water that occupies all the pore space in soils and geological formations below the water table (Gizaw et al., 2023). It moves through the aquifer layer in the direction of the discharge points, which can be wells, springs, rivers, lakes, and the ocean. A portion of the infiltrated water enters the groundwater or aquifer system through the void zone and exits in the atmosphere, surface water in the plant (Todd & Mays, 2004). This process is known as groundwater flow or groundwater recharge. The most significant natural resource on earth is groundwater, which is stored in the hollow space between geological strata and is used for home consumption, economic growth, and any ecological diversity (H. Tamiru & Wagari, 2021). Additionally, the occurrence and flow system of groundwater depends on the

geological characteristics of its porosity and permeability, as well as the formation of landforms like high mountains, rift valleys, and flat areas, as well as the role of landforms on surface runoff and infiltration to the ground (Sharma, 2016; Kabeto et al., 2022b). Natural discharge occurs at springs and seeps and frequently recharges groundwater, which eventually rises to the surface and can create wetlands. If the net saturation flow of groundwater is directed away from the water table in a drainage basin that area is referred to as a recharge area (Wilson, 1983). Usually, the water table in a recharge area is at a certain depth.

2.3 Groundwater recharge zone

The amount of water that flows downward or reaches the water table and adds to the groundwater is known as groundwater recharge. (Misstear, 2000). The passage of water through the saturated zone downward under the influence of gravity or in a direction dictated by hydraulic conditions is typically thought of as the process of groundwater recharge. (Simmers, 2013). The amount of this recharge is determined by the intensity and length of rainfall, the surface conditions at the upper boundary, the soil moisture levels, the depth of the water table, and the geology and structure. (Rawat et al., 2019). Groundwater recharge, which occurs when surface water percolates or infiltrates into the subsurface under the influence of geology and geomorphology (Smith & Pain, 2009). The process by which water moves from an unsaturated zone to a saturated zone through the porosity and permeability of the earth materials above the water table (Rajaveni et al., 2017).

Groundwater systems can be recharged from a variety of sources. These include urban recharge, irrigation losses, inter-aquifer flows, river recharge, precipitation or direct recharge, and inter-aquifer flows. (Lamichhane & Shakya, 2019). The highest groundwater potential comes from recharging in the highland regions, the groundwater aquifer zone receives the rainwater through infiltration. (Thomas & Duraisamy, 2018). In arid climates rather than humid climates, some water enters the subsurface by seeping out of the bottom of surface waters. In low-lying places, groundwater frequently escapes from the saturated zone at springs or the bottom of surface waters and returns to the ground surface. These exit sites are always lower in elevation than the water table when groundwater enters the system as recharge since groundwater always travels towards the lower head (Chow et al., 1998). In regions with humid climates and permeable soil or rock types, recharge is greatest.

2.4 Factors affecting groundwater potential and recharge zone

Knowledge of the biophysical, geological, geomorphological, and hydrometric components is necessary for the exploitation and exploration of groundwater resources. (Kumar & Krishna, 2018; Achu et al., 2020; Abdulkerim et al., 2022). Groundwater potential and recharge zones were affected by different factors like physical factors, climate factors and hydrogeological factors, such as geological/lithological structures, geomorphological landforms, slope angle or steepness, soil porosity, land use/land cover, drainage density/drainage pattern, rainfall (amount, intensity, spatial and temporal distribution), lineament density, soil physical property (type, texture, and so on) can all affect the environment. (Bera et al., 2020; Biyayilgn, 2021).

Study the origin of the occurrence and the location of groundwater flow utilizing remote sensing data based on indirect study of directly observable terrain features such as geological formations, geomorphology, Land-use/land cover, Slope, Rainfall, drainage density, and lineaments. The impact of various elements on the recharge process varies. Since penetration takes a long time, slope might be considered one of the main elements in recharging. (Duguma & Duguma, 2022). Another important element in choosing appropriate artificial recharge sites is land use and cover. Due to its connection to surface runoff, the existence of a natural drainage system serves as an indirect indicator of the terrain's low permeability and porosity. (Todd & Mays, 2004). Faults or fracture systems, which serve as channels for groundwater transport and storage, are thought to be responsible for most geological discontinuities. Lineament density can therefore be utilized to deduce high secondary porosity in a particular area of interest. A 300 m buffer zone around each lineament is typically regarded as a good area for groundwater recharge. (Krishnamurthy et al., 2000).

Slope is one of the key elements influencing a region's capacity for groundwater. Due to the higher water velocity on a steep slope, there is rapid run-off. (Das, 2018). The infiltration of surface water is directly impacted by the slope gradient. On steep slopes, minimal levels of recharging can be seen since the water has little time to enter because it is moving quickly downward. However, flat lands make it easier for groundwater to recharge since they capture a lot of rainwater and have moderate evaporation conditions. (Rajasekhar et al., 2019).

Land use and land cover has also significant roles in absorbing runoff, infiltrating, and recharging groundwater-influenced capacity of every watershed or subbasin (Rafati &

Nikeghbal, 2017). The terms "land usage" and "land cover" describe things like woods, homesteads, water bodies, and flora. The rate of surface runoff, infiltration, and groundwater consumption are all affected by land use and land cover. Land usage and land cover can therefore be considered as a deciding factor when choosing locations for groundwater artificial recharge. Hence, a thick layer of vegetation protects the soil from the force of falling raindrops, lessens soil separation, and slows surface flow, especially on mild slopes, giving water more time to seep into the soil. Additionally, changes in land cover may have an effect on the environment, socio-economics, ecology, and hydrology (Yin et al., 2016; Ag & Oy, 2022). The effective porosity of the soil is typically directly inversely correlated with permeability. The most important parameters affecting soil permeability in clayey soils include grain size, shape, structural arrangement, and stratification, pore fluid characteristics, voids ratio, entrapped air (degree of saturation), other foreign materials, and adsorbed water (Punmia & Jain, 2005).

In general, soil texture affects the soil's moisture content, infiltration rate, hydraulic conductivity, and soil permeability, as well as the soil's grain size and unique composition, all of which have an impact on recharge potentiality. Clay is less capable of infiltration than loam and sandy loam. As a result, sandy loam and loam have better groundwater potential than clayey texture. (B. Berhanu et al., 2013). Geology/lithology is the most significant aspect for the probable occurrence of groundwater because the penetration mostly depends on the permeability or conductivity level of various rock types. (Das et al., 2017; Bera et al., 2020b). Geology gives detailed information on the qualities of the underlying soil and rock strata. Different rock types have different porosities. Effective porosity, which can be natural or artificial, controls the capacity for recharging by allowing for the storage of water. The occurrence, flow, and quality of groundwater are governed by geomorphologic features in conjunction with structures and lithology. The geomorphology of the research region is a crucial factor to be taken into consideration for groundwater recharging since it helps to understand how landform evolution explains the presence of porous and permeable zones. (Gintamo, 2014; Rajaveni et al., 2017).

Concentrated on the geologic structure and geomorphologic landforms, but the occurrence, rate of infiltration, and storage capacity of groundwater are influenced by several factors, including lithology, geomorphology, slope, drainage density, land use, rainfall intensity, soil texture, and so on (Ghosh et al., 2016; Hasibuan et al., 2021). Rainfall that seeps through the soil and rocks beneath the surface of the ground mixes with the water table. If these voids are connected,

groundwater can migrate through them. However, they may be isolated in some rocks and sediments, which prevents water from flowing through the interstices. Thus, it is clear that the mode of groundwater occurrence greatly depends on the kind of formation and the local geology (Chapagain & Hoekstra, 2004). In Ethiopia, geophysical and climatic circumstances of the region have a significant impact on the groundwater's occurrence, which makes it challenging to find productive aquifers. Ethiopia is also unusual in that its geology, topography, and environmental conditions are quite diverse. Additionally, because it depends on a variety of environmental and geological conditions, groundwater is not always present (Alemayehu, 2006; Morsy & Othman, 2021). According to broad categories, the country's geology can be summarized as consisting of 18% of Precambrian basement, 25% of Paleozoic and Mesozoic sedimentary rocks, 40% of Tertiary sedimentary and volcanic rocks, and 17% of Quaternary sediments and volcanic rocks (MOWR, 2009).

2.5 Importance of groundwater potential zone delineation

The defining of groundwater zones is crucial for the environment, economy, ecology, and community. For various reasons, groundwater potential zones are defined by many academics. For example, (Andualem & Demeke, 2019a) used for sustainable use of groundwater resources for development activities and for increasing groundwater recharge by adopting proper management, and also (Chen et al., 2018) It is used for successful groundwater protection and management programs.

According to de Jong, (2015) Groundwater potential zone delineation is used for planning the situation of the latest abstraction wells to satisfy the increasing water demand. Generally speaking, groundwater potential mapping used for a subsistence plan, for optimal development of the water resources, for locating solutions to various management problems associated with natural resources, represents favorable groundwater potential zones, and this information might be used to reduce the risk of public health issues associated with water shortages and poor water quality as well as to prevent situations where the sustainability of the resource is compromised in human development. (Singh, 2014; Kabeto et al., 2022a).

2.6 Role of GIS and remote sensing in groundwater potential and recharge

Many studies have been conducted on the application of GIS and remote sensing to the recharge zone and the potential of groundwater. They identify various thematic maps for delineating groundwater potential and recharge zones like drainage density map, lineament map, land-use land-cover map, hydrogeology map and soil map, and slope map in their study on groundwater potential and recharge zone based on GIS and remote sensing. (Agarwal & Garg, 2016). The Geographic data system provides tools for managing and analyzing spatial data that can help users organize, store, edit, analyze, and display positional and attribute data regarding geographic data. (Burrough et al., 2015).

The earth's top instruments for hydrological science have evolved into remote sensing and geographic information systems (GIS). Because of its established direct association with related fields like geology, soils, vegetation/land use, and hydrology, remote sensing technology has become more significant for geomorphological investigations. Using a geographic information system (GIS) and remote sensing (RS), which can access, alter, and analyze spatial and temporal data from satellite images, can offer all parameters that affect a region's groundwater potential and recharge. (Barik et al., 2017) .

In addition, Gupta & Srivastava, (2010) Explain the various decision analysis approaches like Multi-Criteria Decision Making (MCDM), Analytical Hierarchical Process (AHP), and Fuzzy Logic to fill the gap between groundwater potential and decision-making on evaluation and mapping of recharge zones. The analytical hierarchy process is an effective tool for making complex decisions. A rigorous pairwise comparison matrix for evaluating consistency ratio (Saraf & Choudhury, 1998). These decision-makers employ strategies to lessen bias in their decisions.

In general, several thematic layers such as lineaments, slope, drainage, and overburden thickness were integrated without taking aquifer thickness into account. This demonstrates a thorough understanding of the region's groundwater prospect and the outcome of the groundwater potential zones map developed. Elbeih, (2015) describes the use of GIS and remote sensing and compares their applications to other techniques such as geospatial, numerical modeling, and geophysical methods for groundwater delineation. And concluded that the procedures mentioned above are exceedingly costly, difficult, time-consuming, and damaging. Compared to the

techniques listed above, (Gintamo, 2014) states that because groundwater is found underground, it cannot be seen directly with the naked eye. However, many techniques can provide information about groundwater and recharge potential zones, including hydrological investigation, geophysical and geo-electrical methods, and geophysical seismic refraction techniques, all of which are very costly and time-consuming. With the ability to quickly and readily access all the parameters of the factors that affect groundwater potentials and recharge zone areas, GIS and remote sensing are the most recent, time- and money-efficient technologies for groundwater exploration (Biswas et al., 2020). This model was tested against borehole yield data to determine whether it was accurate and agreed with the outcome.

2.7 Multi-criteria decision analysis and Analytical Hierarchical Process Method

The most crucial method of the Multi-Criteria Decision Analysis (MCDA) procedure is the Analytic Hierarchy Approach (AHP). Numerous issues have been resolved using the AHP method, which (Wind & Saaty, 1980) Suggested as a means of resolving socio-economic decision-making issues. When dimensions are independent, AHP is used. (Saaty, 1996) It offers a way to use measurement and judgment as inputs to create ratio scale priorities for the allocation of influence amongst the various thematic levels. (Saaty, 1996) suggested using AHP to address the issue of independence on options or standards.

The AHP prioritizes elements, but it may also prioritize groupings or clusters of components when necessary (Saaty, 1999) With the use of a context-specific multi-criteria evaluation method offered by AHP, one distinct alternative can be measured in the face of broad criteria. Different researchers employ various weight overlay and decision-making analysis techniques; as a result, (Sajikumar & Pulikkottil, 2013) adopted thematic layers of elevation, land-use/land-cover, lineaments, and drainage that provided precise information about groundwater occurrence and generated the result from Weight Index Overlay Analysis (WIOA) by using analytical hierarchy process methods.

Numerous studies have examined how different thematic layers affect a region's capacity for groundwater and have reported on their respective importance. The weight ages based on (Saaty, 2008) scale have been proposed by (Suganthi et al., 2013) for various thematic maps to identify groundwater potential zones. To define the groundwater potential and recharge zone maps, the

Satty's Analytical Hierarchical Process (AHP), an MCDM technique, is utilized to equalize the weights of various thematic layers and their classes. According to earlier and more recent studies, Ethiopia had undoubtedly conducted a number of studies in order to gradually meet its critical water (Tamiru, 2006). According to Foster, (1998), groundwater accounts for roughly 60% of the world's freshwater supply, or 0.6% of all the water in the universe.

The area's geology, slope aspect, lineaments, drainage density, land use/land cover, rainfall, surface runoff, and geomorphology all affect the availability, accessibility, movement, and occurrence of ground water (Shaban et al., 2005). Because it saves money and time, evaluation, exploitation, exploration, site selection, and groundwater map-making require extreme prudence. Due to the fact that the issue will most likely arise from inappropriate site selection and ground water evaluation (Biyayilgn, 2021). To define the groundwater potential zone based on weight assignment and normalization with respect to the relative contribution of the numerous themes to groundwater occurrence, the Analytic Hierarchy Approach (AHP) is applied.

2.8 Effect of land management factor on ground water potential.

Understanding how the pattern of land use can influence hydrological processes requires an understanding of how to classify the land cover and land use of a region. With respect to specific land use classes, the reaction of groundwater recharge into the aquifer system varies greatly (Verma et al., 2020; Ag & Oy, 2022). Thus, used for determine how the land class change can affect the hydrological area for groundwater potential evaluation.

Changes in land use are found to have a greater impact on groundwater. Groundwater recharge and other hydrological components can be affected by changes to particular land cover classes, such as water bodies and forest vegetation, through changing interception and infiltration processes (Kuroda et al., 2017; Kirimi et al., 2018). According to Harbor, (1994), conversion of woodland to low density residential , high density residential and conversion of woodland to commercial uses reduces groundwater recharge Reduced infiltration has been mostly attributed to increased impermeable area brought on by changes in land use (Chemura et al., 2020). To show the overall level of land constraint with relation to agricultural activities, land capacity class norms at the watershed size are essential (Rossiter, 2009). The changes in land cover, and urbanization has a negative impact on groundwater status (both quality and quantity) and its

recharge (Thapa & Gupta, 2017) this implies how land management factor has influence on groundwater potential zones.

The hydrology of the region has changed because of the conversion of natural, agricultural, and other low-population density lands into urban settlements. Urbanization and the ensuing changes in land use and land cover clearly have very negative effects on the regional environment (Strehmel et al., 2016, ; Patra et al., 2018). The quantity, structure, and form of groundwater recharge as well as surface runoff are impacted by population growth, agricultural expansion, and urban area expansion. A shift of this nature may have a variety of direct and/or indirect effects on the socioeconomic situation as well as the natural environment (Lamichhane & Shakya, 2019). According to Bhattacharya et al., (2020) integration of thematic parameters has more or less influenced on GWPZ, but fluctuation rate of recharge level has mainly depended on land cover dynamics.

Ethiopia has set out to implement a sustainable land management program in order to attain a green economy on a policy level (Gessesse, 2010). By considering this identifies what kinds of land cover alteration processes either negative or positive influences on groundwater potential, using remote sensing and GIS techniques to investigate the effect of changes in land management factors on groundwater potential.

2.9 Previous studies on groundwater potential assessment

As Ethiopian context also many research are conducted on groundwater potential (Andualem & Demeke, 2019; Tamiru & Wagari, 2021 Abdulkarim et al., 2022; Kabeto et al., 2022) which used as model for this work for instance, (Reys, 2016) examined groundwater potential appraisal and use patterns in the upper awash basin. The quantitative understanding of aquifer system and ground water conditions, how to manage ground water potential, and how to use trends to boost its contribution were some of the topics covered in this study.

Along with the aforementioned writers, Gowing et al., (2016) reviewed fifteen sub-Saharan African nations for their groundwater supply and utilization. And enumerates the hydrological aquifers parameters of sub-Saharan Africa and divides them into crystalline basement complex rock, consolidated sedimentary rock, unconsolidated sedimentary rock, and volcanic rocks. He concludes that sub-Saharan Africa's hydrological conditions are the primary controller of underground groundwater more than any other nation. (Tamiru, 2006) done on the groundwater

occurrence in Ethiopia and outline the key elements influencing groundwater flow and storage in volcanic rocks. Additionally, he concludes that variations in the mineralogy, texture, and structure of volcanic rocks result in variations in the region's ability to support water.

Although Andualem & Demeke, (2019b) conducted groundwater potential assessment using GIS and remote sensing on upper blue Nile basin in this studies by integrating several groundwater contributing theme layers, the Multi-Criteria Decision Analysis (MCDA) technique is applied to develop the groundwater prospective prospect zones. By allocating weights to each thematic layer and feature, the thematic layers of land cover, drainage density, lineament density, soil, geology, slope, and geomorphology were generated and used for groundwater potential map generation. Also Duguma & Duguma, (2022) were studied groundwater potential zone on Guder sub- basin , and concluded that The northern portion of the research region, beginning at the center longitude, as well as the northwestern, southern, and southwestern portions of the Guder sub basin, are where the extremely high GWPZs are located. Due to the presence of escapements, hills, steep side slopes, slopes, and rock surfaces, low to very low groundwater potentiality has been observed at various distances from the center. This study shows to the GIS and remote sensing techniques as an effective model for delineation of GWPZs and can be applied at other basins of Ethiopia.

3. MATERIAL AND METHOD

3.1 Description of the study area

The study is conducted in the Muger catchment which is one of the upper blue-Nile basins. The catchment is geographically located between 37°57'15"E-38°57'35"E longitude and between 8°37'0"N-9°58'20"N latitude. The Muger catchment covers the total area of 7332 km² Figure 3.1). This catchment enters the upper Blue-Nile River from the southeast of the basin. The elevation in Muger catchment varies from 975 m amsl to 3538 m amsl. The eastern and southern highlands of the sub-basin are higher in altitude, ranging from more than 2600 meters to 3538 meters. Less than 1700 m amsl of altitude are found in the lowlands of the Muger catchment (Yilma & Awulachew, 2009).

The catchment receives yearly rainfall that ranges from 844 mm to 2937 mm. The annual sub-basin's temperature ranges from maximum 16°C to 31.5°C and minimum 3°C to 16.5°C. The catchment is found in tepid to humid highlands. Lowlands in the northwest is hot to warm and humid area (Amare & Simane, 2017).

The main soil types in the sub-basin are rendzinas, Lithosols, chromic Luvisols, and Vertisols. Pellic Vertisols, eutric nitisols orphic Luvisols, eutric Cambsols.

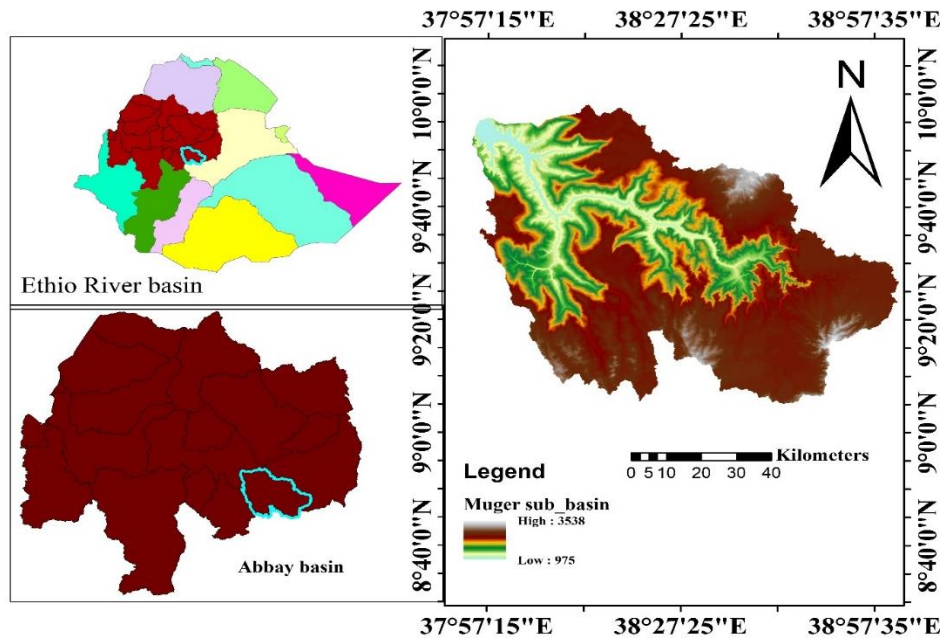


Figure 3. 1 study area Muger catchment

3.2 Climate

3.2.1 Rainfall

The spatial and temporal variation of climate pattern in most part of Ethiopia is controlled by the movement of the Inter Tropical Convergent Zone (ITCZ) with respect to equator (McCartney et al., 2013). The monsoon climate, whose moisture is generated from the Congo vegetation and the Atlantic Ocean, has an impact on the western and south-western parts of Ethiopia. The ITCZ is located in northern Ethiopia, and the area is affected by moisture from the Atlantic and Indian Oceans during the summer (Roth et al., 2018). Most of the study area, as it is situated in the central highland of eastern, southern, and western plateau of the country, it receives the highest rainfall during the summer season in the month of June, July and August and the lowest rainfall in the months of October to February. The rainfall pattern is mono modal. The 25 years of ten station rainfall data from Ethiopian national meteorology agency (1997-2022) of the study area is collected for this study (appendix 1). The area received rain between 844 mm to 2937 mm annually and received 10mm to 298.63 mm average monthly rainfall (Figure 3.2).

