



Remote Sensing of Land

Homepage: www.gathacognition.com/journal/gcj1
<http://dx.doi.org/10.21523/gcj1>



Original Research Paper

Identification of Groundwater Potential Zones Using AHP, GIS and RS Integration: A Case Study of Didessa Sub-Basin, Western Ethiopia



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Abstract

Groundwater is a precious water resource in underground rocks and major water source for drinking, industry and irrigation. Identifying the groundwater potential zones in certain areas of Ethiopia is still challenging in terms of time and cost for resolving water scarcity. Groundwater evaluations in Ethiopia are normally done based on field survey. Therefore, this study aims to use the timely and cost-effective remote sensing data and GIS techniques for the evaluation of groundwater potentials in Didessa Sub-Basin from Western Ethiopia. STRM DEM and Landsat-8 satellite image with secondary data was used for this study. Thematic layers showing distribution of slope, lithology, lineament density, drainage density, LULC, soil texture and rainfall were analyzed using weight overlay analysis and AHP algorithm to determine the groundwater potentials. The weights for each element then assigned according to their relative relevance using Saaty's (AHP) scale. The rainfall and geomorphology showed a higher weight and lithology the lowest. About 4.6% (1289.4km²) of the study area was classified as 'very high potential, 66% (18532.2 km²) classified as 'high potential, 27% (7683km²) as moderate potential and 2.1% (587.5 km²) as 'low' groundwater potential areas. Therefore, this study demonstrates a robust method, efficient and useful technique for delineating and mapping groundwater potential zones for planning and decision-making for better groundwater management.

Article History

Received: 01 January 2022
 Revised: 01 February 2022
 Accepted: 22 February 2022

Keywords

AHP;
 GIS;
 Ground Water Potential Zone;
 Remote Sensing.

Editor(s)

Suresh Kumar
 Vijay Bhagat

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1 INTRODUCTION

Groundwater is one of the most natural resources that support human health and ecological diversity, but nowadays it is decreasing and there is an increase in demand for water (Lakshmi and Reddy, 2018). It's also known as the water that occupies all of the pore space in soils and geologic formations beneath the water table (Wudad *et al.*, 2021). It flows through the aquifer layer towards the discharge point such as wells, springs, rivers, lakes and the oceans (Bekele, 2021). Groundwater is also recognized as one of the most valuable natural resources, an immensely important and dependable source of water supply in all climatic regions all over the world (Debele, 2020).

Ethiopia is one of the countries in Africa known for abundant water resources but minimum utilization of

groundwater for irrigation, domestic purposes and livelihood (Berhanu and Hatiye, 2020). The main part of Ethiopian areas has a shortage of rainfall and water scarcity due to a fluctuation in climate (Andualem and Demeke, 2019). The population of Didessa Sub-basins has used waters for drinking and other livestock from ponds and others by going long travel to fetch the water from rivers. The decreased rainfall in the arid zone and increasing population size and demands of water for irrigation and other livelihood requirements urges sustainable exploitation of the groundwater resources in the region (Kindie *et al.*, 2019; Mengistu *et al.*, 2019). In the study area, there is a large demand for groundwater development and utilization. However, there is a lack of in-depth understanding of the groundwater potentials in Ethiopia. In the recent past,

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<https://doi.org/10.21523/gcj1.2022060101>