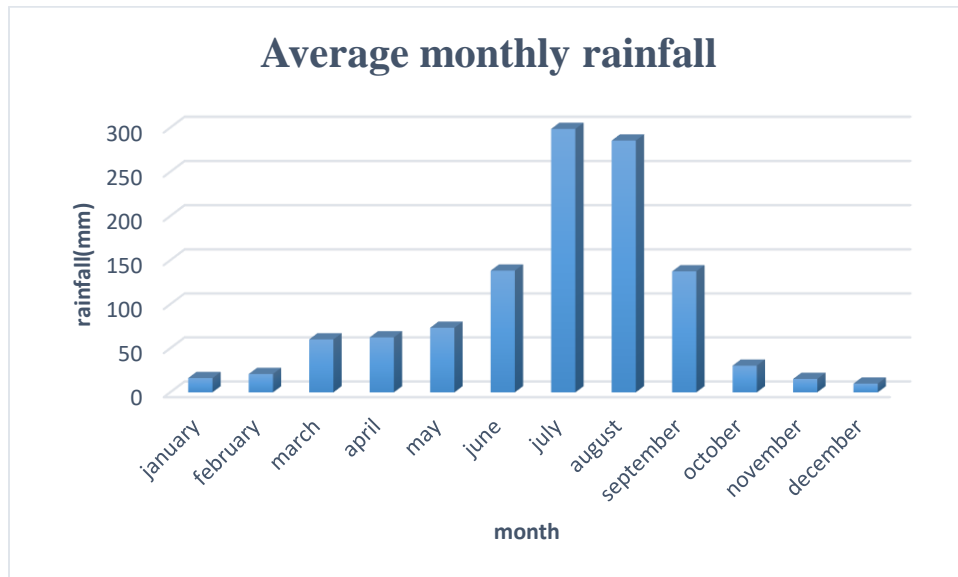


Figure 3. 2 average annual rainfall.

3.2.2 Temperature

The monthly temperature in the area varies considerably. For the currently study area the minimum and maximum temperature was collected (Appendix1). The minimum mean temperature varies from about 7.21 to 9.89 C° throughout the year. The maximum mean

temperature varies from about 20.6 to 24.44 C° and the average mean Temperature is about 16C° (Figure 3.3).

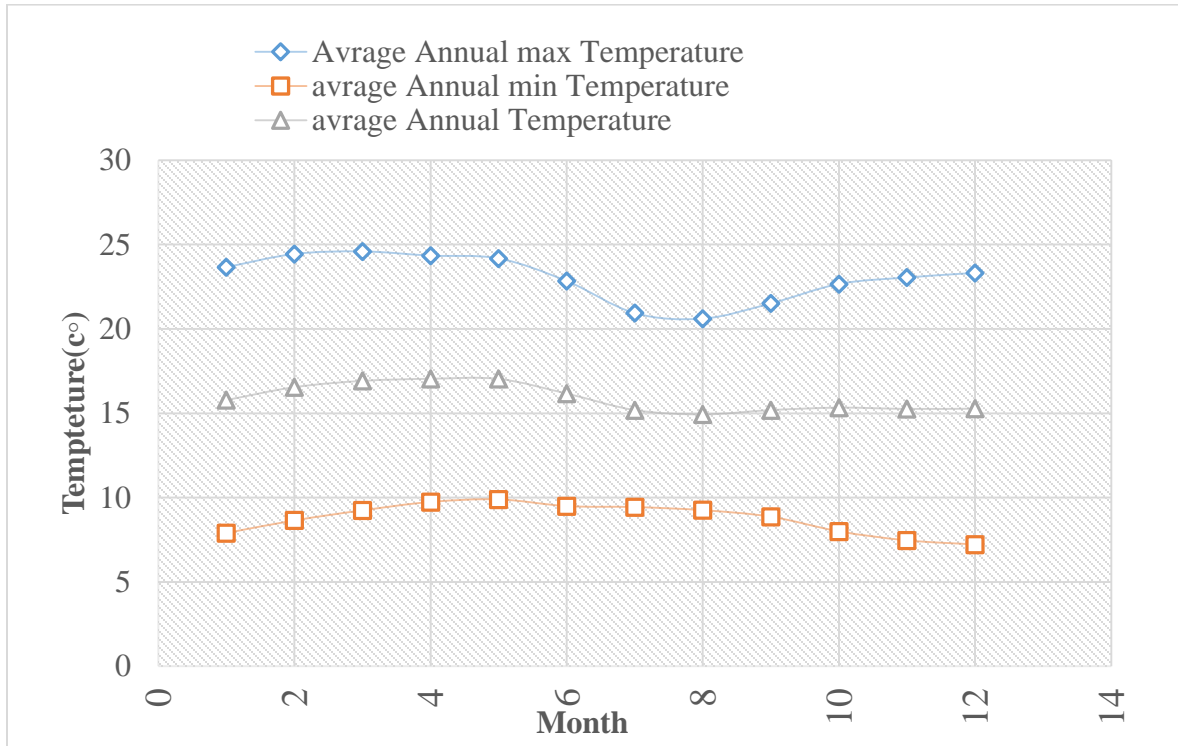


Figure 3. 3 maximum, minimum, and mean temperature of Muger catchment

The Potential evapotranspiration (PET) of the catchment ranges from 1215 mm to 1970 mm annually. PET is greater than 1800 mm/yr. Along the low land where the temperature is high. The eastern half of the catchment highlands have less PET than 1450 mm/yr (Adeba & Tafese, 2021). Due to the temperature and precipitation variation the minimum PET of the area on the contrary occurred during the months of June, July, and August whilst the maximum occurred during the months of October to February.

3.3 Data

To conduct this study eight significant surface and subsurface groundwater potential-influencing data were chosen and established for groundwater potential assessment. Those are LULC, rainfall, slope, elevation, drainage density, liniment density, geology, and soil type. These criteria were selected due to being commonly used in previous literature and advised by several

experts to be used (Andualem & Demeke, 2019b; Hasibuan et al., 2021; Duguma & Duguma, 2022; Kabeto et al., 2022).

To create slope, elevation, lineament density, and drain density maps for the study area, a Shuttle Radar Topographic Mission DEM with a spatial resolution of 30m was acquired from USGS Earth Explorer. For LULC analysis Landsat image was collected from USGS earth explorer (<https://earthexplorer.usgs.gov>), data acquired on (01, December 2022). The data was gathered from Landsat (8, OLI/TIRS) (as discussed in section 3.7.1). Geology and soil layers were created using data sources from the Ministry of Water and Energy, Ethiopia. Rainfall data is acquired from Ethiopia's National Meteorological Agency. The groundwater inventory data for the (borehole, spring, and well data) were received from the Oromia Water and Energy Bureau (OWEB) (Table 3.1).

Table 3. 1 Shows data source, and its purpose to conduct research.

No	Data type	Data source	Resolution	Purpose
1	Land satellite image	USGS (United States Geological Survey) Landsat (8, OLI/TIRS)	30m*30m	To produce a land use land cover map of the study area.
2	DEM	SRTM DEM (30m) www.earthexplorer.usgs.gov	30m*30m	Used to delineate the catchment and analyze drainage characteristics
3	Soil and geology	Ethiopia ministry of water, and energy (EMWE).	1:250000	To realize the characteristics of the soil for the catchment
5	Meteorologic al data	Ethiopian National Meteorological Agency	Point	To use it as input for GIS software to conduct a hydrological impact assessment
6	Borehole and well data	Oromia water and energy bureau and (EMWE).	Point	For validation

3.4 Research Design

The study was conducted in stages to identify groundwater zones with potential, revealing the possibility of using remote sensing and GIS for groundwater exploration. Designing the occurrence and movement of groundwater requires considering several variables, including geology (lithology and lineaments), rainfall, geomorphology/landform, slope, drainage, and land use/land cover and soil. These variables are primarily derived from satellite imagery using digital image processing techniques and pre-existing data. Using ArcGIS software, a large number of analog maps will be acquired from various organizations and are scaled differently and manually digitized as the first step in creating a GIS spatial database.

3.5 Software and material used

Computer hardware and software are among the resources that were employed in this investigation. ARC GIS was used for all row data analysis and ERDAS Imagine 2015 was used for the preparation of land use and land cover map of the study. In general, Table 3.2 provides a detailed explanation of the tools used to analyze the data, including ArcGIS, and ERDAS imagine 2015.

Table3. 2 Software and material that is used for the study.

No	Software and material	Purpose
1	ARC GIS	Data analysis, visualization, and storage
2	ERDAS imagine 2015	Image processing and classification
3	Google earth pro	Visualization and, compare ground truth for accuracy
4	Handled GPS	Collect ground control points (GCPs)
5	AHP (analytical hierarchical process)	For validation and compering of the analysis data each other

3.6 Data Preparation and method of analysis

3.6.1 Preparation of data set used.

The data that was collected from various sources is not offered in the format required for processing and analysis. So, it must be prepared in the format required before being used. Tools for creating feature data sets, tables, and other database elements are available in the ArcGIS software's catalog. The creation of thematic maps for additional processing and analysis involved the use of GIS operations such as transformation and conversion, attribute assignment, projection, interpolation, extraction, and others.

Groundwater potential zones of the study area were generated from eight variables, including land use land cover, geology elevation, slope, geomorphology, lineament density, drainage density, soil, and rainfall, which influence the presence and movement of groundwater in a given location. (Abdulkerim et al., 2022; Kabeto et al., 2022). These factors' relationships are weighted based on expert judgment, their impact on watershed productivity, and earlier research conducted in various watersheds across the world. The overall sum of the weights of each factor influence represents the groundwater potential of the study area. A factor that has a higher influence on groundwater occurrence and distribution than other get a larger weight than others and a factor with a lower weight value shows a smaller influence on groundwater potential interrelationship. The Integration of all these factors with their potential weights is computed through weighted overlay analysis in the ArcGIS environment software.

3.6.2 Method of Data Analysis

This study used geospatial technologies and advanced approaches to evaluate groundwater potential zones in the Muger catchment upper Abay River basin. To identify the research region's groundwater potential zones, various thematic maps with sizes of 1: 250000 and 30m pixels are produced from remote sensing and topographical data. Each thematic layer of factors that influence the groundwater occurrence geology, land use and land cover, drainage density, lineaments density, rainfall, elevation, soil texture, and slope was created by ARC GIS software.

By applying the Multi-criteria Decision Analysis (MCDA) method, the eight thematic layers of geology, land use and land cover, drainage density, lineaments density, rainfall, elevation, soil texture, and slope are considered as determinants of the area. The Pairwise matrix has been used to compute the relative importance based on Saaty 's continuous scale in AHP. Finally, weight

overlay analysis has been used for the detection of groundwater potential zones through integrating thematic maps. The outcome of the study was validated by collecting the well data from the study area. The overall framework of the study methods starting from data collection and analysis up to the suggestion of proper groundwater management strategies was presented in the flowchart (figure 3.4).

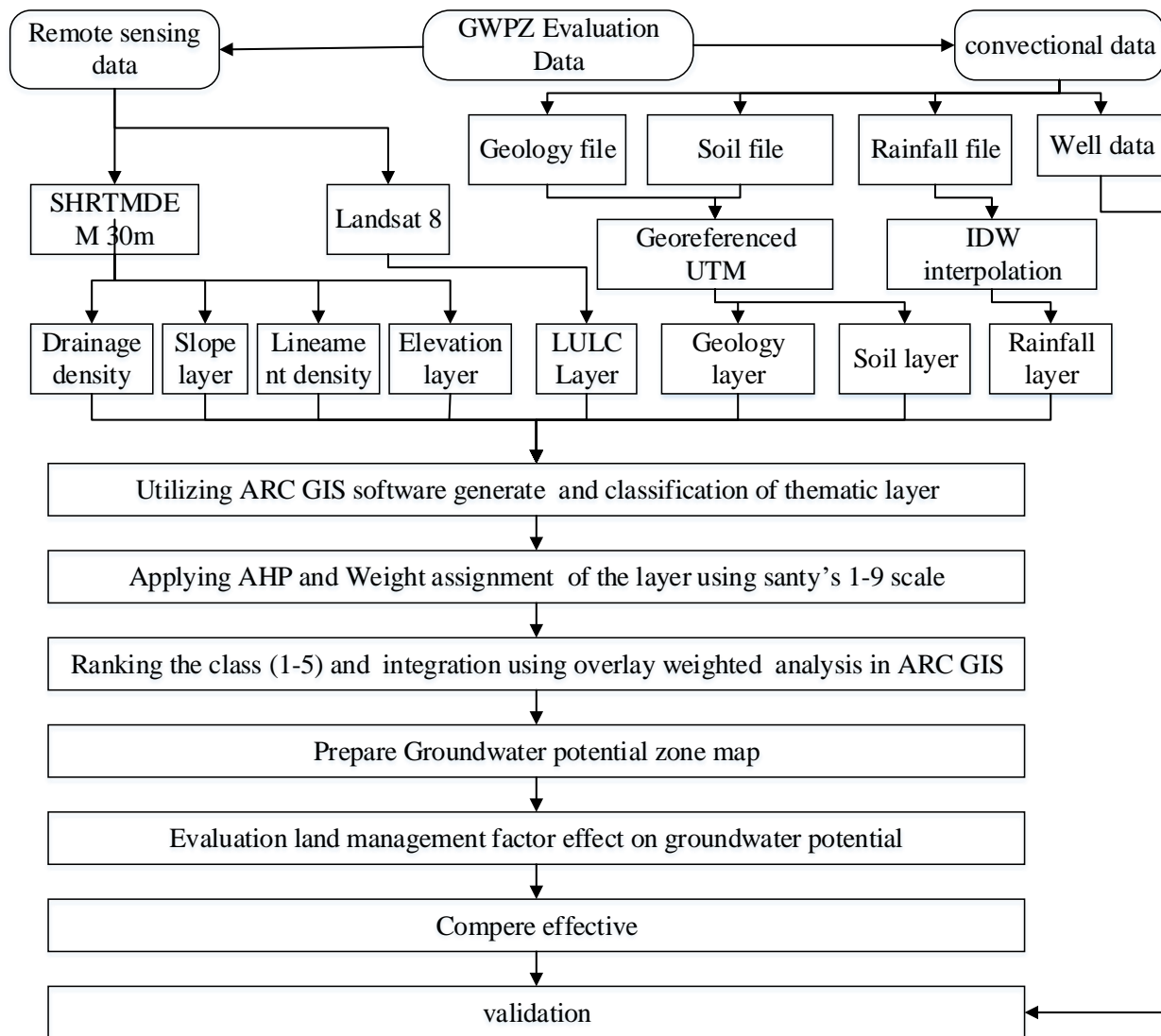


Figure 3. 4 Conceptual Flow chart of groundwater potential evaluation using GIS and RS mapping methodology applied to Muger sub-basin.

3.7 Developing groundwater potential influencing thematic layer.

The groundwater potential zones were prepared by preparing the thematic layers of factors that influence groundwater occurrence, movement, and distribution. literature (Andualem & Demeke,

2019; Atmaja et al., 2019; Tamiru & Wagari, 2021; Kabeto et al., 2022;). In the preparation of the GWPZ map various researchers used varying numbers of theme layers; this could be due to variations in the data that is available. Groundwater is influenced by geology, lineament density, drainage density elevation structure, geomorphology, and drainage; land use, `rainfall, and infiltration rate also have an impact on replenishment (Kumar & Krishna, 2018; Achu et al., 2020; Abdulkerim et al., 2022; Duguma & Duguma, 2022). Also, in the investigation of Muger catchment groundwater potential zone analysis, approximately eight thematic layers including geology, land use/cover, soil type, elevation, slope, drainage density, lineament density, and rainfall were applied.

3.7.1 Geology layer

Geology is the most significant aspect of the probable occurrence of groundwater because the penetration mostly depends on the permeability or conductivity level of various rock types. (Fetter, 2001; Das et al., 2017; Das et al., 2019). Understanding the distribution of geologic materials with different hydraulic conductivity and porosity requires knowledge of how these earth elements developed and the changes they experienced, as groundwater inherently occurs in geological formations.

Higher porosity contributes to higher Groundwater storage and higher permeability contributes to higher groundwater yields. (Keith David Todd, 2005). The study area's geology layer was created by using the ArcGIS software. The Ethiopia geology layer was georeferenced and projected to the WGS1984 UTM Zone 37 using the data management tools' projection and transformation tools. With the use of the clip tool in ArcGIS' analysis tools, the geological formation image for the Muger catchment was cut using the study space shapefile. By converting a dissolved geology shape file to a raster image using the polygon to-raster tool, a study space geology layer was created (Figure 3.5). The area covered and the geological type of the study area are also presented in Appendix 2 Using the reclassify tool of the spatial analysis tools, the geology layer categories were reclassified into five category values ranked as per the suitability for groundwater potential development.

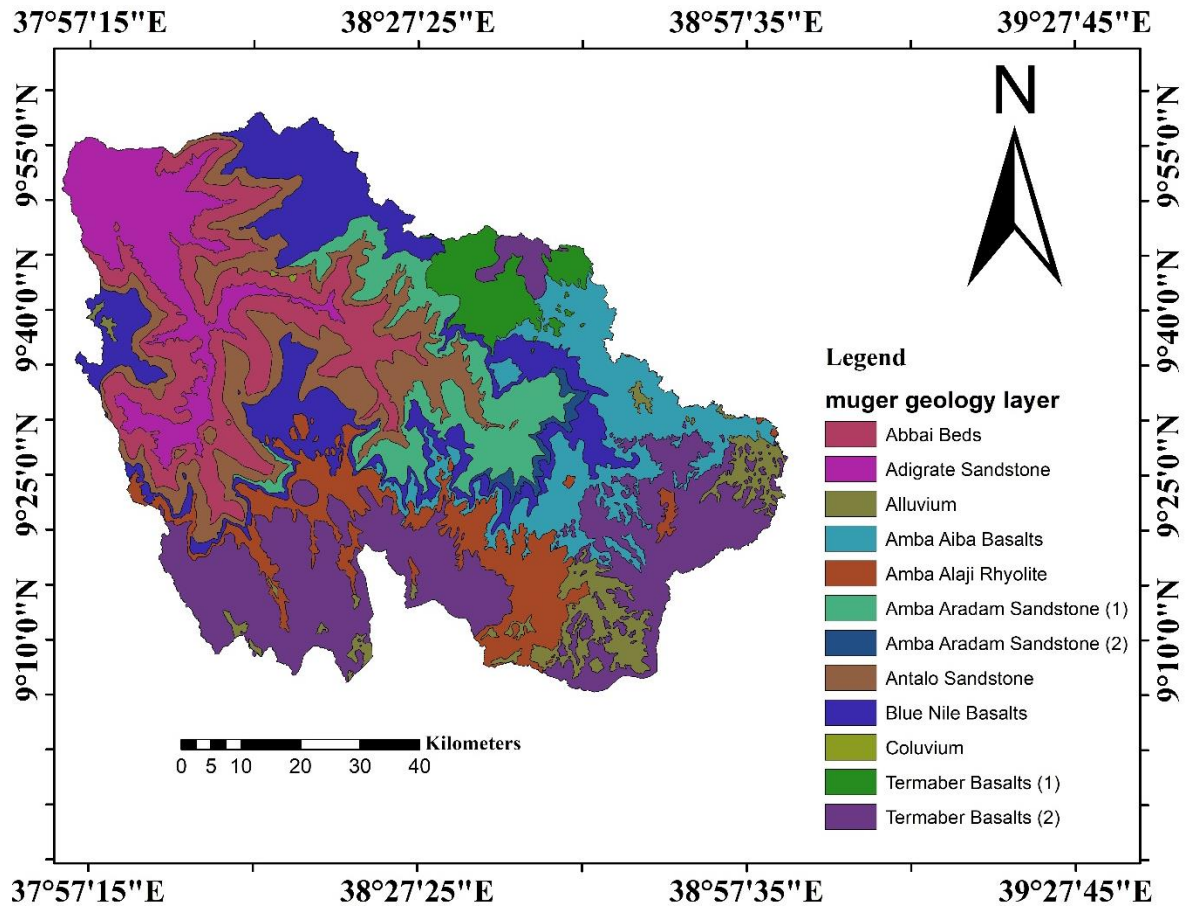


Figure 3. 5 Geology layer of Muger catchment

The study area is situated Within the Blue Nile River basin. According to (ALEMU, 2010; Kebede, 2013; Adeba & Tafese, 2021) There are three stages of volcanism and tectonism in the Cainozoic volcano, more especially the tertiary volcano of central Ethiopia. Alkali rhyolite comes initially, then flood transitional basalt (theoretic), and finally alkali basalt. The initial site of the volcanism was a sizable, lengthy basin. In this stage, the volcanism in the uplifted area dies out. The outside portion of the basin was uplifted and severely degraded (Ashangi peniplanation). Strong, broad crustal displacement resulted in a resurgence of volcanism, which characterizes the escarpment in the end. Finally, the fissural (Alajie rhyolite and Alajie basalt) to central type (Termaber-Megezez basalt) transition of volcanism occurred.

3.7.2 Slope

The slope is a significant factor that aids in defining the groundwater potential zone (Barik et al., 2017) It has a direct impact on surface runoff and infiltration. While a high to moderate slope

increases surface runoff, a low/nearly level slope has high infiltration and minimal runoff, which leads to good groundwater recharge (Szabó et al., 2015; Rawat et al., 2019).

A slope map of the study area under investigation was created using the DEM satellite's (digital elevation model) spatial resolution of 30 m* 30 m. Under the guidance of ArcGIS spatial analyst tools, the slope was produced and classed into five groups, the degree of the slope served as the basis for classification. According to its impact on the likely occurrence of groundwater, the attribute table's weighting was assigned.

The research area has a slope of 0 to 76%, and the eastern, northern, and southern portions of the mugger catchment have gentle slopes (Figure 3.6). The slopes are classified into five classes according to natural breaks in the ArcGIS spatial analyst tool. (Singh et al., 2013; Haile, 2022). About 38.35% of the study area is covered with a gentle slope of 0-5° area 2811.502 km², (31.69%), of the study area slope of 5-12° area 2323.397 km², (19%), slope of 12-21° area 1392.907km² (8.23%), slope of 21-33° area 603.0411 km² and, (2.73%), slope of 33-76° area 200.2974 km². Table 3.3 shows the slope area coverage of the Muger catchment.

Table3. 3 Slope class area

Degree	Shape Length	area km ²	area percent	Rank
0_6.3 (%)	36492460.51	2812.49	38.36	5
6.4_13.2 (%)	66793780.47	2243.32	30.60	4
13.2_21.9 (%)	47845296.78	1446.11	19.73	3
21.9_34.2 (%)	21905738.22	621.15	8.47	2
33_76 (%)	6249411.69	208.08	2.84	1

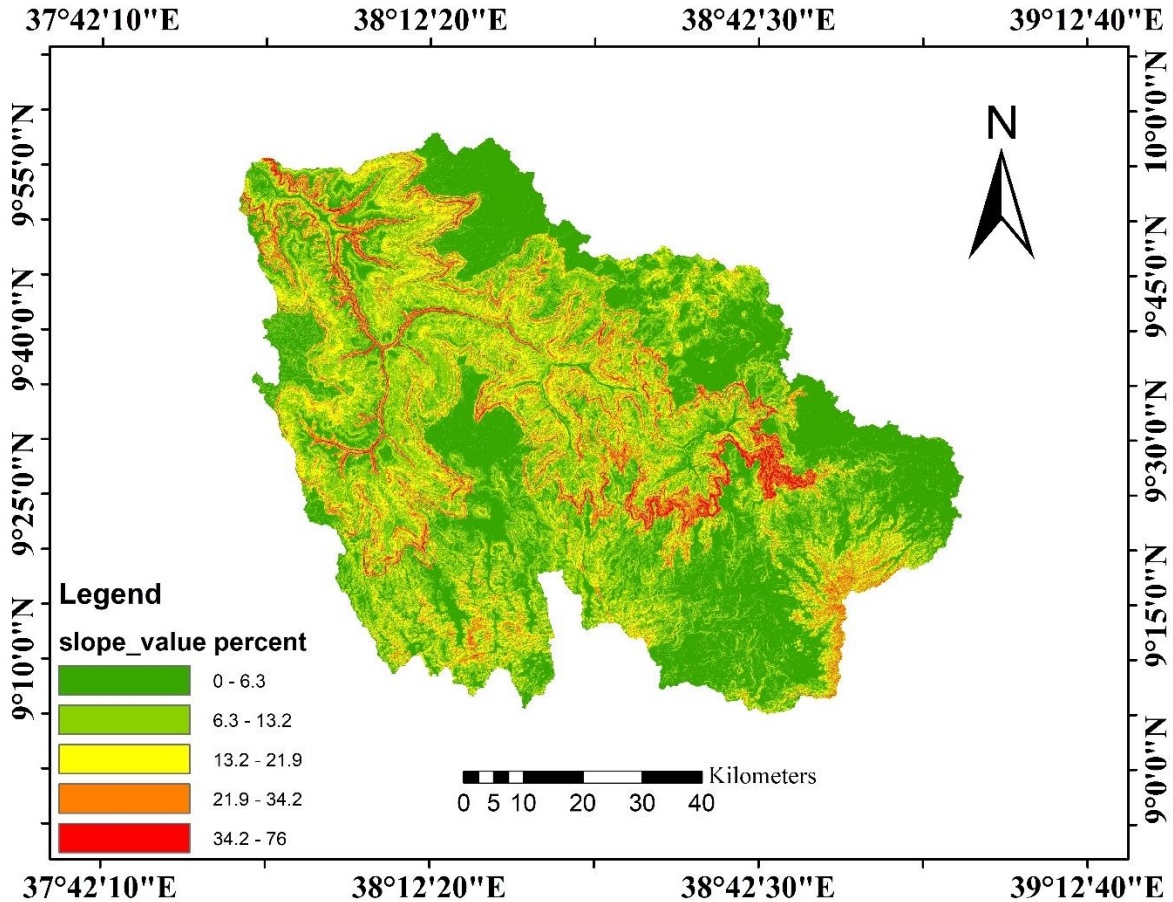


Figure 3. 6 slope layer of Muger catchment

3.7.3 Soil type

The type of soil and its permeability have an impact on the moisture capacity of the soil (Kumar et al., 2016). As a result, it may be regarded as one of the crucial criteria in determining the distribution of groundwater potential zones. Different types of soil have different water infiltration and movement patterns. The amount of water that can permeate into subsurface formations and, consequently, affect groundwater recharge.

The Muger catchment soil layer was created, the Ethiopian soil data was collected from the Ministry of Water and Energy (MOWE) and FAO soil classification map was used in combination. Using ARC GIS tools, data management tools' transformation and projection capabilities were used to georeferenced the Ethiopia soil layer and project it to the WGS1984 UTM Zone 37. The soil type layer of the Muger Catchment was cut using the study space shapefile using the clip tool in ArcGIS' analytical tools. Transformed into a raster using the

polygon-to-raster tool of the conversion tools. This soil group map has been divided into eight new groups based on permeability and texture figure 3.7.

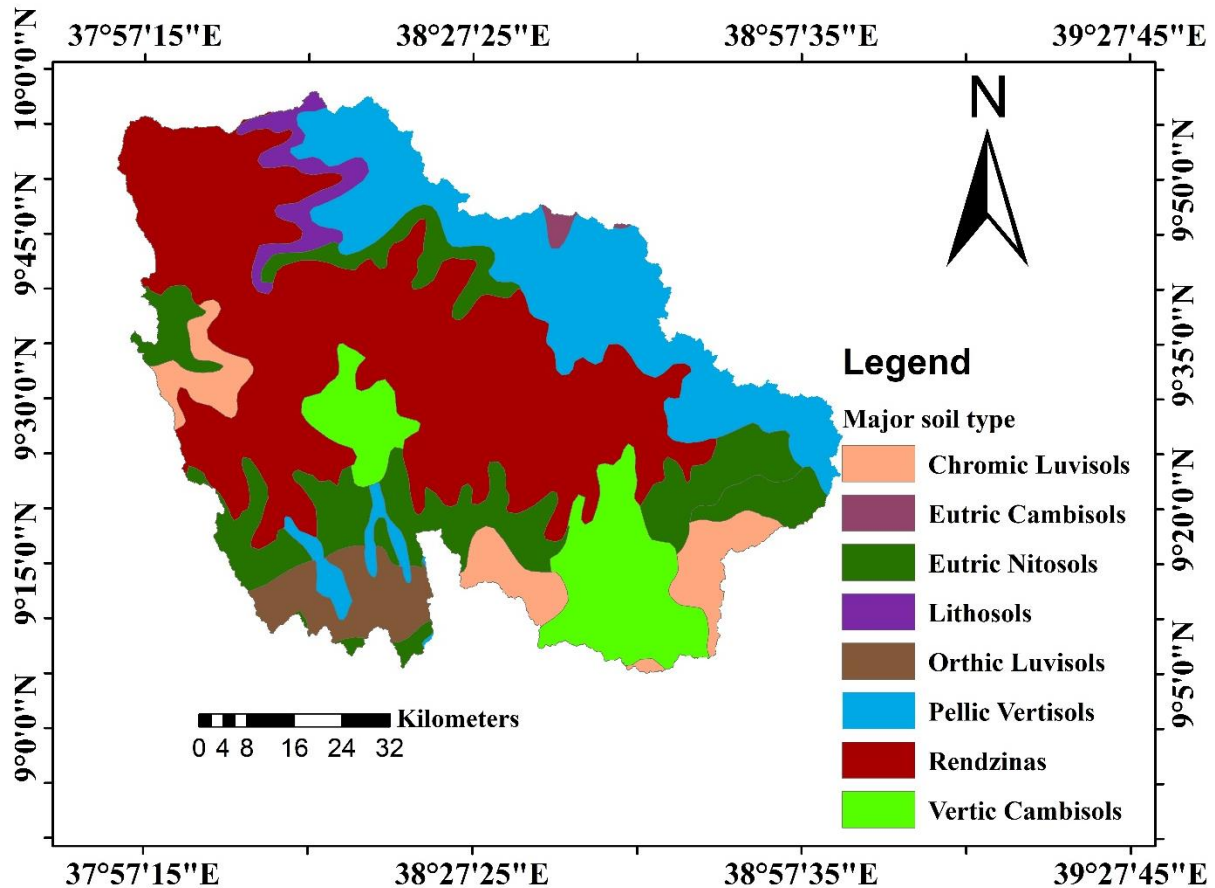


Figure 3. 7 soil type layer Muger catchment

3.7.4 Rainfall layer

The hydrologic cycle and the groundwater potential are both significantly influenced by rainfall. According to numerous researchers (Kumar et al., 2014; Berhanu & Hatiye, 2020; Ahmad et al., 2020) Rainfall is the principal source of ground water which is percolated or infiltrated into the subsurface. High rainfall amounts suggest a high likelihood of groundwater recharge, whereas low rainfall amounts have a low likelihood of reaching the ground (Shakya et al., 2019; Wang et al., 2020; Achu et al., 2020; Abdulkirim et al., 2022).

Understanding the nature and features of rainfall may also help one to conceptualise and forecast how it will affect runoff, infiltration, and the potential and recharge of groundwater (Mahalingam & Vinay, 2015; Kotchoni et al., 2019). For the currently study area the rainfall layer was created by using ArcGIS software. From the National meteorology service of Ethiopia for the preceding

25 years (1997-2022) from ten stations within and around the study area monthly rainfall data was collected. Using an ArcGIS geoprocessing tool that interpolates by inverse distance weighted (IDW) method, a surface from points and generates a rainfall layer of the study area (Figure 3.8). The classes of the rainfall map were reclassified into five class values in accordance with their rank according to the influence of the groundwater potential. After the interpolation was done the mean annually rainfall of the catchment ranges from 906.11-1325.59mm/year (Figure 3.8)

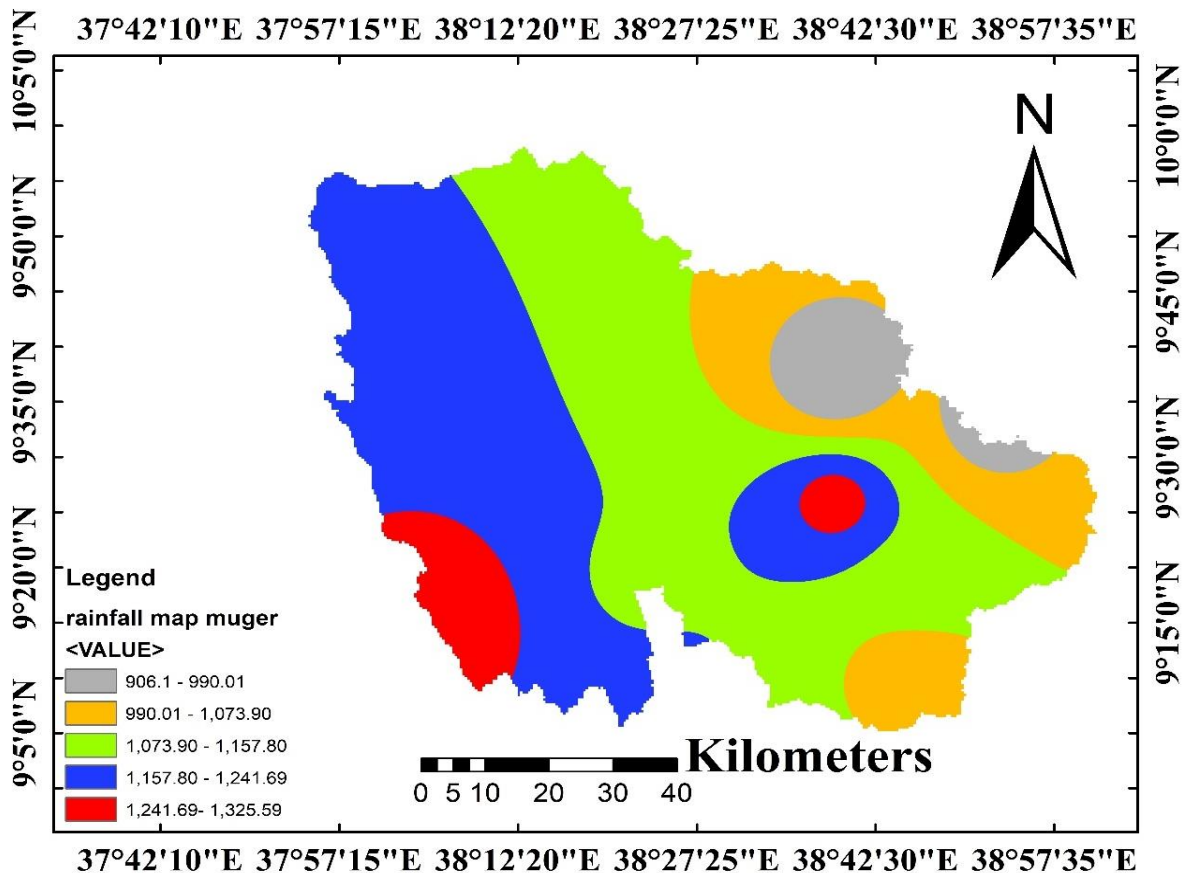


Figure 3. 8 rainfall layer of Muger catchment

3.7.5 Land use land cover

3.7.5.1 Data and classification

Land use land cover (LULC) is a representation of the geographical aspects of the Earth's surface, both naturally occurring and man-made, including flora, water, and human habitation (Mahmon et al.,2015). The hydrogeological and geo-hydroclimatic processes of runoff, infiltration, groundwater recharge, and evapotranspiration are all greatly influenced by land use

and land cover (Guru et al., 2017; Tolche, 2021). Remote sensing information on the geography of the Earth has been consistently used to study the Earth's surface and sub-surface information of the land, thanks to the USGS-managed Landsat program. Landsat images have been utilized in numerous studies on land use impact (Wen et al., 2019, Chemura et al., 2020).

Also in the current study, Landsat image was collected from the USGS Earth Explorer (<https://earthexplorer.usgs.gov>), data acquired on (01, December 2022). The data was gathered from Landsat (8, OLI/TIRS) with the Path of 168 and rows 053,054. Also have cloud cover of land values of 0- 0.01, and 30 m spatial resolution/cell size. The image process and classification were done using ERDAS Imagine 2015 software. For this investigation, the three visible bands blue, green, and red as well as shortwave infrared bands 1, 2, 3, 4, 5, 6, and 7 for LC08 were taken into consideration. The image Composite using the process of toolboxes from bands 1, 2, 3, 4, 5, 6, and 7 was created.

From the composited image it is necessary to stack the several images that represent the various bands to analyse remotely sensed images. The layer stack is used to integrate various image bands into a single multispectral image file by using the raster layer stack tool. For the current study area 2 adjacent images with path 168, and adjacent rows of 053 and 054 layer stacked images are finally mosaiced in ERDAS imagine 2015. By using the raster subset toolbox the muger catchment was clipped out from mosaiced images for further analysis and classification. The nosies reduction and haze reduction were done utilizing radiometric and spatial methods (convolution) to create better smooth edges and eliminate gaps between the image.

3.7.5.2 Image classification

The three main techniques for classifying images used in remote sensing are unsupervised classification, supervised classification, and object-based image classification. For the classification of medium-resolution satellite images, the MLC has been frequently utilized. (Islam et al., 2018; Iqbal & Iqbal, 2018 ;Vivekananda et al., 2021). According to (Richards & Richards, 2022), supervised classification is a process in which "the user develops the spectral signatures of known categories, such as urban and forest, and the software assigns each pixel in the image to the cover type to which its signature is most comparable." "Supervised classification is the process most frequently used for quantitative analyses of remote sensing image data"(Rwanga & Ndambuki, 2017).

In this study supervised classification is used by using the Maximum Likelihood Classifier (MLC) algorithm. This technique has been applied after the development of training classes. One or more training sites were used to assign each class. For usage in the classification process during the supervised classification phase, the full Signature editor was chosen. Then, from the Editor Menu bar, the classify/supervised option was chosen. Then a Muger catchment image was classified also into five classes Figure 3.9: agricultural, water bodies, settlements, grasslands, and vegetation Table 3.4.

Table3. 4 Land cover classification and its area coverage

grid code	class name	area(ha)	Area (km ²)	Area (%)
1	Agriculture	538116.48	5381.16	73.27
2	grassland	101379.15	1013.79	13.80
3	Settlement	8647.02	86.47	1.18
4	Vegetation	83028.69	830.29	11.30
5	water bodies	3287.16	32.87	0.45

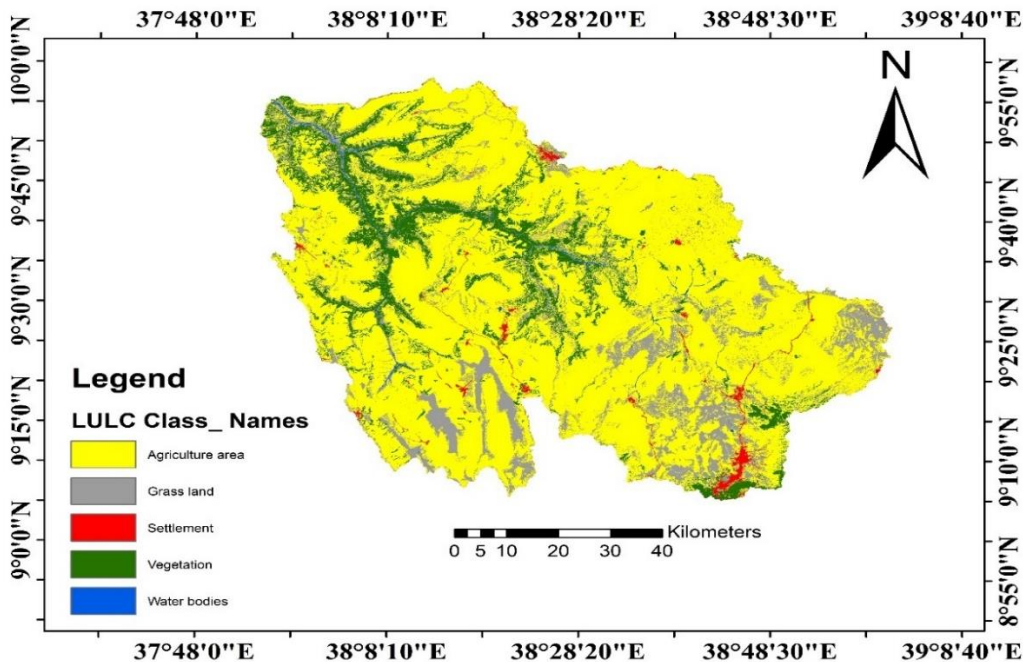


Figure 3. 9 Land use land cover of Muger catchment.

3.7.5.3 Accuracy assessment of classified image

After image classification, evaluating classification accuracy is a crucial step. In the current study using the ERDAS Imagine 15 software, with Google Earth Professional the accuracy of the classified images was assessed. Through stratified random selection of the classified images, the accuracy assessment tool of the supervised classifier created 256 reference points at random. Each point had a unique color and pixel value that the software immediately recognized.

The classifications in the image were used as reference classifications. The class for each set of randomly produced points was then manually assigned by the user. The self-generated report portion of ERDAS Imagine 15 was used to construct the error matrix and kappa statistics for the two classed images. The kappa coefficient was used to determine whether model predictions and reality were in a high degree of agreement. According to the recommended rating criteria for the kappa coefficient data, the strength agreement ranges from 0.61 to 0.80, and the 0.81–1.00 strength agreement is nearly perfect. (Rwanga & Ndambuki, 2017).

The ground truth from Google Earth Pro was also used as reference fill and from the accuracy box report the overall classification accuracy was computed by ERDAS Imagine 2015 the Overall Classification Accuracy of 84.0460%. This is in strong agreement with the ground truth and the kappa coefficient is (Overall Kappa Statistics of 0.8160). The details of overall accuracy and Kappa Statistics are shown in Table 3.5.

Table3. 5 Overall Classification Accuracy

class Name	reference Totals	classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Agriculture area	112	137	125	91.15%	87.58%
Grassland	32	32	26	81.25%	81.25%
Settlement	27	30	24	88.88%	83.00%
Vegetation	38	33	30	78.95%	90.91%
Water bodies	24	20	19	80.00%	95.00%

Overall Classification Accuracy = 84.046% and KAPPA (K[^]) STATISTICS Overall Kappa Statistics = 0.8160.

3.7.6 Elevation layer

Elevation might be directly related to precipitation, including the amount, frequency, and distribution of local precipitation. (Berhanu & Hatiye, 2020). In the local and regional relief context, topography provides insight into the overall direction of groundwater flow and its impact on groundwater recharge and discharge. The groundwater potential of the research area is also significantly impacted by altitude/elevation because Ethiopia experiences orographic rain. (Van den Hende et al., 2021). It is often assumed that high-elevation areas favor recharge in deep-settled confined aquifers situated in low-elevation or low-land areas. (Todd & Mays, 2004; Berhanu & Hatiye, 2020). In other ways, highland areas can also contribute some recharge through springs and play an important role in the occurrences of groundwater.

Therefore, higher elevations are guaranteed to have more groundwater recharge and ensure that groundwater is accessible in the watershed. Since water tends to retain more effectively at lower topographies than at higher topographies, the Muger catchment at low elevation encourages greater groundwater potential. The groundwater potential decreases with increasing elevation above sea level and vice versa.

The elevation layer of the study area was created by using arc GIS from DEM, as a result, the Muger catchment's highest and lowest altitudes were determined to be 3538 msal and 975 msal above sea level, respectively. As seen from the elevation layer of the study area, the catchment has a lower elevation at the western parts where the river enters the Abay River, moderate elevation was also referred at most of the central part of the catchment, and a higher altitude at the edge of southern section and the boundary (Figure 3.10).