the best estimates of the country's exploitable groundwater potential ranged between 12 and 30 billion cubic meters (Berhanu, 2014). The groundwater potential inside Ethiopia's territory was estimated to be around 1000 billion cubic meters based on hydrogeological parameters (Kebede, 2013). Other studies have found a different amount for Ethiopia's groundwater potential about 40 billion cubic meters (Mengistu *et al.*, 2019; Berhanu and Hatiye, 2020). Furthermore, there were just a few studies on the groundwater potentials of smaller catchments. As a result, there is a compelling need to investigate and develop the nation's groundwater resources so that more people, particularly in rural areas, can benefit from improved water supplies. On the other hand, there is very little research in Ethiopia on the use of groundwater for irrigation (Mengistu *et al.*, 2021). This could be due to a lack of knowledge about the existing groundwater resource and the necessity for big upfront investment in groundwater development for irrigation in the country (Berhanu and Hatiye, 2020). Groundwater potential investigation may thus be a necessary step in ensuring the nation's long-term usage of groundwater for a variety of needs, including household, agricultural, and industrial uses (Mengistu *et al.*, 2021; Dile *et al.*, 2018). However, extensive use of groundwater based on only limited information may cause unsustainable use of the resource. Subsurface studies are often carried out when there arises a need for local specific development of groundwater exists including borehole, spring, shallow or hand-dug wells for domestic water supply (Wudad *et al.*, 2021). Unsustainable groundwater use is becoming a visible problem and a major source of concern for many developing countries (Hussein *et al.*, 2016). One of these problems is the absence of updated spatial information on the quantity and distribution of groundwater resources (Mengistu *et al.*, 2021). Nowadays, there is a strong need to use groundwater for socio-economic development in Ethiopia, especially in rural areas (Dile *et al.*, 2018). The ministry of water resources, through the water well design and monitoring enterprise, has performed a multi-disciplinary study incorporating hydrogeology and geophysics to investigate Ethiopia's groundwater potential by employing time-consuming and costly geophysical and hydrogeological procedures, the potential can be realized. Aside from that, the groundwater potential for the Didesa sub-basin has not been characterized in prior research using GIS and RS approaches, separately (Kindie *et al.*, 2019; Mengistu *et al.*, 2019; Bashe, 2017). Since there is a limitation of previously work done in the area of the potentials and recharge zone in detail, the present study fills the gap by applying GIS and remote sensing techniques. These techniques are very easy to access, identify groundwater potential, and recharge zone of large and inaccessible areas (Gidey, 2018; Wudad *et al.*, 2021; Mengistu *et al.*, 2021; Andualem and Demeke, 2019). Considering the problems and the gaps from the other studies in terms of cost and time, an increasing number of population

densities and fluctuation of climate on water scarcity in Didessa Sub-basins, this research focused on identifying the potential and mapping the spatial and temporal distribution of groundwater availability in the study area.

The availability, accessibility, movement, and occurrence of groundwater depends on geology, slope aspect, lineaments, drainage density, LULC, Rainfall, surface runoff, and geomorphology of the area (Wudad *et al.*, 2021; Kindie *et al.*, 2019; Bekele, 2021; Debele, 2020). Evaluation, exploitation, exploration, site selection/delineation, and maps of groundwater need serious caution as it is cost and time-effective (Tamiru and Wagari, 2021; Ahmad *et al.*, 2020). It is out of our site improper evaluation of groundwater and site selection is mostly expected to pose the problem.

There are several methods available for the investigation of groundwater exploration or its availability in the sub-surface environment. They range from the oldest traditional water dowsing methods to the recent electromagnetic resonance (EMR) technologies (Wudad *et al.*, 2021). In general, all the methods can be categorized into two broad classes: surface and sub-surface. The most cost-effective and simple methods of groundwater exploration or potential assessment are those that take place on the surface (Gintamo, 2014). Surface geophysical approaches, as well as esoteric geomorphological, geological, soil related, and microbiological remote sensing techniques, are among these technologies. The sub-surface methods mainly consist of test drilling of boreholes and geophysical logging techniques (Bashe, 2017; Tamiru and Wagari, 2021). Although the sub-surface methods are accurate for groundwater exploration, they incur large investment since drilling, completing and development of wells may be needed for the effective application of these methods (Bawoke *et al.*, 2020; Melese and Belay, 2021). Therefore, it is a usual practice to undertake surface investigation methods for locating potential groundwater sources (Gidey, 2018). Remote sensing technique integrated with GIS is becoming a potent tool for the identification and mapping of groundwater potential zones in a time and cost-effective manner (Berhanu and Hatiye, 2020; Kindie *et al.*, 2019; Bekele, 2021). GIS and remote sensing approaches are particularly effective in the identification of groundwater potential of any region and often use spatial data to analyze and characterize required information (Abiy *et al.*, 2014). The geographic information system uses some proxy data from the ground surface to examine subsurface phenomena or objects. Geology, often known as lithology, is the study of rocks and minerals. landforms or geomorphology groundwater potential zones are typically identified using drainage density, rainfall, geological features or lineaments, slope, LULC, and soil properties (Melese and Belay, 2021; Debele, 2020; Kahsay *et al.*, 2019). These data were used as proxy data for groundwater potential mapping in this study. When there are few

direct measurements of groundwater, especially in smaller catchments, using such data to assess groundwater potential for Ethiopian conditions is extremely beneficial (Tamiru and Wagari, 2021; Kindie *et al.*, 2019; Mengistu *et al.*, 2021). The Didessa sub-basin is not exceptional to this constraint and there have been no previous investigations on the sub-basin's groundwater potential. The goal of this work was to use GIS and remote sensing approaches to identify and map the groundwater potential zones in the Didessa sub-basin using groundwater proxy data. The study also aimed to test the veracity of the qualitative analysis GIS and remote sensing techniques yielded. Groundwater potential maps that have been found and organized may provide information on productive wells in the research area. The findings could be utilized as a geo-database to help decision-makers and other stakeholders in the research area appropriately use and manage groundwater resources.