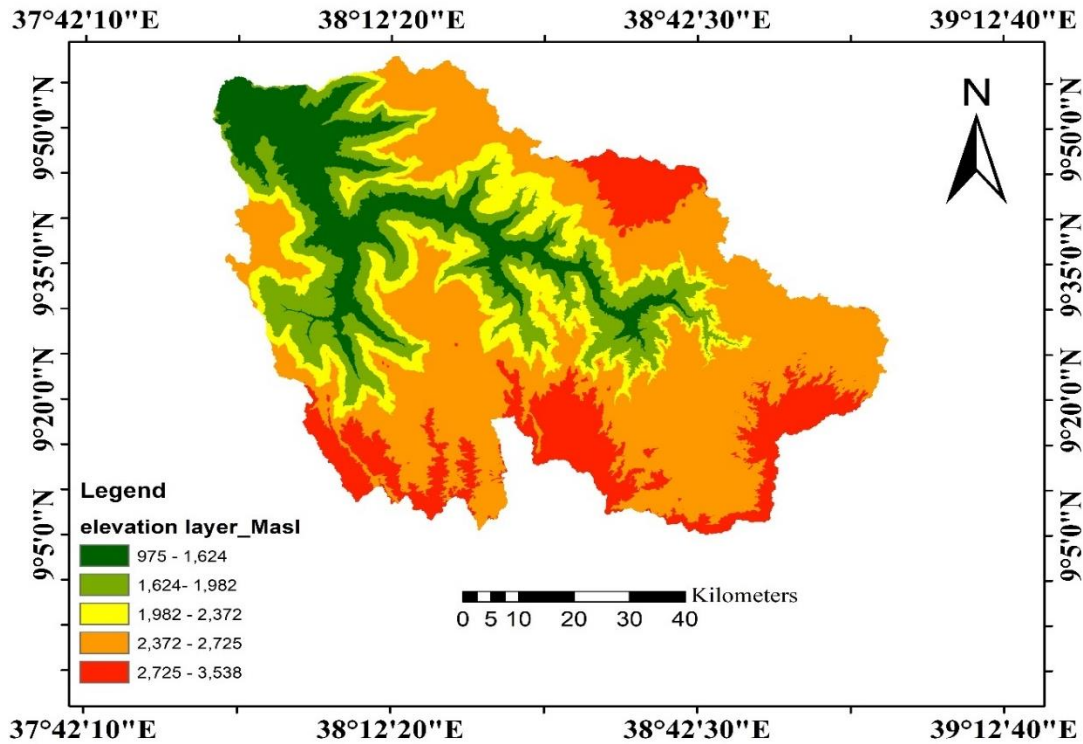


Figure 3. 10 Elevation layer of Muger catchment

3.7.7 Drainage density

Another crucial factor in determining a region's groundwater potential is drainage density. This index quantitatively describes the types of topographical circumstances where variations in runoff, soil permeability, and stream network development occur. (Nag et al., 2020). Drainage density measures how closely spaced stream channels and by comparing their combined length across all orders to their area (Singh, 2014b). According to several studies (Bagyaraj et al., 2013; Jenifer & Jha, 2017; Thomas & Duraisamy, 2018) Areas with lower drainage densities have more groundwater potential because run-off is more prevalent on impermeable rock and the range of low drainage density (0-5 km/km²), moderate drainage density (5-10 km/km²), high drainage density (10-20 km/km²) and very high drainage density (>20).

High drainage density is an unfavorable location for groundwater to exist, moderate drainage density has a moderate potential for groundwater, and low or no drainage density is a zone with a high groundwater potential. (Todd & Mays, 2004). The length of time that runoff stays in the watershed has an impact on runoff volume depending on drainage density. Longer residency durations are possible at low densities, which gives water abstraction systems more time to work.

To create the drainage density maps of the study area, using the DEM data manipulation tool of the terrain-preprocessing tool, a filling sink was first carried out to remove the highest elevation and lowest elevation that attract the water to create a drain density map of the area. Using the flow direction tool of the land preprocessing tools, a flow direction map was produced from the fill sink. Using the flow accumulation tools of the surface preprocessing in Arc Hydro tools, a flow accumulation map was produced from the flow direction. Using the raster calculator tool of the map algebra tool in the spatial analysis tools, the stream definition map was created using the flow accumulation data.

A peak is a cluster of one or more cells that is higher than all surrounding cells, whereas a sink is a cluster of one or more cells that is lower than all surrounding cells. (Rusli & Majid, 2012). With the help of the density tool in the ArcGIS spatial analyst tools, the drain density layer for the area was built from a network of dissipated streams (Figure 3.11). By using a reclassifying tool from the spatial analysis tools, these drain density map categories were classed into five category values based on their rank as per their appropriateness for groundwater potential and recharge.

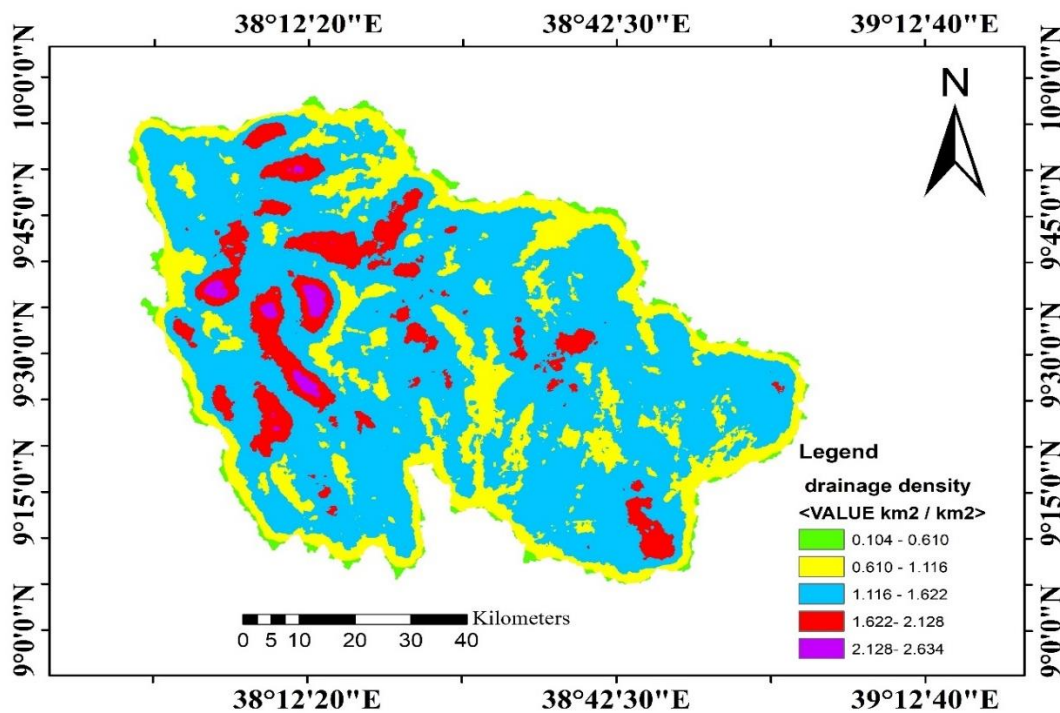


Figure 3. 11 drainage density layer of Muger catchment

3.7.8 Lineament density

According to (Todd & Mays, 2004), lineaments (linear features) serve as conduits for groundwater flow and provide information about underlying faults and fractures. Geological lineaments are the manifestation at the earth's surface of deeper geological structures (faults and fractures that have obvious displacement, ruptures that have no significant fracture displacement) it has been used to investigate the distribution of minerals and the regional distribution of groundwater potential. (Han et al., 2018; Andualem & Demeke, 2019a; Tolche, 2021).

Faults and fractures are expressed linear features on satellite images, and mapping of lineaments is an important component in hard-rock terrain where the occurrence and movement of groundwater are significantly influenced by linear features. These units largely reflect the discontinuities on the Earth's surface brought about by geologic or geomorphic processes. (Clark & Wilson, 1994). For the present study the lineament density map generated from a dem image, (SRTM 30m), was downloaded from <https://SRTM.csi.cgiar.org>. The USGS Earth Explorer website and had a spatial resolution of 30 m extracted using the Muger catchment shape file. By using the arc GIS spatial analysis tool the surface hillshade was done.

The line tool in the algorithmic librarian tool in PCI Geomatica Banff was used to mechanically extract the lineament of a photograph from photos exported in .tiff format and saved as file sort Arc read. Application of the editor tool, feature tool of the data management tool, and density tool of the spatial analysis tool operation resulted in the generation of line split, line split at vertices, and lineament density maps (Figure 3.12). From the extracted Muger catchment dem image, the lineament, and reclassified lineament density layer were created. These lineament density map classifications were by applying the reclassify tool of the spatial analysis tools in the arc GIS tool, the lineament density of the study area was ranked as suitable for groundwater potential and recharge zone delineation into five.

The North East and South West are where the main fault that cuts through the study area is located. Chain Mountain is located southwest of the study area, and to the north of it is the Moger River Gorge's continuation that leads to the Blue Nile River. The majority of the lineaments primarily follow linear tendencies of mountain ranges, river valleys, and streams (Fentaw & Alemayehu, 2011; Azagegn et al., 2015). And the range of low lineament density (0-2 km/km²), moderate lineament density (2-4 km/km²), high lineament density (4-6 km/km²), and

very high lineament density (> 6) which indicate that the muger catchment lies in low lineament density.

Table3. 6 lineament class area.

Value km/km ²	Grid code	Area km ²	Area percent (%)
0-0.15	1	2533.75	34.56
0.16-0.3	2	2646.59	36.10
0.31-0.45	3	1726.39	23.55
0.46-0.6	4	362.69	4.95
0.61-0.74	5	60.98	0.83
total		7330.39	100.00

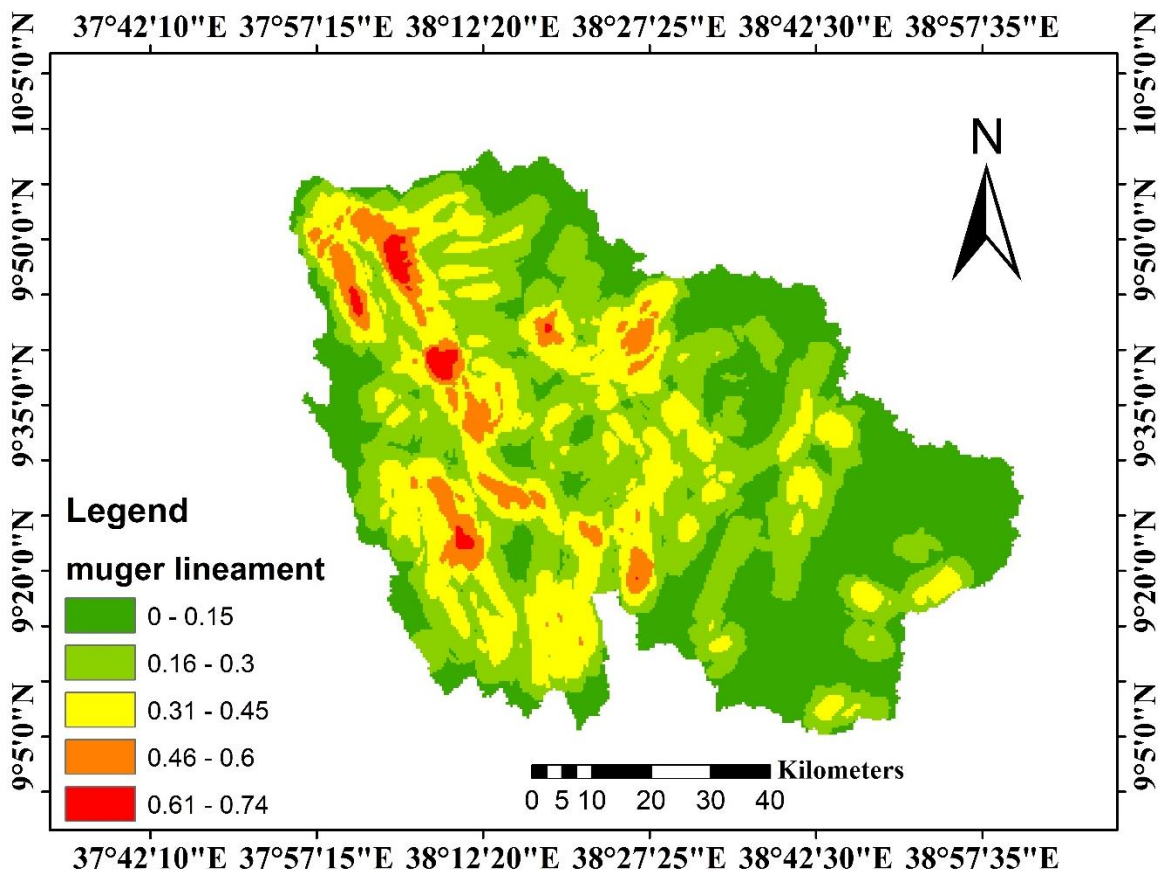


Figure 3. 12 lineament density layer Muger catchment

3.8 Analytical Hierarchy Process to Assign Weight

The Analytical Hierarchy Process (AHP), one of the methods, makes it possible to methodically identify the most influential factors. (Singh et al., 2017; Razavi-Termeh et al., 2019; Gizaw et al., 2023) . AHP is a method to derive ratio scales from the paired comparison which is one of the multi-criteria decision-making methods that was originally developed by Prof. Thomas L. Saaty (Saaty, 1996) . The commonly employed method for mapping groundwater potential is the Analytical Hierarchy Process (AHP) for the determination of weighted scale for criteria.

To define the groundwater potential and recharge zones, the pairwise comparison matrix $P(n \times n)$, was used. Where n is the number of parameters to be compared, was modified to be constructed based entirely on the quantity of the entered elements. (Saaty, 2008). When this method is applied reviewing a wide range of research, making personal judgments, and consulting experts are all required to rank and put a scale for the criteria (elements) affecting groundwater potential. (Bera et al., 2020; Gizaw et al., 2023). Based on this the Muger catchment groundwater potential zones evaluation of eight factors, rainfall, lithology, lineament density, land use/land cover, soil group, slope, elevation, and drain density, might analyzed. This is predicted to have an impact on the distribution and occurrence of groundwater in the study area.

The major objective of AHP was to select the proper Normalised Principal Eigen Vector (NPEV) or Percent Weight in the ArcGIS environment for the weight overlay analysis. The analytical hierarchy process (AHP) is a pairwise comparison measurement theory that relies on the determination of priority scales by experts. The comparison was done using a scale of 1 to 9 to indicate how much more essential one layer is than the other. (Saaty, 1996). Saaty's one-to-nine factor scale was utilized, with 1 referring that both parameters are equally important and 9 referring that one parameter is extremely important over the other in terms of goal influence (table 3.7).

Table 3. 7 The scale applied by AHP and definition.

intensity	Definition	Explanation
1	Equal importance	The two elements contribute equally to the objective
3	Moderate importance	Slightly favor one element over another
5	Strong importance	Strongly favor one element over another
7	Very strong importance	Very strongly favor one element over another
9	Extremely importance	The evidence favoring one element over another is of the highest possible order of affirmation.
2,4,6,8	Can be used to express intermediate value	

To assign the scale for groundwater potential assessment and place the criterion into pairwise comparison, all of the elements in the AHP Excel sheet must first be arranged logically. Thus primarily according to the degree of suitability for groundwater potential and recharge zone contribution analytic hierarchy process pairwise comparison matrix scale assigned to table 3.8. The procedures used to locate and validate the normalized principal eigenvector were presented as a conceptual flow chart in Appendix 3.

Table 3. 8 analytic hierarchy process pairwise comparison matrix and scale assigned.

		Criteria		more important?	Scale
i	j	A	B	A or B	(1-9)
1	2	Geology	Slope	A	3
1	3		Soil	A	3
1	4		Rainfall	A	3
1	5		Lulc	A	5
1	6		Elevation	A	5
1	7		Drainage density	A	7
1	8		Linemeant density	A	9
2	3		Slope	Soil	A
2	4	Rainfall		A	3
2	5	Lulc		A	3
2	6	Elevation		A	5
2	7	Drainage density		A	5
2	8	Lenimeant density		A	7
3	4	soil		Rainfall	A
3	5		Lulc	A	3
3	6		Elevation	A	5
3	7		Drainage density	A	5
3	8		Lineneant density	A	7
4	5	rainfall	Lulc	A	3

4	6		Elevation	A	3
4	7		Drainage density	A	5
4	8		Linemeant density	A	7
5	6	Lulc	Elevation	A	5
5	7		Drainage density	A	5
5	8		Linemeant density	A	7
6	7	Elevation	Drainage density	A	3
6	8		Linemeant density	A	5
7	8	Drainage density	Linemeant density	A	3

3.9 Normalized weights for thematic layers

The eigenvector method A. Kumar & Krishna, (2018) was used to determine the major eigenvalue. The choice parameters for evaluating the input layers for designating the groundwater zone using ArcGIS were carefully selected using the analytical hierarchy process (AHP) technique. Using Saaty's AHP technique, field experience and expert judgement were used to determine the weights given to various thematic maps and their features (Al-shabeeb, 2015; Kumar & Krishna, 2018; Andualem & Demeke, 2019a; Tolche, 2021). In the analytical hierarchy approach, the relative relevance of each pair of factors within a given cluster is assessed individually (Table 3.13). Using the right eigenvector, which is obtained from the highest absolute eigenvalue (λ_{max}), the weighting factor of the ranking criteria and the consequent sub criteria are determined. By considering two themes and classes at once in accordance with their respective importance, it is possible to normalize assigned weight using AHP, based on Saaty's scale, and establish the groundwater potentials and recharging zone.

Then, using (Saaty, 2008), AHP and weights normalized by eigenvector technique, pairwise comparison matrices of assigned weights to various thematic layers and their individual classes

Finally, the consistence ratio (CR) can be computed using the following equation, suggested by saaty(1987) to verify the consistency of the comparison.

w = Eigenvector, w_i = Eigenvalue for criteria I, and λ_{max} = Average Eigenvalue for Pair-Wise Comparison Matrix.

$$CR = \frac{CI}{RI} \dots \dots \dots (equation 3.4)$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \dots \dots \dots (equatoin 3.5)$$

The consistency ratio (CR) of these matrices is a consistency feature. If the matrix's consistency ratio is larger than 0.1 for high matrices, it should be re-evaluated. The value of random consistency index is from table 3.9

Table 3. 9 Random consistency index (saaty’s 1999)

Matrix size	3	4	5	6	7	8	9	10
RI	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.5

From this table for the currently study, depend on number of criteria influence groundwater of the study area $n=8$, and Random consistency index (RI) = 1.41 used. And $CI = 0.109929$, the consistency ratio (CR) was calculated using the Analytical Hierarchy Process between 0 and 0.1 using equation (3.4).

3.10 Weighted Overlay Analysis

To define the groundwater potential zones of the study area, eight factors;geology, slope, LULC, lineament, drainage, soil, elevation, and rainfall were determinened. These factors do not all have the same effects on groundwater potential zonation. Each factor's weight was assigned based on how it affected movement and storage of groundwater and with reference to literature (Pande et al., 2018; Andualem & Demeke, 2019; Atmaja et al., 2019; Tamiru & Wagari, 2021; Kabeto et al., 2022). A factor's weight value is a representation of the proportion of its value. As an example,in the currently research geology is very important and has the highest score weight of 27.09%, followed by slope, soil, rainfall, LULC, elevation, drainage density and linemeant

density, which have score weights of 24.78%, 14.43%, 13.32%, 9.68%, 4.88%, 3.02 and 1.80%, respectively.

High weight was assigned to the area with the highest lineament density, and less weight was assigned to where the area has lowest lineament density (Naghibi et al., 2017; Atmaja et al., 2019; Tolche, 2021). Unlike that an area which has high drainage density has assigned very low weight (Rafati & Nikeghbal, 2017; Andualem & Demeke, 2019; Biswas et al., 2020; Kabeto et al., 2022). Low slope to flat areas received a high weighting, but steep slope areas had a low weighting (Ibrahim-Bathis & Ahmed, 2016; Andualem & Demeke, 2019). High weight was given to the region with high rainfall since the distribution of rainfall directly influences the rate at which runoff water infiltrates the ground. Furthermore, soil with a coarse texture was given a lot of weight (Tolche, 2021). In the weighted overlay analysis, using the Analytic Hierarchical Process (AHP) method, the ranks were supplied for all parameters of all theme layers that is chosen for groundwater potential (Saaty, 2008).

After all the thematic levels were given weights. The sub-variables of each theme layer given rankings or scale values. Which may range from 1 to 5, in accordance with their significance for the occurrence of groundwater, the feature with the highest predicted groundwater potentiality is given the highest value 5, while the feature with the lowest predicted groundwater potentiality is given the lowest value 1 (Appendix 4).

3.11 Groundwater Potential Map Development

After all the thematic layer become weighted according to their influence on groundwater potential zone map the groundwater potential map was developed. The weight value of each thematic layer was added together to create a groundwater potential map utilising a weighted index overlay analysis in arcGIS software. The weighted overlay tool in ArcGIS software was used to create a map showing the spatial distribution of the groundwater potential districts inside the study area (Biswas et al., 2020). According to (Andualem & Demeke, 2019; Achu et al., 2020; Abdulkerim et al., 2022; Kabeto et al., 2022;). The area score with a high weighted value was regarded as a groundwater potential area.

All thematic layers of geology, slope, rainfall, elevation, lineament density, drain density, soil group, and land use/land cover have an impact on groundwater potential reclassified (Bhattacharya et al., 2020; Hasibuan et al., 2021). The reclassified values in the input raster layers

are using the Weighted Overlay analysis tool according to a standard evaluation scale of 1, 2, 3, 4, and 5 or 2,3,4,5 (very low, low, moderate, high, and very high, respectively). The weighted overlay analysis tools use a method of multiplying the cell values (rank) of each factor class by the factor weight and adding the resulting cell values together to create a map of groundwater potential zones (Raviraj et al., 2017).

$$GWPI = GewRGe + SLwSlr + SwSr + RFwRFr + LULCwLULCr + ELwELr + DDwDDr + LDwLDr$$

.....equation (3.6)

Whereas GWPI stands for groundwater potential index, Ge stands for geology RF for rainfall, LD for linear density, LULC for land use/cover, Sl for slope, E for elevation, S for soil, DD for drain density index, and subscripts w and r for weight and rank, respectively, represent the groundwater potential. In the Muger catchment, after overlay analysis was done, the groundwater map was generated, and the scale values 2, 3, 4, and 5 were observed. This indicates that the groundwater potential zone of the study area was categorized as poor, moderate, good, and very good.

3.12 Validation of Groundwater Potential Zone Map

Well, yield was chosen as a better candidate for use in validating groundwater potential zones than other current data. Well, yields can be divided into a few classification schemes according to the specific site characteristics. Some divide groundwater potential zones into categories like zero to three L/s: low, three to six L/s: moderate, six to twenty L/s: high, and more than twenty L/s: very high. (Yesilnacar & Topal, 2005; Naghibi & Dashtpajardi, 2017; Kumar & Krishna, 2018; Kabeto et al., 2022).

3.13 Effect of land management factor on groundwater potential zone.

Following the evaluation of the groundwater potential zone, it is preferable to assess the impact of land management practices on the GWP zones. Groundwater recharge and other hydrological components can be affected by changes to particular land cover classes, such as water bodies and forest vegetation, through changing interception and infiltration processes(Kuroda et al., 2017; Kirimi et al., 2018). The susceptibility of the soil, geology, water, and ecology would be matched with the use of the land (Lerner & Harris, 2009; Chemura et al., 2020). It implies that all

parameters that influence the groundwater potential zones are affected by land management factors, the difference between recharge and necessary natural discharge made by land use.

Human activities can change recharge rates, such as through urbanization, deforestation, or changes in land cover by land use practices. One of the things influencing changes in watershed hydrology in the farming system is land misuse, which includes changing the land's usage or cover. (Wang et al., 2006; Heyi & Mberengwa, 2012). The management of forest land use and cover can improve groundwater recharge and overall stream flow, which can result in more water availability during dry spells, especially in light of climate change. (Van Dijk et al., 2013).

In geographical study and land use planning, slope is one of the most significant terrain elements for depicting ground surface attributes. Slopes have an impact on land use patterns; for example, places with extremely steep slopes might not be used for farming. (Nut et al., 2021). Because of their impact on runoff, slopes are thought to play a significant influence in defining the kind of land use. (Zelege & Hurni, 2001; Landon, 2014). In this regard, growing annual crops on land with a slope of 30% or more is discouraged by Ethiopian land-use regulations. (Taye et al., 2019).

Ethiopia has set out to implement a sustainable land management program to attain a green economy on a policy level. (Gessesse, 2010). By considering this identifies what kinds of land cover alteration processes either negative or positive influences on groundwater potential were evaluated for sustainable use. In the current study area, the effect of the land management system on the groundwater potential zone was examined using the combination of ArcGIS and ERDAS Imagine 2015 software. Therefore, to identify the effect of land management factors in this study first identify and convert where the area has extremely steep slopes used for agriculture practices to forest. And evaluate its factor influence on GWPZ by analyzing the slope from the Digital Elevation Model (DEM) using a Geographic Information System.

Previous research (Wakode et al., 2018; Alqurashi & Kumar, 2019; Vivekananda et al., 2021) has demonstrated the significance of satellite images and field observations for trend analysis as well as for evaluating the effects of LULC changes on groundwater potential zone mapping. Based on this point of view in the current study the effect of land management factors, on groundwater potential zones was analyzed from satellite image data. The land use land cover data was analyzed to examine the relationship between LULC and the groundwater potential

zone in the Muger catchment. The effects of land use changes on the groundwater system in the Muger catchment were examined from the perspective of the groundwater recharge area. Using the combination of ARC GIS and ERDAS Imagine 2015 software the land cover change of land class was done. Thus, based on the slope of the study area changing land class which has a degree of slope 20% value covered by agricultural area was covert to forest area. This was not recommended for agriculture due to the steepness of the area, strong steep and extremely steep slope areas were not advised for farming practice (FAO), 2006; State et al., 2015; Nut et al., 2021). To do these tasks using ArcGIS software from spatial analytic tools classify, create the slope of the study area, and classify the slope depending on the degree of slope. Using the conversion tool of ArcGIS to convert the slope map of the study area from raster to vector, then using the editor tools to edit the vector, from the attribute table selecting by attribute table grid code to get a unique value of the area has > 20 % slope value, merge and save the editing. From the geoprocessing tool clip, the slope has a value >20% vector layer. Then after, using the ERDAS Imagine 2015 the classified land use land cover map and vector slope value >20% were overlaid. From the raster thematic tool, recode the map and change the land class depending on the slope value. Finally, create the new land use land cover map of the study area with the perspective of some land class change from agriculture area to forest area table 3.10. As a result, around 351.91 km² (4.79%) of the study area LULC class was converted from farmland to forest.

Table3. 10 Land use land cover class area after land management evaluation

class name	Area before LULC change(km ²)	area After LULC change (km ²)	area changed(km ²)	Area (%) before LULC changed	Area (%) after LULC changed	Area (%) changed
Agriculture area	5381.16	5029.25	-351.91	73.27	68.48	-4.79
Grassland	1013.79	1013.77	0.00	13.80	13.80	0.00
Settlement	86.47	86.45	0.00	1.18	1.17	0.00
Vegetation	830.28	1182.30	352.01	11.30	16.10	+4.79
Water bodies	32.87	33.03	0.00	0.45	0.45	0.00

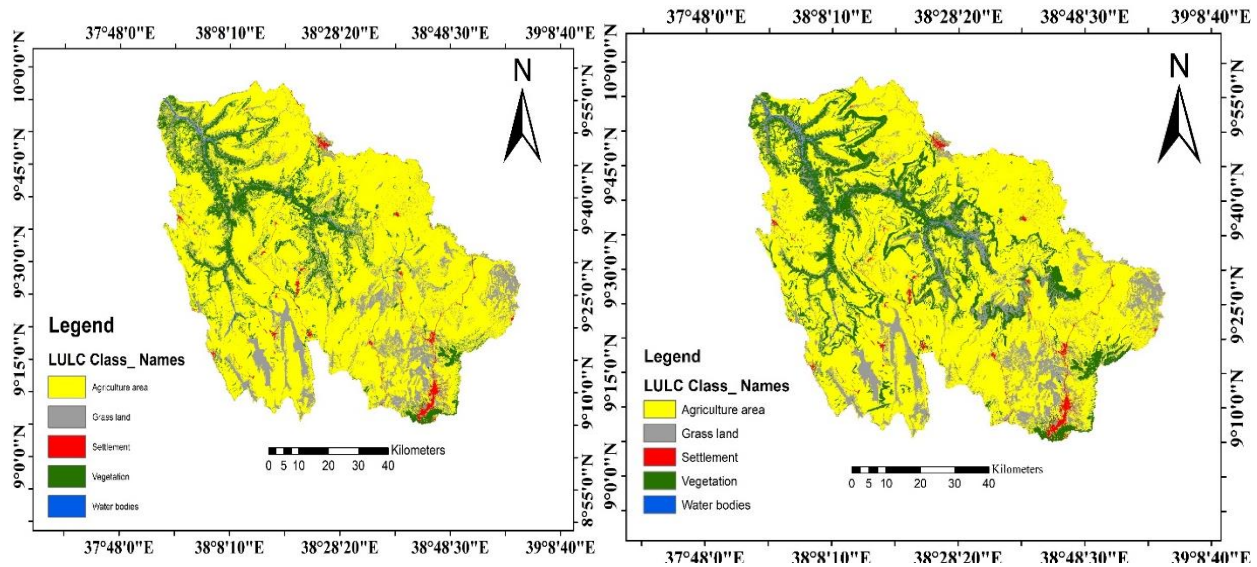


Figure 3.13 LULC of study area before LULC evaluation, (b) After LULC class >20 % slope value change from agriculture land to vegetation.

3.13.1 Groundwater Potential zone Map development after LULC evaluation.

After the LULC of the study area was evaluated some land cover was shifted from agriculture to vegetation area. Thus, the change in land cover of the area affected the suitability percent of the study area with the perspective of the groundwater potential zone evaluated.

Following to land management evaluation the suitability percent of the study area with perspective to LULC was increased by 4.79% (11.30 to 16.10 km²). Which has some impact on the groundwater potential of the catchment. And by using the layer of the changed land use land cover the new groundwater potential map of the study area was created. Then by considering the area of the two layers of groundwater potential zone maps, the effect of the land management factor on the groundwater potential was determined. To do this task the overlay analyses were done using weighted overlay analysis from the spatial analytic tool ArcGIS and compared the outcome with the GWPZ map produced before the land management evaluation was prepared. The land management practices influence the groundwater potential zones of the area.

4. RESULTS AND DISCUSSION

4.1 Identify and analyze key factors influencing groundwater potential zones

In this research the main eight parameters, that influenced the presence of groundwater potential zone are identified, geology, slope, soil, rainfall, land use land cover, elevation, drainage density, and lineament density. All criteria have influenced groundwater potential zones by controlling the movement, distribution, direction of flow, infiltration, runoff, porosity, permeability, and storage within time and space. However, all criteria have not equally influenced the groundwater potential of the study area, in the current research area geology is very important and has the highest score weight of 27.09%, followed by slope, soil, rainfall, LULC, elevation, drainage density and lineament density, which have score weights of 24.78%, 14.43%, 13.32%, 9.68%, 4.88%, 3.02 and 1.80%, respectively.

4.1.1 Geology

The Muger catchment geology is distinguished by localized sedimentary rocks, tertiary volcanic, and quaternary alluvium sediments in the plateau area. The majority geology of the study area was dominated by basalts, which were covered by highly to moderately weathered and fractured basalts. There are eleven types of geological units within the study area were referred those are: Termaber Basalts 24.884% Blue Nile Basalts 14.36%, Amba Aiba Basalts 9.72%, Abbai Beds 11.61%, Antalo Sandstone 10.79%, Amba Alaji Rhyolite 8.273%, Adigrate Sandstone 8.21% Amba Aradam Sandstone 7.9%, Alluvium 4.2%. Using the reclassify tool of the spatial analysis tools, the geology layer type was reclassified into 1, 2, 3, 4, and 5, this class values ranked as per the suitability for groundwater potential development indicates very poor, poor, moderate, good, very good table 4.1.

Blue Nile Basalts (TBNB) are the thick basalt flows only found in central Ethiopia. They are the Ashangi group's oldest basalt flows. They are thought to be highly productive and permeable. Amba Aiba Basalts (TAAB), this unit is exposed to river basins and canyons in the northern and central regions of the study area. It mostly creates cliffs and steep slopes. Amba Aradam Sandstone (KAA2), The Upper Sandstone Unit (Amba Aradam formation) is made up of sandstone with thin beds of conglomerate, mudstone, and shale. Amba Alaji Rhyolite (TAAR)

Amba Alaji rhyolites, trachyrhyolites, and flood basalts are all found in the Amba Alaji rhyolites. The northern portion of the plateau of the Western highlands and the center of the study area is covered in thick flows of ignimbrites from this formation. Termaber Basalts (TTB2), in the southeast part of the research region, this basalt is exposed. Its formation is due to fissure eruption and primarily takes the shape of a plateau with a mild slope. The strata are aphanitic to porphyritic, with occasionally very coarse-grained porphyritic basalt and vesicular basalt.

Alluvium Along the river courses and in the plain area, thick alluvial deposits of clay, silt, sand, and gravel are present. These strata sit on top of the basaltic formation, which has undergone varying degrees of weathering and fracture. Most of the rivers in the region are classified as being strongly meandering, indicating the presence of dense alluvial material.

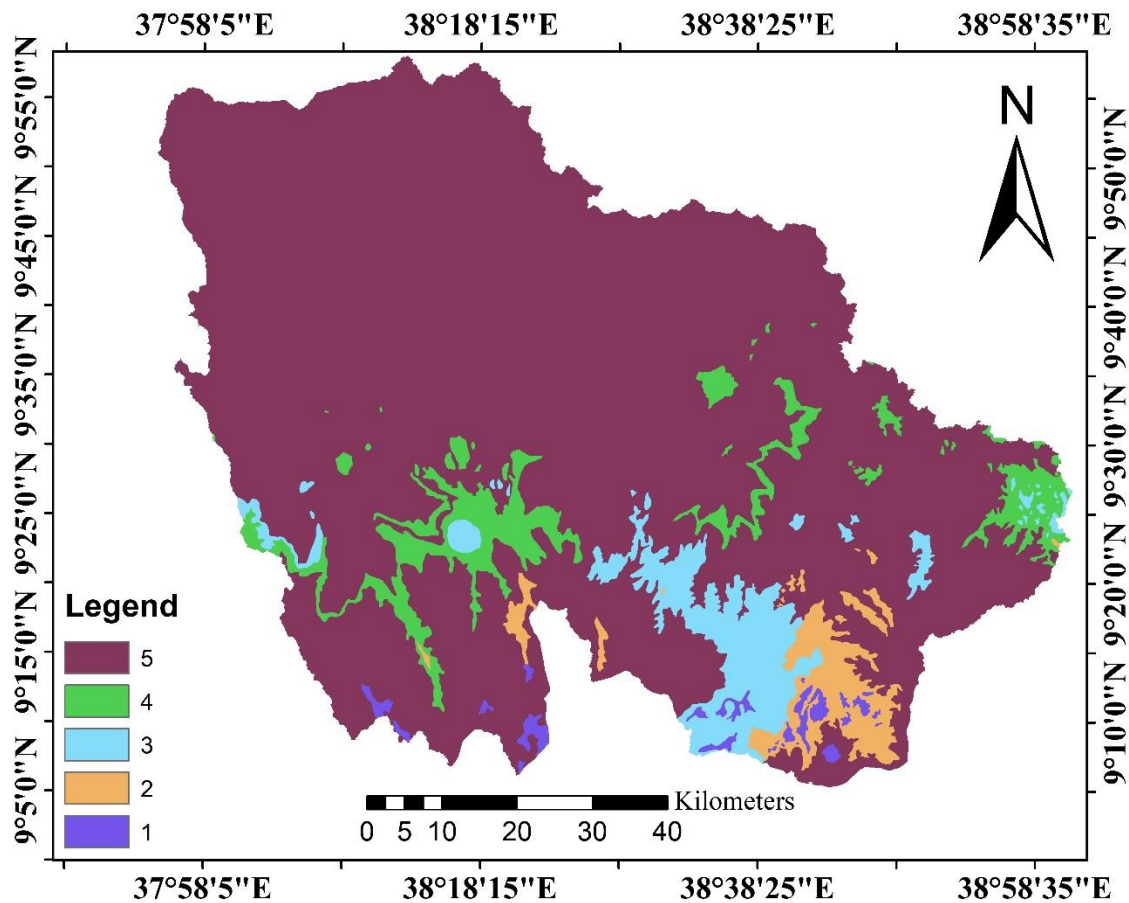


Figure 4. 1 Reclassified geology of Muger catchment.

Table 4. 1 Geology rank as per suitability for groundwater potential zone

Code	Shape Length	Shape Area	Area km ²	Area (%)	Rank
TBNB,JABB,JADS,KAA1,QUA, T AAB,T AAR,TTB,TTB2	1792444.0 5	6170104732	6170.10	84.71	5.00
OCOL	838667.73	428853622.8	428.85	5.89	4.00
KAA1	528520.87	394825797.6	394.83	5.42	3.00
JANL	393832.45	219896909.6	219.90	3.02	2.00
QALL	218145.88	69729326.44	69.73	0.96	1.00

As shown in the figure (4.1) the reclassified geology of the study area concerning groundwater potential, around 84.7% are covered by basalt group and sandstone type (JABB, JADS, KAA1, QAU, TAAB, TAAR, TTB, TTB2), which are highly weathered and fractured basalt. Followed by 5.89% OCOL, 5.42% KAA, and 3.02% JANL, and 0.96% QALL. All the geological types are not equally suitable for the groundwater potential zone evaluation. From this discussion around 84.7% of the geological study area is predicted to have good to very good groundwater potential zone concerning geology.

4.1.2 Slope

Following to generation of the slope map of the study area the map was reclassified and ranked based on the influence of groundwater potential zones. The research area has a slope of 0 to 76%, and the eastern, northern, and southern portions of the mugger catchment have gentle slopes (Figure 4.2). A very good rank was given to the area with has gentle slope because in the area with a gentle slope, the ability to keep the water on the surface of the earth is high which reduces runoff and the water easily infiltrates the groundwater recharge. Unlike that very poor rank was given to the areas which have steep slopes because they result in increased surface runoff and reduce the infiltration to minimize groundwater recharge. According to its impact on the occurrence of groundwater, the slope of the study area was grouped into five classes. About 68.96% of the study area is predicted to have good to very good groundwater availability concerning slope table 4.2

Table 4. 2 Slope rank as per suitability for groundwater potential zone

Degree	Shape Length	Shape Area	Area km ²	Area (%)	Rank	Remark
0_5 (%)	36492460.51	2812485570.71	2812.49	38.36	5.00	Very good
6_13 (%)	66793780.47	2243317996.36	2243.32	30.60	4.00	Good
13_21 (%)	47845296.78	1446107359.68	1446.11	19.73	3.00	Moderate
21_33 (%)	21905738.22	621152972.00	621.15	8.47	2.00	Poor
33_76 (%)	6249411.69	208081416.59	208.08	2.84	1.00	Very poor

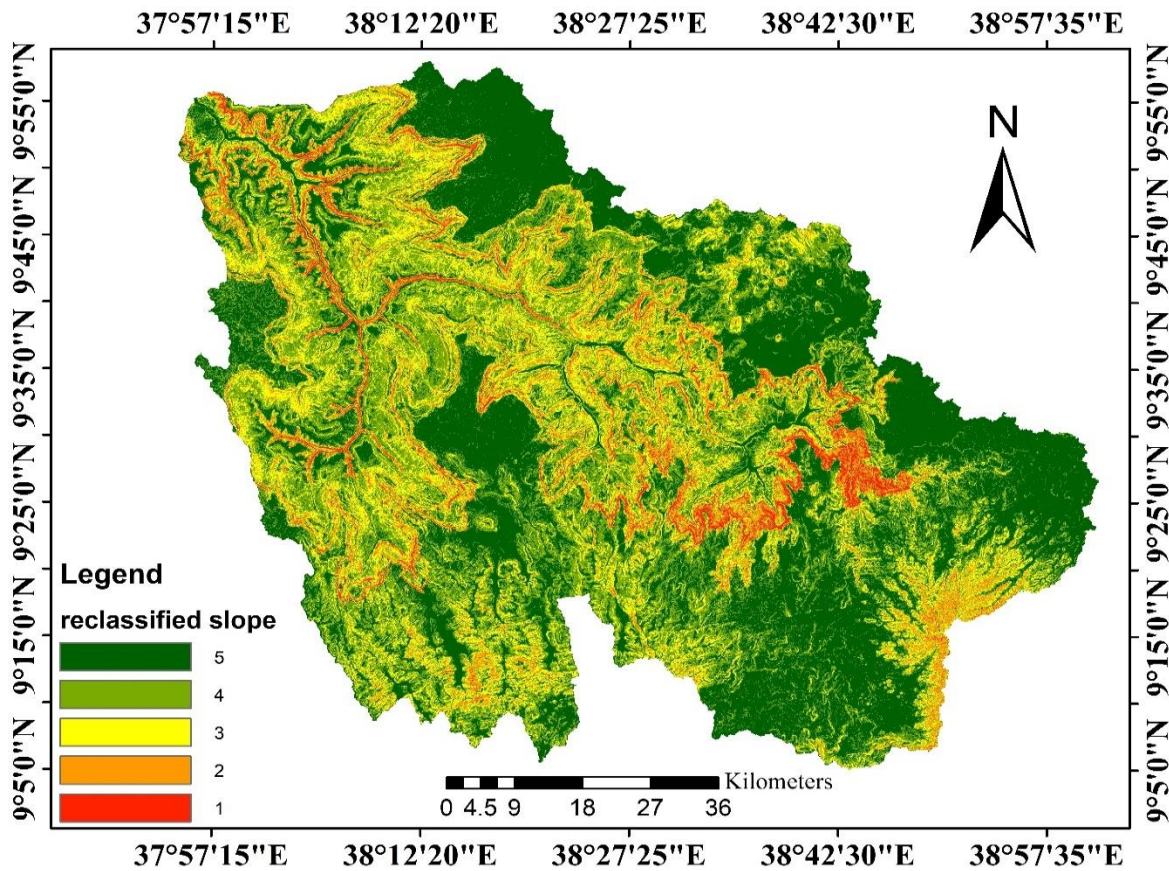


Figure 4. 2 Reclassified slope of Muger catchment.

4.1.3 Soil

The infiltration rate of the area is also affected by soil type, where some soil types have a high infiltration rate and some soil types have a low infiltration rate. The Muger catchment major soil type map has been divided into eight based on permeability. This type has been reclassified depending on the suitability for groundwater potential zones Figure 4.3. The soil type of the study area was reclassified into five class values and ranked as per their suitability for groundwater potential creation. According to the data gathered and analysis of the soil type reveal that the study area is predominantly covered by rendzinas, which covered 3019.52 km² (41.186%) of the study area. This type of soil is humus-rich, dark, and grayish-brown in color and this kind of soil has a sizable amount of gravel and stones in it. It typically develops beneath grassland created by the weathering of soft rock types, typically carbonate rocks (dolomite, limestone, marl, chalk), but sporadically sulfate rocks (gypsum) such type of soil is suitable for groundwater recharge. Followed by camisoles and luvisols 1533.05 km² (20.90%) these soils are mostly found in rugged topography, it is young, shallow, and coarse-textured and so have low water holding capacity. This type of soil is found the low rainfall areas. Lithosols 181.103km² (2.470223%) are the Mineral type of soils, which were formed on hard rock. These types of soils are unsuitable for erosion risk.

Vertisols "Heavy clay soils called "vertisols" are found in the study area covering 1373 km² (18.73%). Due to the clay's swelling, the subsoil has very poor drainage, which presents another challenge for groundwater suitability. The most favorable soil type for the groundwater potential is also nitosols which cover around 1223 km² (16.69%) of the study area. The soil map for the research region is shown in Figure 4.3. As a result, about 37.19% of the study area is predicted to have good to very good groundwater potential availability concerning soil table 4.3.