Geographical Information System (GIS) and Remote Sensing (RS) are the optional methods to provide all parameters which influence the groundwater potential of one area and it can access, manipulate, and analyze the spatial and temporal data from satellite images (Yifru *et al.*, 2020; Adeyeye *et al.*, 2019). Besides this, Gupta and Srivastava (2010) explain many decision-making analysis approaches such as Multi-Criteria Decision-Making (MCDM), Analytical Hierarchy Process (AHP) (Wind and Saaty, 1980), and Fuzzy Logic to fill the gap of water scarcity and decision-making on groundwater potential zone for evaluation and mapping. AHP is useful method for complex decision-making. A pairwise comparison matrix is used for checking the consistency ratio (Dinka *et al.*, 2014; Wind and Saaty, 1980). These decision-makers use this to reduce the bias in decision-making (Wind and Saaty, 1980; Kahsay *et al.*, 2019). Therefore, this study was focused on the evaluation of groundwater potential zone in the Didessa sub-basin by the integrated approach of remote sensing and GIS techniques using the AHP modeling approach. Besides this, the specific objectives of the study were to prepare the thematic maps of the study area such as lithology, LULC, slope, lineaments, soil texture, drainage density, and geomorphology and runoff depth to identify the factors that more affects the groundwater potential and recharge zone to assess, evaluate and delineate groundwater potentials of the area by using remote sensing and geospatial data.

2 MATERIALS AND METHODS

2.1 Study Area

The Didessa sub-basin is the largest among the major sub-basins in Abay Basin in terms of its annual discharge (Kabite and Gessesse, 2018). In the Blue Nile basin, the Didesa sub-basin is the most important both hydrologically and physiographically. The Nile basin, which has supported millions of people since prehistoric times, receives around 60% of its yearly discharge from

the blue Nile river, with the Didessa river accounting about 25% of that discharge (Kabite and Gessesse, 2018). The Didesa sub-basin is located in western Ethiopia, and it encompasses the East and West Wollega zones, the Illubabor zone, the Jimma special zone of the Oromiya area, and some parts of the Kamashi zone of Benishangul Gumuz. Geographically the sub-basin is located between 7° and 9°N and 35° and 36°E in the western part of Ethiopia. The elevation in the basin ranges between 654m MSL and 3154m MSL. The river drains an area of 28092km², and the Didessa River, which is the blue Nile's greatest tributary, contributes nearly a quarter of the river's total flow. In the research region, the average annual rainfall is around 1745mm. The river basin is classified under a humid tropical climate with heavy rainfall with an annual amount that is mainly received when the weather is wet. The highest and lowest temperature ranges between 21 and 31°C and 10 and 15°C, respectively. Geologically, Didessa sub-basin is dominated by Jimma Volcanic and the central part with Wellega Basalt and the lower parts are dominated by undifferentiated lower complex, Wellega Basalt and Adigrat Sand Stone.

2.2 Data

In this study, eight thematic layers (drainage density, rainfall, slope steepness, LULC, lineaments density, soil, geomorphology, and lithology) were used. The rainfall map was prepared using Inverse Distance Weighting (IDW) interpolation of long term mean annual rainfall data recorded at 23 stations. The information of lithology and soil are collected from the Ethiopian Geological Survey. These thematic layers were prepared with the help of ArcGIS 10.7 platform. The drainage and lineament density maps have been prepared using the line density analysis tool in Arc GIS 10.7. The slope and drainage density were derived from the Shuttle Radar Terrain Mapping Digital Elevation Model (STRM DEM) of 30m resolution. Landsat-8 Operational Land Imager (OLI) satellite images were obtained from the United States Geological Society (USGS) website and used to generate the lineament density and LULC maps.