Table 4. 3 Soil rank as per suitability for groundwater potential zone (FAO 1990)

FAO_Class	Shape Length	Area Km ²	area percent	Rank
Nitosols	773399.14	1223.74	16.69	5
Luvisols, Cambsols	275400.71	1533.46	20.90	4
Rendzinas	494760.64	3019.52	41.18	3
Vertisols	638221.44	1373.58	18.73	2
Lithosols	219537.21	181.103	2.47	1

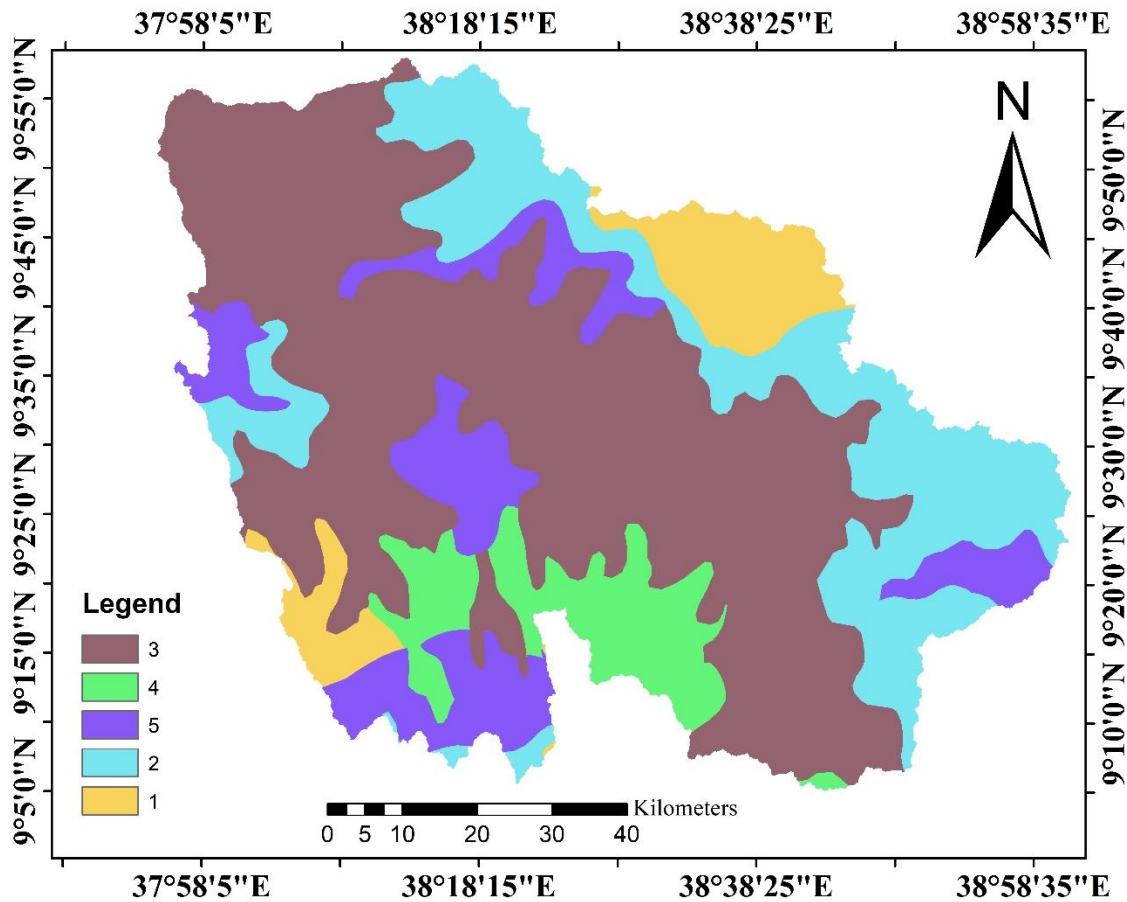


Figure 4. 3 Reclassified soil map of Muger catchment.

4.1.4 Rainfall

Groundwater recharge is the result of a long-term period effect. As a result of the 25 years (1997-2022) from ten stations within and around the study area the mean annual rainfall of the catchment ranges from 906.11-1325.59mm/year figure (4.4). Because the generated rainfall map of the study area was greater than 500mm, the rainfall of the study area is favorable. The classes of the rainfall map were reclassified into 5 class values by their rank according to the influence of the groundwater potential Table 4.4. According to the analyzed and generated rainfall map of the study area was classed as moderately to very good and favorable concerning groundwater potential recharge. The area that has high rainfall are expected as good groundwater potential and areas have low rainfall have poor groundwater potential. In this study area, the high rainfall distribution along the area has high elevation areas in the southwest and southeast parts of the study area highland parts that affect the infiltration rate groundwater potential zones in the

downstream Muger valley. About 34.77% of the study area is predicted to have good to very good groundwater potential availability concerning rainfall.

Table 4. 4 Rainfall rank as per suitability for groundwater potential zone

mm/year	Shape Length	Shape Area	Area Km ²	area percent	Rank
906.12-999.3	206598.18	788320955.74	788.32	10.75	1
999.3-1092.5	375968.32	1286058927.79	1286.06	17.54	2
1092.5-1185.76	411070.54	2707443433.30	2707.44	36.93	3
1185.76-178.973	386772.30	2046525035.84	2046.53	27.91	4
1278.974-1325.5	139924.24	503025550.42	503.03	6.86	5

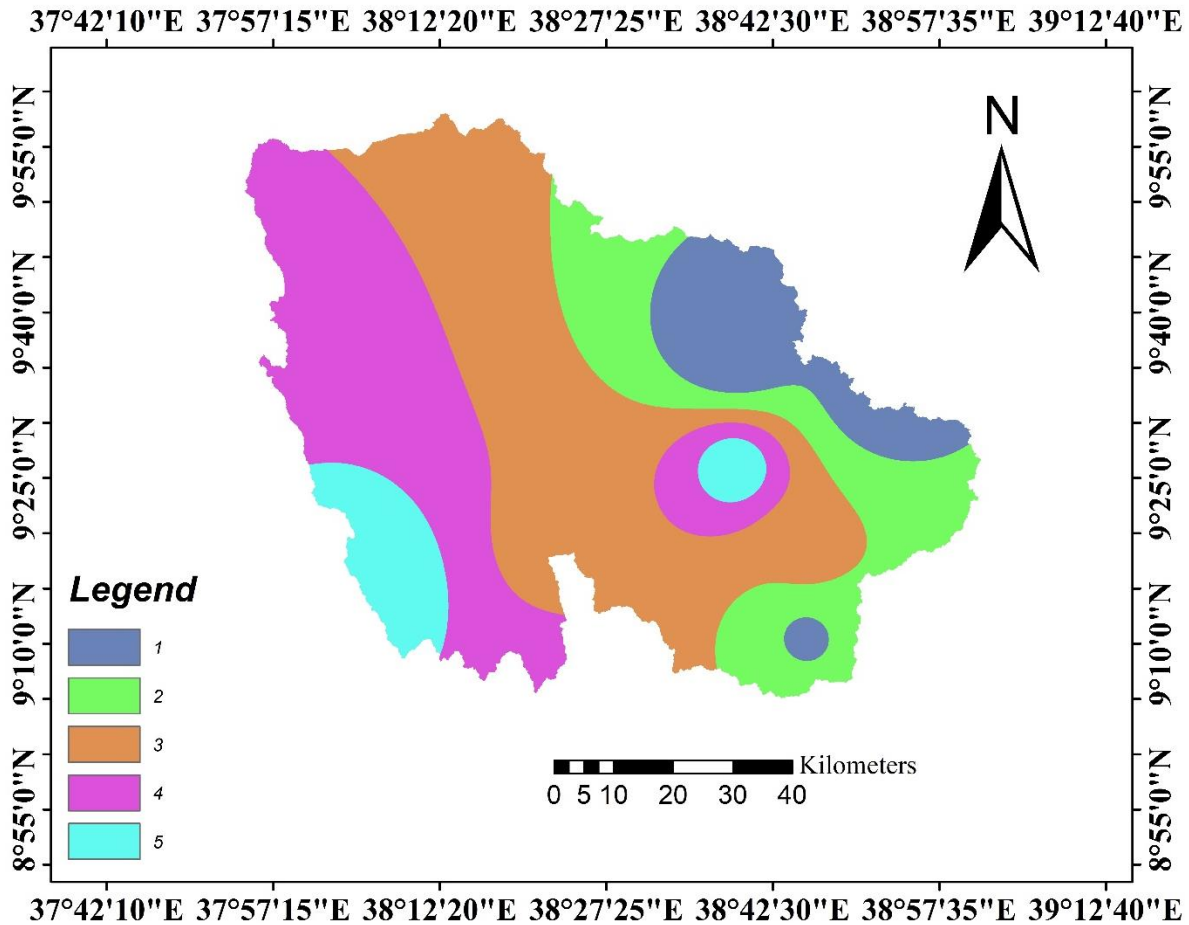


Figure 4. 4 Reclassified rainfall of Muger catchment.

4.1.5 Land use land cover

The hydrogeological and geo-hydroclimatic processes of runoff, infiltration, groundwater recharge, and evapotranspiration are all greatly influenced by land use and land cover. (Guru et al., 2017; Tolche, 2021). According to this study, land use land cover of the study area is classified as supervised classification into five classes, water body, vegetation, agriculture, grassland, and settlement figure (4.5). Water bodies and vegetation areas are predicted as high to very high groundwater potential recharge zones. While agricultural land and grassland have moderate and settlement have low groundwater potential recharge. Most of the land use land cover of the Muger catchment is covered by agricultural land. About 11.75% of the study area is predicted to have good to very good groundwater potential ability concerning land use land cover and about 73.27% of the study area is predicted to have moderate groundwater potential recharge table (4.5).

Table 4. 5 LULC rank as per suitability for groundwater potential zone.

grid code	class name	area(ha)	Area (km ²)	Area (%)	rank
1.00	Agriculture	538116.48	5371.16	73.27	3
2.00	grassland	101379.15	1011.79	13.80	2
3.00	Settlement	8647.02	86.47	1.18	1
4.00	Vegetation	83028.69	830.29	11.30	4
5.00	water bodies	3287.16	32.87	0.45	5

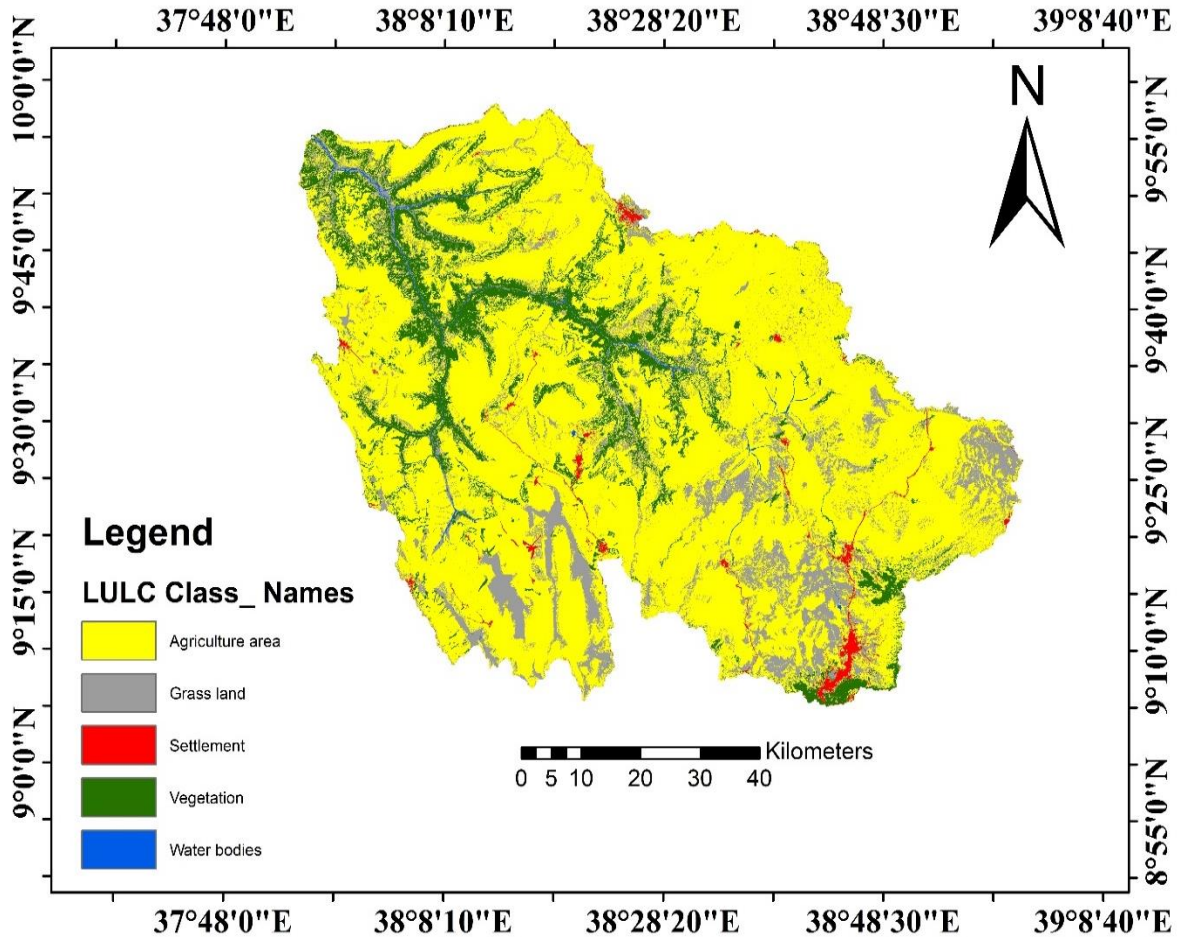


Figure 4. 5 land use land cover classes

4.1.6 Elevation

The low elevation area is predicted as a good groundwater potential zone, however high elevation area is suggested as a good groundwater recharge zone, as it is the source of recharge groundwater to the low land area (Todd & Mays, 2004, Berhanu & Hatiye, 2020). The elevation layer of the study area was created by using arc GIS from DEM have a resolution of 30m*30m. As a result, the Muger catchment's highest and lowest altitudes were determined to be 3538m and 975m above sea level, respectively. Since water tends to retain more effectively at lower topographies than at higher topographies, the Muger catchment at low elevation encourages greater groundwater potential. The elevation of the study area was reclassified into five class values and ranked as per their suitability for groundwater potential. As seen from the elevation layer of the study area, the catchment has a lower elevation at the western parts where the river enters the Abay River, moderate elevation was also referred at most of the central part of the catchment, and a higher altitude at the edge of southern section and the boundary (Figure 4.6).

As a result, about 27.62% of the study area is predicted to have good to very good groundwater potential availability concerning elevation (Table 4.6).

Table 4. 6 Elevation rank as per suitability for groundwater potential zone

Meal	Shape Length	Shape Area	Area (Km ²)	area percent	Rank
195_1487.20	792953.01	872969730.71	872.97	11.91	5.00
1487.2_1999.4	1696632.15	1151616191.72	1151.62	15.71	4.00
1999.4_2511.6	1675804.42	979811667.47	979.81	13.37	3.00
2511.6_3023.8	2079608.50	3278586843.27	3278.59	44.74	2.00
3023.8_3538	1298259.76	1045724252.23	1045.72	14.27	1.00

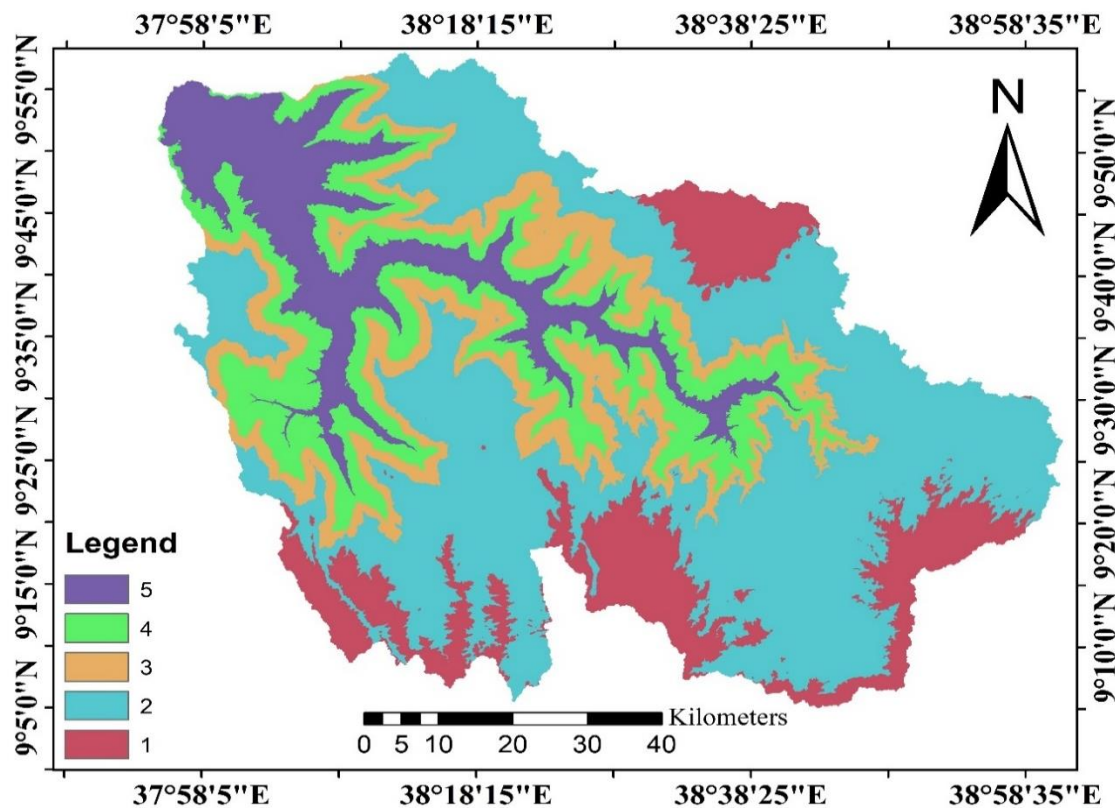


Figure 4. 6 Reclassified elevation map of Muger catchment.

4.1.7 Drainage density

(Jenifer & Jha, 2017; Thomas & Duraisamy, 2018) Areas with lower drainage densities have more groundwater potential because run-off is more prevalent on impermeable rock. High drainage density is an unfavorable location for groundwater to exist. The length of time that

runoff stays in the watershed has an impact on runoff volume depending on drainage density. Longer residency durations are possible at low densities, which gives water abstraction systems more time to work. As a result, low drainage density received the most weight because high drainage density entails poor groundwater potential. With the help of the density tool in the ArcGIS spatial analyst tools, the drain density layer for the area was built from a network of dissipated streams. By using a reclassifying tool from the spatial analysis tools, these drain density map categories were classed into five category values based on their rank as per their appropriateness for groundwater potential and recharge. As a result, about 24.73% of the study area was predicted to have good to very good groundwater potential availability concerning drainage density (table 4.7).

Table 4. 7 Drainage density rank as per suitability for groundwater potential zone

km/km ²	Shape Length	Shape Area	Area (Km ²)	area (%)	rank
0.1041-0.61	622887.57	141232233.83	141.23	1.93	5
0.61-1.12	2817292.28	1671247082.59	1671.25	22.80	4
1.12-1.62	3274180.53	4780395712.56	4780.40	65.22	3
1.62-2.12	1029876.84	684059658.26	684.06	9.33	2
2.12-2.63	93600.05	52555652.70	52.56	0.72	1

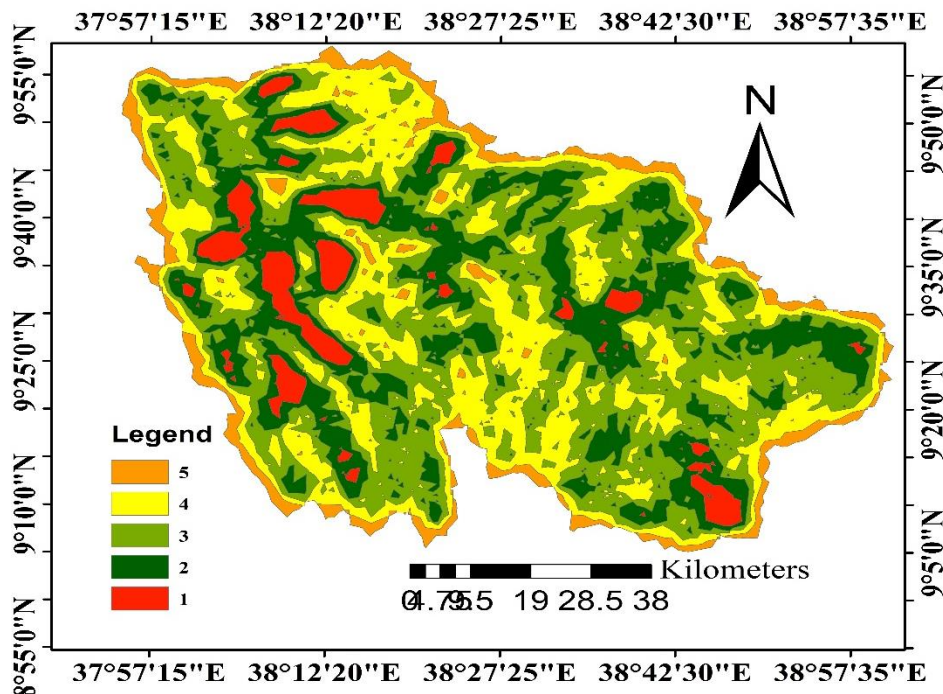


Figure 4. 7 Reclassified drainage density of Muger catchment

4.1.8 Lineament density

Lineament density has been used to investigate the regional distribution of groundwater potential. (Han et al., 2018; Andualem & Demeke, 2019a;). Faults and fractures are expressed linear features on satellite images, and mapping of lineaments is an important component in hard-rock terrains. Where the occurrence and movement of groundwater are significantly influenced by linear features of the spatial analysis tools in the arc GIS tool, and it was ranked as suitable for groundwater potential and recharge zone delineation into five (Figure 4.8). The lineament density map of the study area was reclassified by using the reclassify tool spatial analytic tools arc GIS. The area located at high lineament is considered as lineament density predicted as good for groundwater recharge zone because lineament implies the area has fault and fracture. The area has low lineament density refers to having poor groundwater potential. Only about 1.12% of the study area is predicted to have good to very good groundwater potential availability concerning lineament density (table 4.8).

Table 4. 8 lineament density rank as per suitability for groundwater potential zone

km/km ²	Shape Length	Shape Area	Area (Km ²)	area (%)	Rank
0-0.15	1690955.58	4350429241.63	4350.43	59.36	1
0.16- 0.3	1626437.05	2385116563.34	2385.12	32.54	2
0.31-0.45	572508.09	510220496.55	510.22	6.96	3
0.46-0.6	100789.20	68397554.89	68.40	0.93	4
0.61-0.74	20856.93	15303631.67	15.30	0.21	5

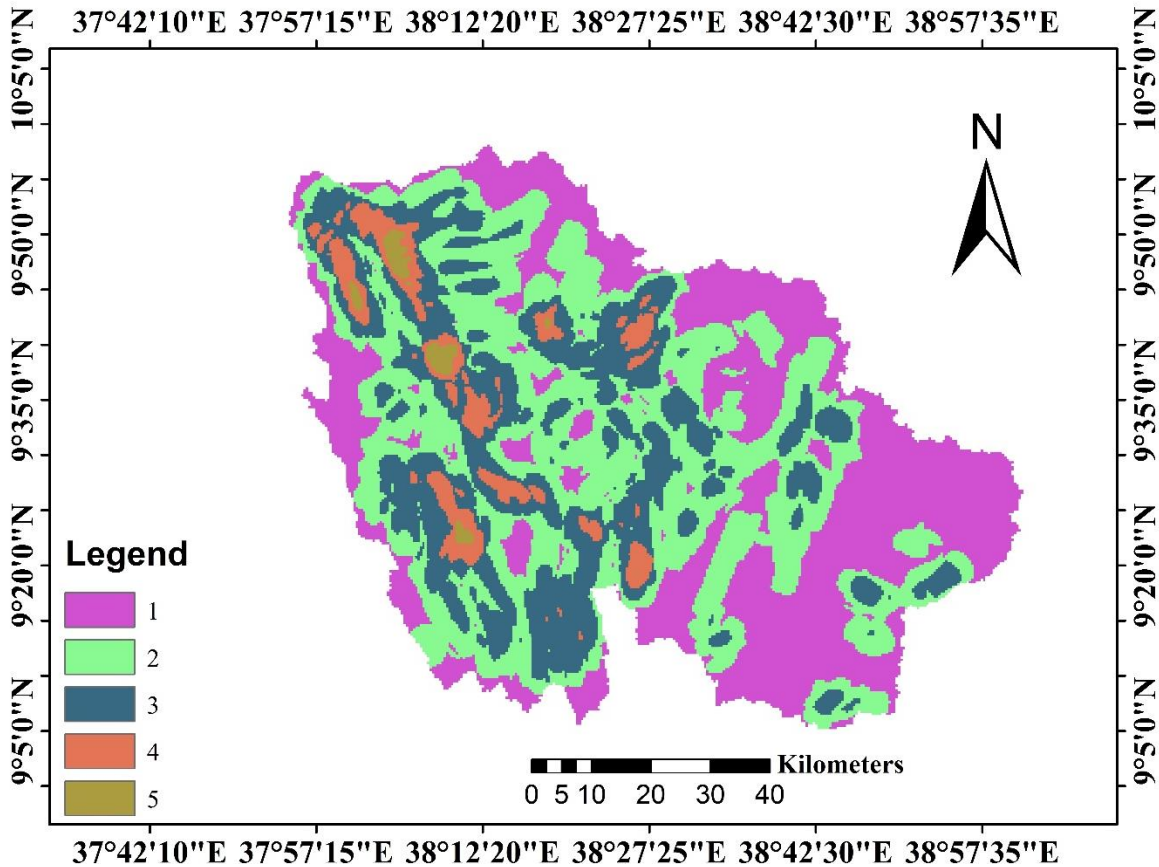


Figure 4. 8 Reclassified lineament density of Muger catchment.

4.2 Delineation of groundwater potential zones in the catchment using weighted overlay analysis techniques with AHP and ArcGIS.

4.2.1 Weighted overlay analysis.

In the current study, the weight of all parameters that influence groundwater potential zones of the study area was supplied by using an AHP Excel sheet. The weight evaluation of groundwater potential zones in Muger catchment for eight factors, rainfall, lithology, lineament density, land use/land cover, soil group, slope, elevation, and drain density, might analyzed. That was predicted to have an impact on the distribution of groundwater in the study area. In the weighted overlay analysis, using the Analytic Hierarchical Process (AHP) method, the ranks were supplied for all parameters of these layers chosen for groundwater potential prospects. Thus, by considering all influencing factors of the groundwater potential zone of the study area a more suitable factor takes the highest value. A factor's weight value is a representation of the proportion criteria value to each other. The comparison was done using a scale of 1 to 9 to

indicate how much more essential one layer is than the other (Saaty, 1996). The individual weight of all parameters was determined. As a result, geology is very important and has the highest score weight 27.09%, of the study area. Followed by slope, soil, rainfall, LULC, elevation, drainage density, and lineament density, which have score weights of 24.78%, 14.43%, 13.32%, 9.68%, 4.88%, 3%, and 2%, respectively. The feature with the highest predicted groundwater potentiality is given the highest weight, while the feature with the lowest predicted groundwater potentiality is given the lowest weight table (4.9) which was created utilizing the AHP Excel sheet and pairwise comparison matrix, provides a summary of this hierarchy, pairwise comparison, and assigned scale table 4.9.

In this study, all of the factors are ranked based on the characteristics of the study region and the adequacy of the criteria elements for groundwater potential and recharge zone contribution. As a result in comparison to the other factors taken into account, the geology conduct of the Muger catchment indicates that more than 80% of the surrounding area is suitable for groundwater potential. This indicates that the Geology of the area is covered by highly to moderate weathered and fractured basalt. Which allows for additional rainfall or surface water to percolate.

According to the study area criteria suitability for groundwater potential zone, the rate of the water that reaches the earth's surface is determined by the slope. It has a direct impact on surface runoff and infiltration. While a high to moderate slope increases surface runoff, a low/nearly level slope has high infiltration and minimal runoff, which leads to good groundwater recharge. (Rawat et al., 2019). In comparison to the other factors, the slope conduct of the study area indicates that 69% of the surrounding area is suitable for groundwater potential and surface water recharge. This indicates that a location's 69% is practically level to gently inclined, allowing for rainfall or surface water to percolate and recharge the groundwater table.

According to the suitability of the criteria for groundwater potential, a location's soil of the study area 37.15% of the soil group is predicted to have high and very high groundwater potential and recharge. The kind of soil and its texture also affect permeability and infiltration rates that were the area covered by tools, camisoles, and luvisols favorable and very favorable for groundwater potential zones (FAO1990). From the perspective of rainfall, the study area rainfall is almost favorable to groundwater potential recharge, because the area receives a rail greater than 500mm. Groundwater formation is significantly influenced by rainfall. More rainfall may also result in

increased capacity for recharging, even though this capacity is constrained by a variety of factors, including slope, geology, land use/cover, drainage density, lineament density, and others. Therefore, large groundwater potential regions are always associated with excessive recharge areas (Kotchoni et al., 2019). As a result, only 28.29% of a site will have a high or extremely high groundwater potential. This shows that rainfall contribution for groundwater potential creation and recharging sector may be moderate, in comparison to slope, soil type LULC, geology, elevation, drainage density, and lineament density.

In terms of meeting the criteria for groundwater potential and recharge zone, the total area protected by a water body, and vegetation contributes to approximately, 12.5% and 73.27% agriculture, of a location. From the perspective of lineament density, only 2% of an area has high to very high lineament density. When combined with drainage density, which contributes 24.73% to high and very high groundwater potential, an elevation of 27.62% was deemed adequate for groundwater potential which was created utilizing the AHP Excel sheet and pairwise comparison matrix, provides a summary of this hierarchy, pairwise comparison, and assigned scale. Table 3.12 Analytic hierarchy process pairwise comparison matrix and the assigned.

Table 4. 9 summer of (AHP) analytical hierarch process and weight assigned

Matrix		Geology	Slope	Soil	Rainfall	Lulc	Elevation	drainage density	lineament density	normalized principal Eigenvector
		1	2	3	4	5	6	7	8	
Geology	1	1	3	3	3	5	5	7	9	28.09%
Slope	2	1/3	1	3	3	3	5	5	7	24.78%
Soil	3	1/3	1/3	1	1	3	5	5	7	14.43%
Rainfall	4	1/3	1/3	1	1	3	3	5	7	13.32%
Lulc	5	1/5	1/3	1/3	1/3	1	5	5	7	9.68%
Elevation	6	1/5	1/5	1/5	1/3	1/5	1	3	5	4.88%
drainage density	7	1/7	1/5	1/5	1/5	1/5	1/3	1	3	3.02%

lineament density	8	1/9	1/7	1/7	1/7	1/7	1/5	1/3	1		1.80%
Sum		3	3.54	8.87	9	15.5	24.5	31.3	46		100%

4.2.2 Normalized weights for thematic layers

The normalized principal Eigenvector value (λ_{max}) was calculated to verify the weights provided to each parameter. In the analytical hierarchy approach, the relative relevance of each pair of factors within a given cluster is assessed individually. Using the right eigenvector, which is obtained from the highest absolute eigenvalue (λ_{max}), the weighting factor of the ranking criteria and the consequent sub-criteria are determined. By considering two themes and classes at once by their respective importance, it is possible to normalize assigned weight using AHP, based on Saaty's scale, and establish the groundwater potentials and recharging zone.

Then, using (Saaty, 2008). AHP and weights are normalized by the eigenvector technique, and pairwise comparison matrices of assigned weights to various thematic layers and their classes are generated (Table 4.10).

Table 4. 10 pairwise comparison matrix and normalized weight

Geo	Slope	Soil	Rainfall	Lulc	Elevation	DD	LD	sum	C.W	C.W (%)	NPEV
0.30	0.28	0.34	0.33	0.32	0.20	0.22	0.20	2.20	0.275	27.518	28.09%
0.30	0.28	0.34	0.33	0.19	0.20	0.16	0.15	1.97	0.246	24.568	24.78%
0.10	0.09	0.11	0.11	0.19	0.20	0.16	0.15	1.13	0.141	14.092	14.43%
0.10	0.09	0.11	0.11	0.19	0.12	0.16	0.15	1.05	0.131	13.073	13.32%
0.06	0.09	0.04	0.04	0.06	0.20	0.16	0.15	0.81	0.101	10.110	9.68%
0.06	0.06	0.02	0.04	0.01	0.04	0.10	0.11	0.43	0.054	5.434	4.88%
0.04	0.06	0.02	0.02	0.01	0.01	0.03	0.07	0.27	0.033	3.341	3.02%
0.03	0.04	0.02	0.02	0.01	0.01	0.01	0.02	0.15	0.019	1.925	1.80%
1	1	1	1	1	1	1	1			1	1

The consistency of the judgments is verified using the consistency ratio (CR) calculation. For various consistent pairwise evaluation matrix sizes, Saaty (1995) recommended a different consistency ratio value. The consistency ratio value for a three-by-three matrix should be

substantially lower than 0.05, a four-by-four matrix should be 0.09, and huge matrices should be 0.1 (Saaty, 1996).

Table 4. 11 Pairwise comparison matrix and normalized principal Eigenvector.

Matrix	Sum	C.W	SUM/C.W
Geology	2.520	0.275	9.158
Slope	2.213	0.246	9.006
Soil	1.321	0.141	9.375
Rainfall	1.213	0.131	9.280
LULC	0.901	0.101	8.917
Ele	0.447	0.054	8.225
DD	0.271	0.033	8.126
LD	0.155	0.019	8.068
			$\lambda \max = 8.7695$

Then using the equation (3.4 and 3.5) the consistency index (CI) and consistency ratio (CR) for all influencing factors on groundwater potential and recharge zone weight assigned were examined. From the table of Random consistency index (saaty's 1999), the value random index is determined, for $n=8$, $RI = 1.41$. In this study, the consistency ratio of the weight assigned was calculated from a pairwise comparison matrix for an eight-by-eight matrix, the Principal Eigenvalue was determined and the value is $\lambda \max = 8.7695$ which is always larger than or equal to the number of criteria (n). The Principal Eigenvalue ($\lambda \max$), is 8.7695, computed in Table 4.11, which is greater than the number of criteria (8), pairwise comparison is therefore credible. So the consistency index (CI), by equation (3.5) from the Principal Eigenvalue ($\lambda \max$) was identified and the value is 0.109929. Also for the eight multi-criteria influence factors, the Random Index (RI) value was taken from the table of the random index and the value is 1.41 (section 3.9.1). The Consistency Ratio (CR) was computed by (equation 3.4) and the value is 0.0785, from this result for the eight-by-eight matrix, the consistency is valid. Because the consistency ratio value for the large matrix is between 0 and 0.1 0.0785 is less than 0.1. As a result, the weight or percentage impact assigned to each theme layer is appropriate, and the CR obtained is suitable.

4.2.3 Groundwater Potential Map Development

The groundwater potential zones of the study area have been determined by overlaying the lithology/geology, slope, soil type, rainfall distribution, land use/cover, drainage density, lineament density, and elevation shapefile of the area in ArcGIS software. Using all the key parameters that were used to identify groundwater potential zones, the reclassified values in the input raster into ArcGIS Weighted Overlay analysis tools (overlay analysis) the groundwater potential zones were created. The thematic levels were given weights, and the sub-variables of each theme layer given rankings or scale values were supplied. Which may range from one to five, by their significance for the occurrence of groundwater. The feature with the highest predicted groundwater potentiality is given the highest value, while the feature with the lowest predicted groundwater potentiality is given the lowest value. Appendix 4 shows the weight assigned and the rank of each thematic layer). 1 refers to very poor, 2 is poor, 3 moderate 4 good and 5 refers to very good with groundwater potential zones suitability. The area score with a high weighted value has been recommended as a good to very good groundwater potential area. The weighted overlay analysis tools use a method of multiplying the cell values (rank) of each factor class by the factor weight and adding the resulting cell values together to create a map of groundwater potential zones.

According to equation (6, section 3.11) and the output is based on their proportional significance for groundwater potential, rating tasks for each class were developed in a themed layer (Appendix 4). The weights of each subclass and thematic layer were as follows: lithology/geology (28.09%), slope (24.78%), soil type (14.43%), rainfall (13.32%), land-use (9.69%), elevation (4.88%) drainage density (3.02%), and lineament density (1.80%), (Appendix 2). The Groundwater potential index of the study area is the weight overlay output of the summation of all criteria weight multiplied by the individual sub-criterial rank which is $28.09R_{Ge} + 24.78S_{lr} + 14.43S_{wSr} + 13.32R_{Fr} + 9.69LULC_{r} + 4.88E_{lr} + 3.02DD_{r} + 1.80 LD_{r}$ Whereas GWPI stands for groundwater potential index, Ge stands for geology RF for rainfall, LD for linear density, LULC for land use cover, Sl for slope, E for elevation, S for soil, DD for drain density index, and the subscripts w and r for weight and rank, respectively. The results delineation of groundwater potential zones in the study area, four distinct zones that make up the designated groundwater potential and recharge zone were determined. Table 4.12 and Figure 4.9 shows that the identified groundwater potential zones (GWPZs) were categorized into four

classes based on the overall weightage in percentage: The output of this evaluation scale in the study area was 2, 3, 4, and 5 which refers (poor, moderate, good, and very good, respective). A very good zone indicates that the area is appropriate for exploring groundwater and the best place to prospect for groundwater. The research areas at low slope and high lineament density, high rainfall area, low elevation, in alluvial plains, basalts, weathered, fracture, and valley are extremely high potential areas. The volcanic landform, grassland areas, high slope, high drainage density high elevation area, limited rainfall area, settlement area, and area covered by Vertisols, and Lithosols in the area have very limited groundwater potential.

About 192.9204 km² (2.79 %) of the study area has a very good groundwater potential zone, and about covers 5114.0826 km² (73.97 %) of the study area has a good groundwater potential zone. About 1600.0542 km² (23.14 %) and 5.9958 km² (0.0867%) of the study area have moderate and poor groundwater potential zone respectively Table 4.12. So, by using ARC GIS and remote sensing techniques the groundwater potential zones of a Muger catchment were evaluated and classified.

Table 4. 12 groundwater potential zone Muger catchment

Value	Count	Area (km ²)	Area (%)	Value definition
2	6662	110.00	0.0867	Poor
3	1777838	1704.05	23.14	Moderate
4	5682314	5218.08	73.97	Good
5	214356	296.92	2.79	Very good

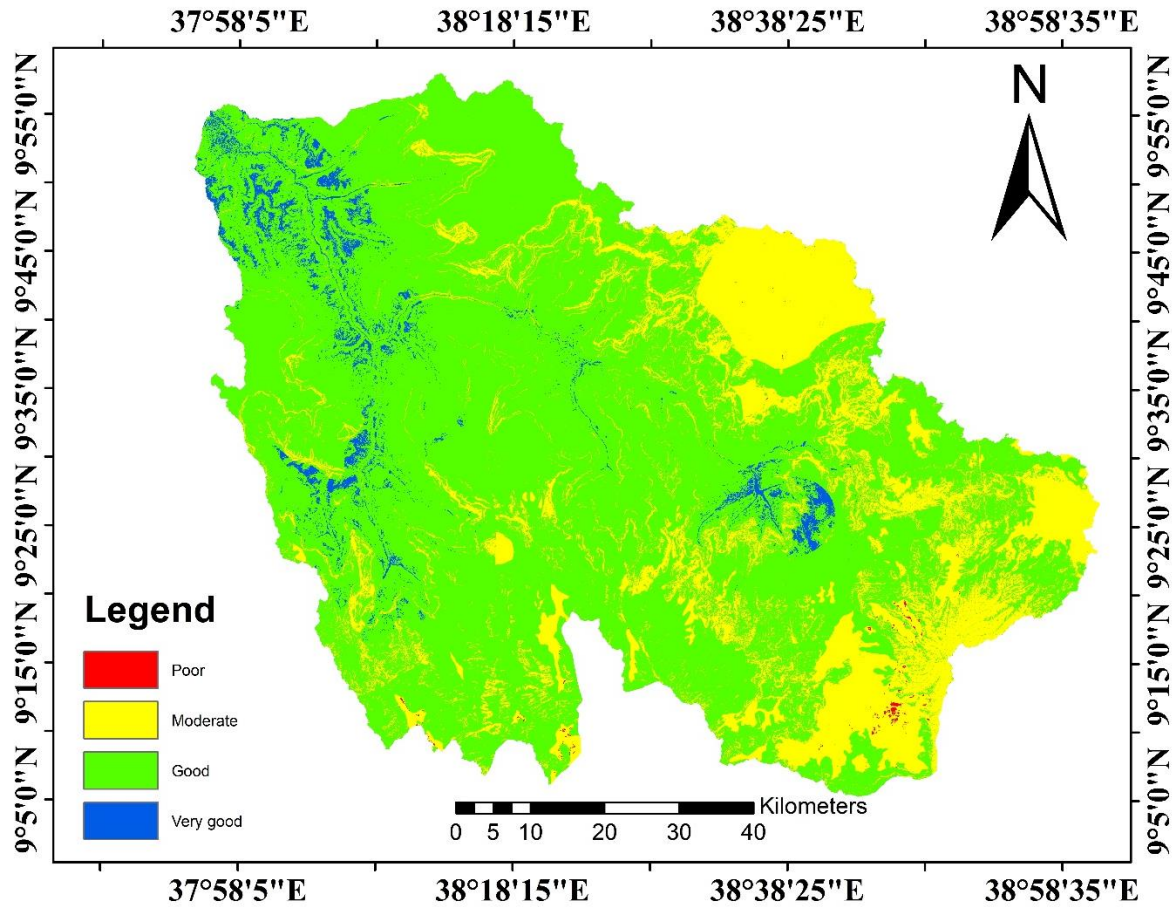


Figure 4. 9 Groundwater potential zone map of Muger catchment.

4.3 Effect of land management factor on groundwater potential zone.

Following the change in land use of the study area the suitability of the groundwater potential zone was evaluated. In geographical study and land use planning, slope is one of the most significant terrain elements for depicting ground surface attributes. Slopes have an impact on land use patterns; places with extremely steep slopes might be used for farming hurts groundwater recharge. The effects of land use changes on the groundwater system in the Muger catchment were examined from the perspective of groundwater recharge and discharge systems. In this investigation, the map of land class change was generated using the combination of ArcGIS and ERDAS Imagine 2015 software. Thus, based on the slope of the study area, by changing land class which has a degree of slope >30% value covered by agricultural area was covert to forest area. As a result, the classified land use land cover map of the study area about, 351 km² or 4.79% of the study area were shifted from agricultural area to vegetation area (Table

4.13). Due to this change of LULC, there is some change referred to groundwater potential area as the suitability of groundwater is affected by land use land cover.

Table 4. 13 land classification area before and after land evaluation

class name	Area before LULC change(km ²)	area After LULC change (km ²)	area changed(km ²)	Area (%) before LULC changed	Area (%) after LULC changed	area (%) changed
Agriculture area	5381.16	5029.25	-351.91	73.27	68.48	-4.79
Grassland	1013.79	1013.77	0.00	13.80	13.80	0.00
Settlement	86.47	86.45	0.00	1.18	1.17	0.00
Vegetation	830.28	1182.30	+352.01	11.30	16.10	+4.79
Water bodies	32.87	33.03	0.00	0.45	0.45	0.00

As the results due to 352.01 km² (4.79%) area of agricultural land which has a value of slope >20% was changed to vegetation area the suitability of LULC with perspective groundwater potential zone was increased by 30.14 km² (0.44%). Thus, the Poor and moderate groundwater potential zone of the study area was decreased by 30.14 km² (0.44%). However, the area of good and very good groundwater potential zone was increased by 24.39 km² (0.35%) and 5.76 km² (0.08%) respectively Table 4.14. This reflects the sustainability of groundwater recharge in the watershed was affected by the misuse of land cover class. If the tendency to turn forestlands into agricultural lands keeps growing and increases the possibility of erosion it indicates a decreased ground recharge. Therefore, land use and land cover changes have a significant effect on groundwater potential. It refers to the sustainability of groundwater uses for domestic and agricultural purposes, where proper land management systems with good site selection. According to our country Ethiopia has set out to implement a sustainable land management program like Green Legacy to attain a green economy on a policy level. Such a strategy might be a good opportunity to increase the groundwater potential zone if the green legacy is employed properly. Therefore, it's important to reduce agricultural deforestation, particularly on steep

slopes, these practices will help achieve sustainable surface runoff control and create a chance for groundwater recharge.

Table 4. 14 Groundwater potential area changed due to land management factors.

	GWPZ area before LULC changed			Value	GWPZ area after LULC changed			
Value	Count	GWPZ Area km ²	GWPZ Area (%)	Scale value	GWPZ Area km ²	GWPZ Area (%)	GWPZ area Changed (km ²)	GWPZ area Changed (%)
2	6662.00	110.00	0.09	Poor	109.99	0.09	0.01	0.00
3	1777838.00	1704.05	23.15	Moderate	1673.91	22.71	30.14	-0.44
4	5682314.00	5218.08	73.98	Good	5247.47	74.33	+24.39	+0.35
5	214356.00	296.92	2.79	Very good	302.68	2.87	+5.76	+0.08

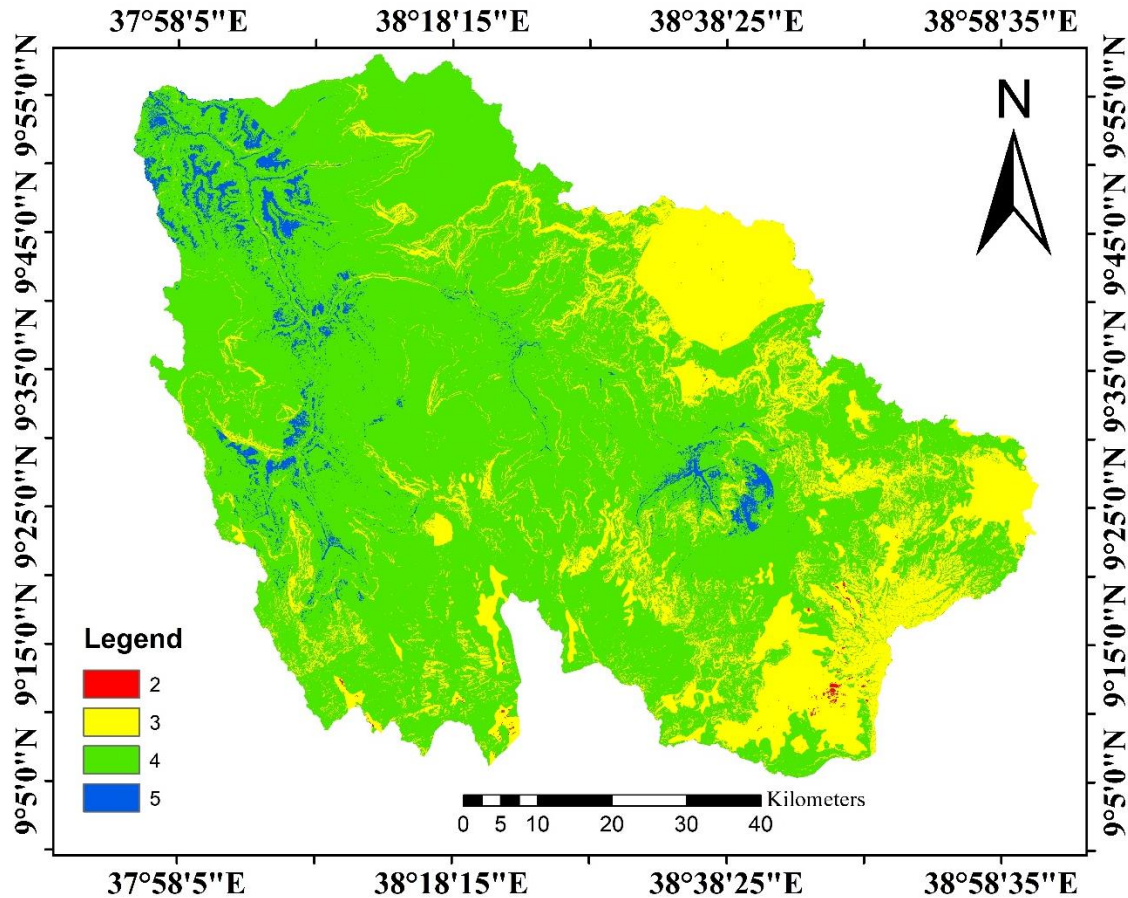


Figure 4. 10 Groundwater potential zone map after LULC evaluated.

4.4 Groundwater Potential Layer Results Validation

The outcomes overlaid layer were compared with the yields of collected data from deep wells, test wells, springs, and hand-dug in the study area. In the current study 13 deep wells, 2 shallow wells, 2 test wells, and 2 hand dug were collected from Oromia Water, and Energy Bureau (Appendix 5). However, the well data inventory is not equally distributed within the study area. The west, northwest, and central parts of the catchment have limited data availability for validation. Furthermore, it was not feasible to produce the groundwater level map because of the unequal distribution of point data. Thus, only the point data from hand-dug wells, deep wells, and test wells were overlaid with the weighted index overlay analysis map to verify the validity of the groundwater potential map (Figure 4.11). For the current study, the groundwater potential zones so discovered were verified using well yield data from 21 boreholes and test wells that ranged in depth from 11 to 858 m. Thus out of the 3 total wells classified as low yield, 2 failed

under the low groundwater potential region; of the 5 total wells classified as moderate yield, 4 failed under the moderate groundwater potential region; and of the 13 total wells classified as high yield, 9 failed under the high groundwater potential region (Table4.15). And, the overall result validation of the study is out of 21 borehole yields, 15 (71.42%) meet the respective groundwater potential region classifications from the qualitative evaluation in the cross-validation evaluation. The delineation of the recharge zone and groundwater potential using integrated GIS and remote sensing approaches closely aligns with the existing point source inventory data. The overlay result implies that the generated groundwater potential zones map of the study area by ArcGIS and the well data collected from the study area for the overlay is strong agreement so the study is valid (Figure 4.11).

Table 4. 15 Maps of groundwater recharge zones and borehole yield show agreement.

GWPZ class	yields(l/s)	number of wells collected from the study area	number of good falls in the GWPZ class
Poor	< 3	3	2
Moderate	3-6	5	4
Good and very good	>6	13	9
Overall, well		21	15

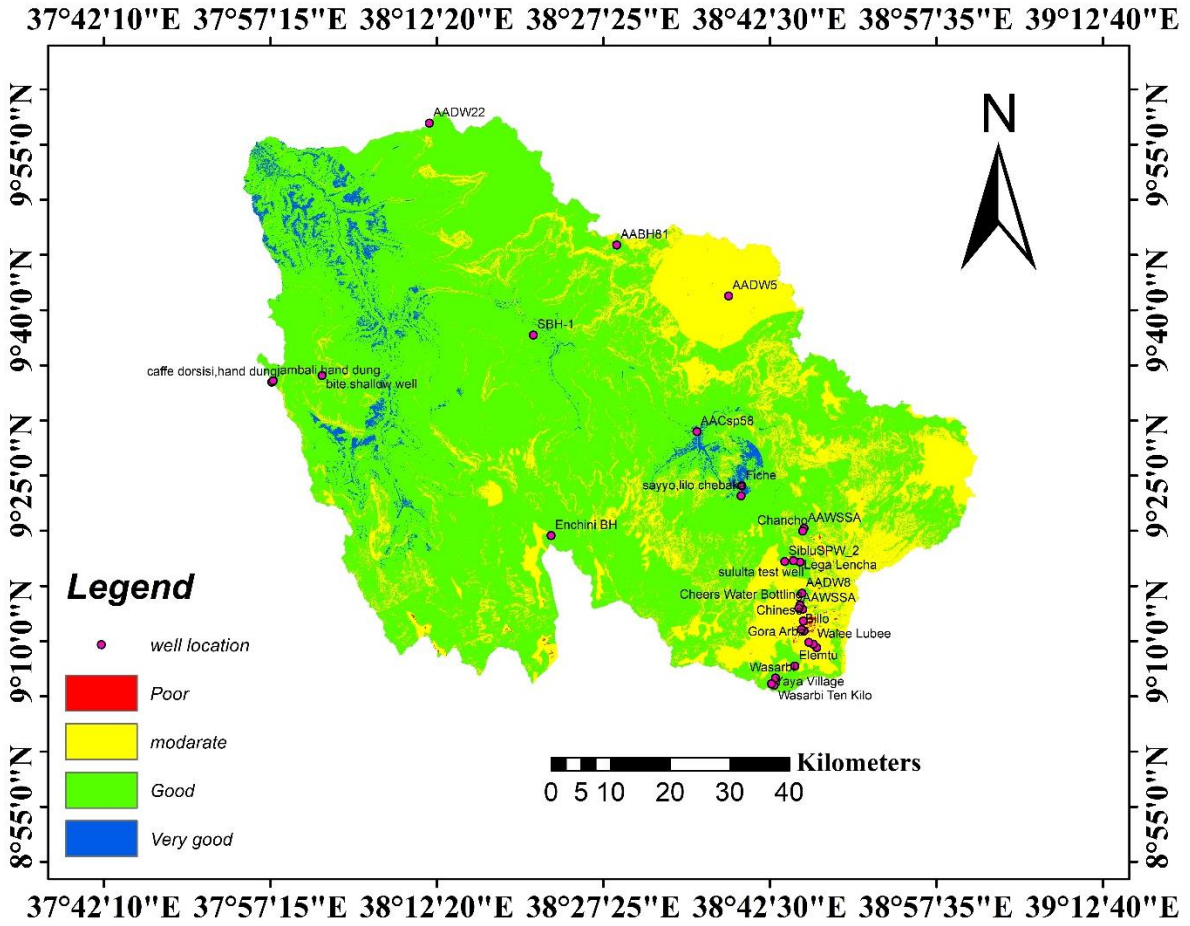


Figure 4. 11 well inventory validation

5. Conclusion and Recommendation

5.1 Conclusion

The investigation evaluated the factors that influence groundwater potential, mapped and defined groundwater potential zones, and evaluated the effects of land management factors, and changes on the groundwater potential of the Muger catchment. An increased amount of remotely sensed data is available, which has made it easier to analyze the natural environment without doing direct field measurements. When compared to traditional ground survey and resistivity approaches, remote sensing (RS) and geographic information systems (GIS) offer faster, more accurate, and more cost-effective techniques for groundwater potential and recharge sector evaluation. It includes using various groundwater spatial factors to compare the research area's groundwater potential zones. Particularly, the elements that affect groundwater potential determine the occurrence and dispersion of groundwater potential.

The study identified geology, soil, land use, lineament density, drainage density, elevation, slope, and rainfall as the most important factors influencing groundwater potential and the recharge zone. Consequently, an examination of those criteria was used to determine a location's groundwater potential zones. The significance of each parameter component in determining groundwater potential was taken into consideration when reclassifying and ranking them. Using the provided reclassified theme and the ordered maps, a weighted value or percent influence determination was made. Reclassified, thematically arranged, and produced maps were used to complete the weighted value or percent of influence determination.

All parameters that affect groundwater potential are considered by weight overlay analysis, which also provides the appropriate weight for each parameter, ranks the parameters according to their qualities, and exercises the cell. As a result, its estimation of the probable distribution of groundwater in the region was improved. The study's characteristics about groundwater potential and recharging district do not have a comparable impact on the distribution of groundwater potential and the recharge zone.

Using pairwise comparison matrix approaches, the Multi-Criteria Decision Making (MCDM) Analytic Hierarchy Process (AHP) determined the percent influence (weight) of those parameters.

The weighted overlay analysis produced Geology 28.09%, slope 24.78%, soil 14.43%, rainfall 13.32%, land use land cover 9.68%, elevation 4.88%, drainage density 3.02%, lineament density 1.80%. The result, the consistency ratio was 0.0785.

The geological formation of the study area was dominated by basalts. Blue Nile Basalts (TBNB) (JABB) Abbai bed, (KAA1) Ambadiba basalt, (QALL), Amba Aiba Basalts (TAAB), Amba Alaji Rhyolite (TAAR), Termaber Basalts (TTB2), are the suitable groundwater potential and recharge areas. The distribution of groundwater potential in the study area was appropriated in LULC areas that are covered in vegetation, and water bodies. Areas with high yearly average rainfall were endowed with high groundwater potential. A site with a low slope, elevation, and drainage density is recommended for a good groundwater potential zone. Groundwater potential and recharge were found in the area of high lineament density. Infiltration and percolation are allowed in soil groups with sandy loam and loamy sand texture, rendzinas, lithiosols, and nitosols.

The Delineation of groundwater potential zones in the Muger catchment was examined. Four distinct zones make up the designated groundwater potential and recharge zone. The weighted overlay analysis output was ranked as 2, 3, 4, and 5 which indicates "poor," "moderate," "high," and "very high" respectively. A very high zone indicates that the area is appropriate for exploring groundwater and the best place to prospect for groundwater. The research areas at low slope and high lineament density, high rainfall area, and low elevation, are extremely high potential areas in alluvial plains, basalts weathered, fracture valleys, and valley fills. The volcanic landform, grassland areas, high slope, and high drainage density in the area have very limited groundwater potential. And the study quantifies the distribution of groundwater in the Muger catchment categories as very high (2.79%, or 192.92 km²), high (73.79%, or 5114.08 km²), moderate (23.14%, or 1600.054 km²), and low (0.0867%, or 5.9958 km²). Data from the borehole inventory was used to validate the groundwater potential distribution assessment and the resulting map. Consequently, there was very good agreement (71.42%), between the inventory borehole yields discovered in the rank analysis and the groundwater potential recharge zone map that was created.

In addition to the groundwater potential map evaluation, the effect of land management factors on the groundwater potential zone was identified. Using ArcGIS and ERDAS imagine 2015 the

effect of land management factor on the GWPZ of the study area was analyzed and the suitability percent of the study area was increased by 352 km² or 4.79% (11.30% to 16.10%). Due to these changes, the groundwater potential zone of the study area increased. Thus very good and good groundwater potential zones of the study area were increased by 0.08% and 0.35%, respectively. Therefore, land use land cover changes in the area have an impact on groundwater potential and good land management practices can help to grow the groundwater recharge zone.

5.2 Recommendation

After the groundwater potential zone of Muger catchment was evaluated, through analyses, discussion, results, and conclusion a high potential groundwater area was identified, and the researcher made the following recommendation.

- ❖ The present study identifies groundwater potential areas based on logical conditions and reasoning; the same method can be used with appropriate modifications for further study.
- ❖ The results could serve as a first guide for choosing appropriate locations for groundwater resource exploration.
- ❖ It is recommended to conduct comprehensive discharge measurements of the catchment sites' springs, boreholes, and hand-dug wells for additional validation.
- ❖ Any organizations involved in groundwater development should pay a credible value to gathering, organizing, and distributing data to various scholars.
- ❖ For any groundwater development, a pre-feasibility assessment involving the integration of GIS and remote sensing techniques is recommended as it is useful in evaluating and monitoring the availability, vulnerability, and status of groundwater resources easily.
- ❖ To counteract the negative effects of land use and land cover on groundwater recharge rate and runoff, the area should implement integrated watershed management with the participation of all stakeholders including water resource experts.
- ❖ The current study uses logic and reasoning to identify possible locations of groundwater potential zones and, the effect of land management practices on groundwater potential zones, and with the right adjustments, the same approach can be applied for further investigations.

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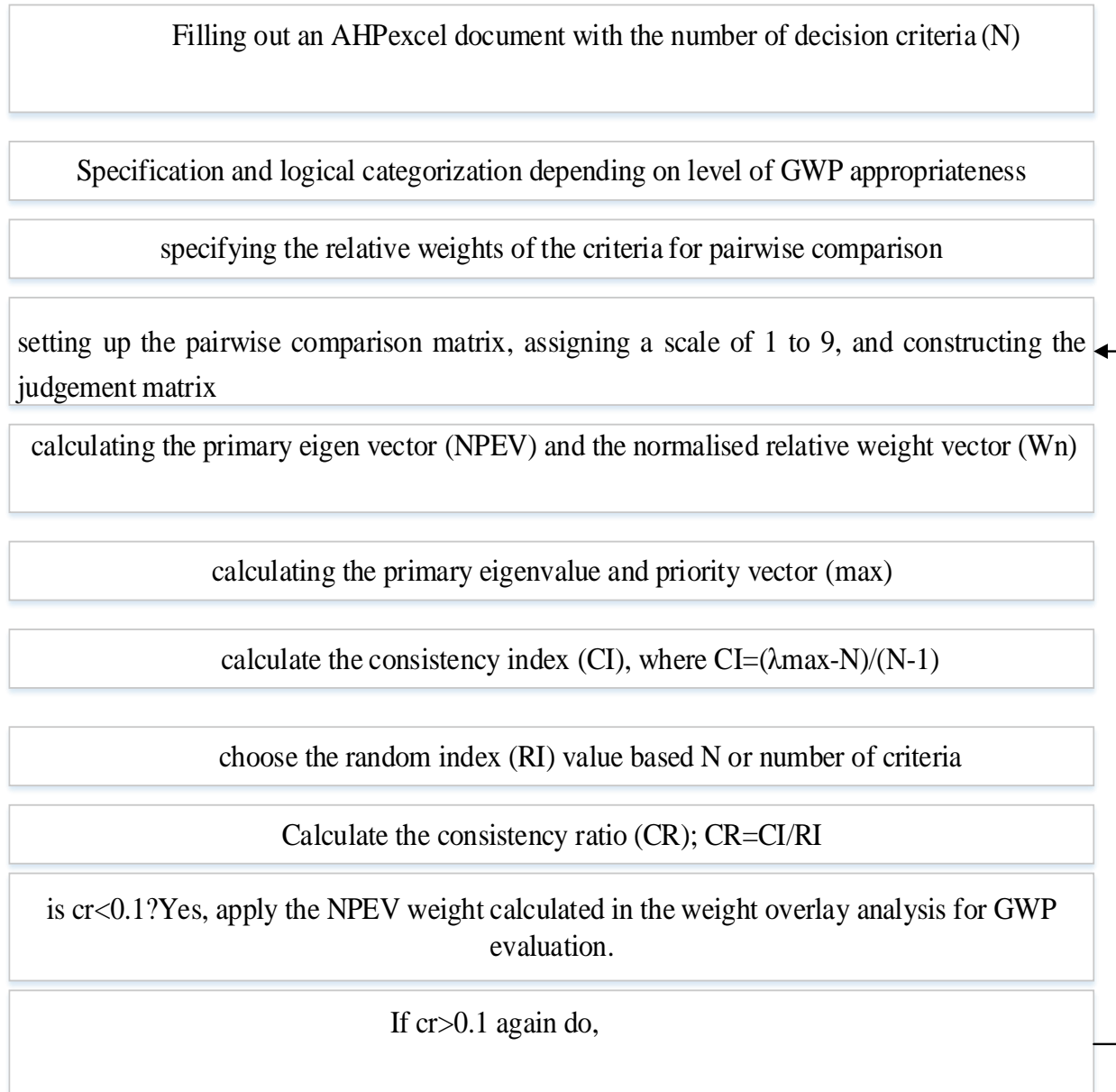
Appendix 1 Mean max, mean, mean min temperature of the study area

month	Mean max Temp	Mean Temp	Mean min Temp
January	23.66	15.78	8.00
February	24.44	16.54	8.95
march	24.6	16.91	9.24
April	24.34	17.07	9.73
may	24.17	17.03	9.89
June	22.82	16.16	9.49
July	20.93	15.18	9.43
August	20.6	15.00	9.25
September	21.51	16.18	8.86
October	22.66	16.33	7.99
November	23.05	15.25	7.46
December	23.32	15.26	7.21

Appendix 2 Geological type and area coverage of the study area

FID	Shape *	Geology	Areas	Area (%)
0	Polygon	Abbai Beds	845.5	11.608s
1	Polygon	Adigrate Sandstone	597.9	8.208
2	Polygon	Alluvium	305.7	4.19
3	Polygon	Amba Aiba Basalts	708.1	9.72
4	Polygon	Amba Alaji Rhyolite	602.6	8.27
5	Polygon	AmbaAradam Sandstone (1)	523.01	7.18
6	Polygon	AmbaAradam Sandstone (2)	54.01	0.74
7	Polygon	Antalo Sandstone	786.22	10.79
8	Polygon	Blue Nile Basalts	1045.9	14.36
9	Polygon	Coluvium	2.05	0.028
10	Polygon	Termaber Basalts (1)	260.30	3.57
11	Polygon	Termaber Basalts (2)	1552.17	21.31

Appendix 3 The procedures used to locate and validate the normalized principal eigenvector Conceptual flow chart.



Appendix 4 weight assigned and rank of each thematic layer for Overlay Analysis

thematic layers	Classes	Weight (%)	rank	GWP suitability
LULC	Agriculture	9.69	3	Moderate
	grassland		2	Poor
	Settlement		1	Very poor
	Vegetation		4	Good
	water bodies		5	Very good
Rainfall	mm/year	13.32	rank	
	906.12-999.3		1	Very poor
	999.3-1092.5		2	Poor
	1092.5-1185.76		3	Moderate
	1185.76-178.97.37		4	Good
	1278.974-1325.5		5	Very good
Soil type	FAO_Class	14.43	rank	
	Nitosols		5	Very good
	Luvisols, Cambsols		4	Good
	Rendzinas,		3	Moderate
	Vertisols (Heavy Clay)		2	Poor

	Lithosols		1	Very poor
Lineament Density	km/km ²	1.8		
	0-0.15		1	Very poor
	0.16-0.3		2	Poor
	0.31-0.45		3	Moderate
	0.46-0.6		4	Good
	0.61-0.74		5	Very good
Drainage Density	km/km ²	3.02	rank	
	0.1041-0.61		5	Very good
	0.61-1.12		4	Good
	1.12-1.62		3	Moderate
	1.62-2.12		2	Poor
	2.12-2.63		1	Very poor
Elevation	Mlas	4.88	rank	
	195-1487.20		5	Very good
	1487.2-1999.4		4	Good
	1999.4-2511.6		3	Moderate

	2511.6-3023.8		2	Poor
	3023.8-3538		1	Very poor
Slope	Degree	24.78	rank	
	0-6 (%)		5	Very good
	6-13 (%)		4	Good
	13-21 (%)		3	Moderate
	21-33 (%)		2	Poor
	33-76 (%)		1	Very poor
Geology	Code	27.09	rank	
	TBNB,JABB,JADS,KAA1 ,QAU,TAAB,TAAR,		5	Very good
	TTB, TTB2			
	OCOL		4	Good
	KAA1		3	Moderate
	JANL		2	Poor
	QALL		1	Very poor

Appendix 5 well data

wells name	Latitude	Longitude	station id	depth(m)	Yield (l/s)
Arki Water bottling	9.215	38.758	2554		
Cheers Water Bottling	9.221	38.754	2564		1.5
Chinese	9.197	38.759	2560	100	10
AAWSSA#1	9.216	38.752	2554	200	2.3
AAWSSA#2	9.337	38.76	2504	848	1.6
Wasarbi Ten Kilo	9.1	38.715	2737	858	7
Wasarbi	9.111	38.717	2734	402	110
Yaya Village	9.102	38.711	2746	440	
Elemtu	9.129	38.746	2686	342	
Wale Lube newly drilled	9.157	38.779	2619	250	6.3
Qeye Meskele	9.182	38.76	2597	403	8
Billo	9.184	38.756	2585	180	5
Chancho	9.333	38.758	2496	150	8
Lega Lencha	9.286	38.754	2567	180	5.08
SBH-1	9.629	38.351	2352	463	10.21
Fiche	9.401	38.666	2413	42	5.5

gorfo GPW_1	9.393	38.838	2564	243	22
SibluSPW_2	9.287	38.731	2538	75	5.2
mulo,eyyo darba	9.401	38.666	2405	171	25
sayyo,lilo chebaka	9.386	38.665	2445	185	12
Muger BH	9.474	38.35			
Bite. shallow well	9.568	38.032		artesian	17
Caffe dorsisi, hand dung	9.558	37.956	2532	11	13
jambali,hand dung	9.56	37.9583	2532	16	8.7
AACsp58	9.483	38.598			
AACsp116	9.772	38.259			
AABH81	9.765	38.477			
AADW5	9.688	38.646			
AADW8	9.239	38.757			
AADW22	9.949	38.194			

Source; Oromia water and energy bureau