2.3 Methodology

GIS and remote sensing techniques were applied to delineate the groundwater potential of the Didesa sub-basins through the AHP. The methodology used in this work includes the stages: i) identification and evaluation of criteria, ii) data collection, iii) preprocessing, iv) input dataset, vi) reclassified input layers, vii) pairwise comparison of criteria and give weight with AHP, and x) overlay analysis with weight sum overlay analysis in ArcGIS tools and ranking the final value (Figure 2). The long-term average point rainfall values were used to generate areal rainfall map. IDW interpolation approach was used to interpolate the areal rainfall map. Twenty-three stations data were employed for the preparation of areal rainfall of the study area. In this study, data sets such as SRTM data, Landsat-8, and geological data of

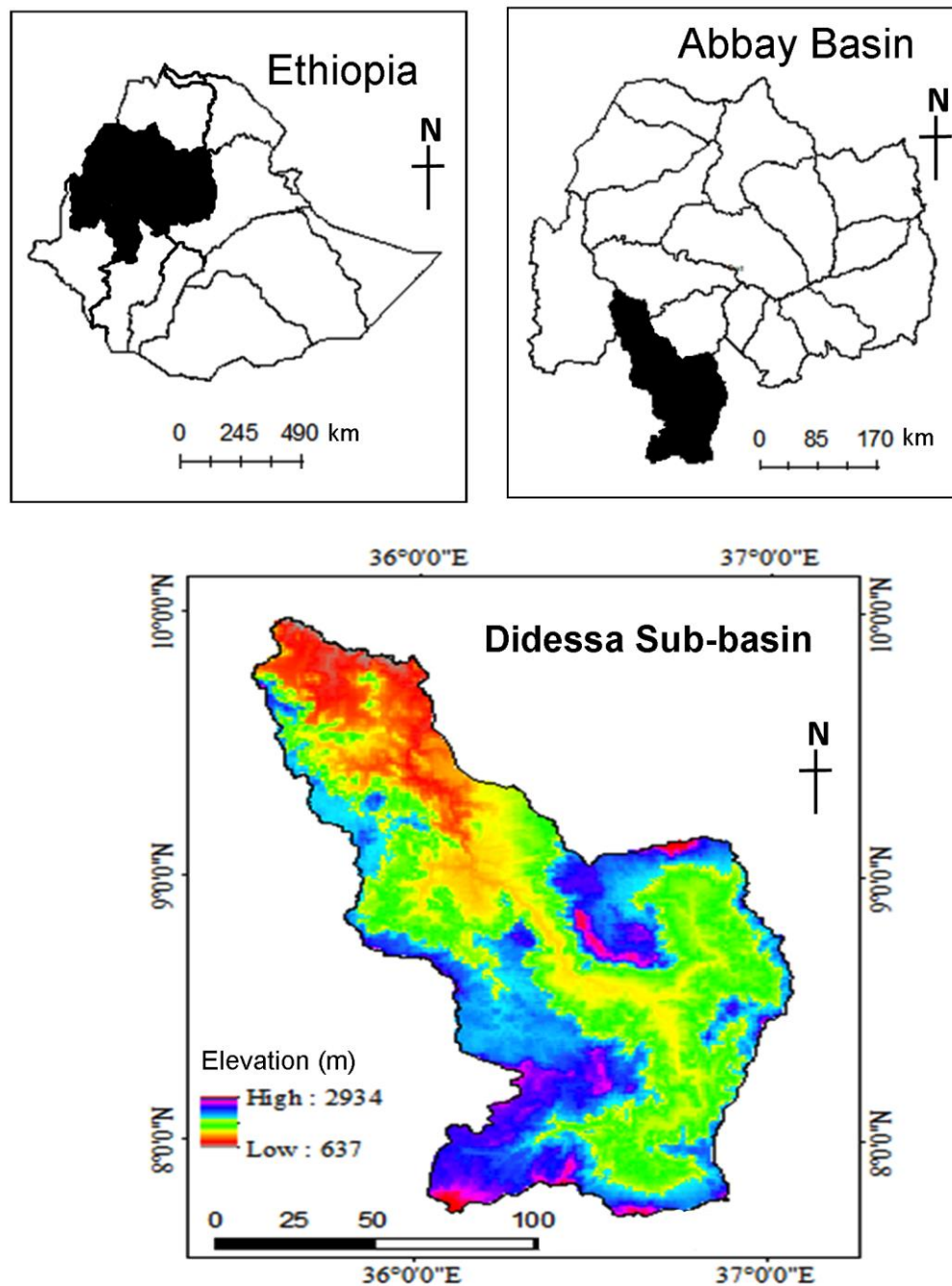


Figure 1. Study area: Didessa sub-basin in Ethiopia

Table 1. Data

Data	Sources	Remarks
Annual rainfall (1998-2016)	National Meteorological Agency (NMA)	Areal rainfall map prepared using IDW technique.
SRTM DEM 30m	https://earthexplorer.usgs.gov/	Used to prepare the elevation, drainage density and slope maps
Landsat-8 OLI/TIRS	https://landsatlook.usgs.gov/	Used for mapping of lineaments, LULC and geomorphology.
Maps	Ethiopian Geologic Survey	Procured lithological and soil maps

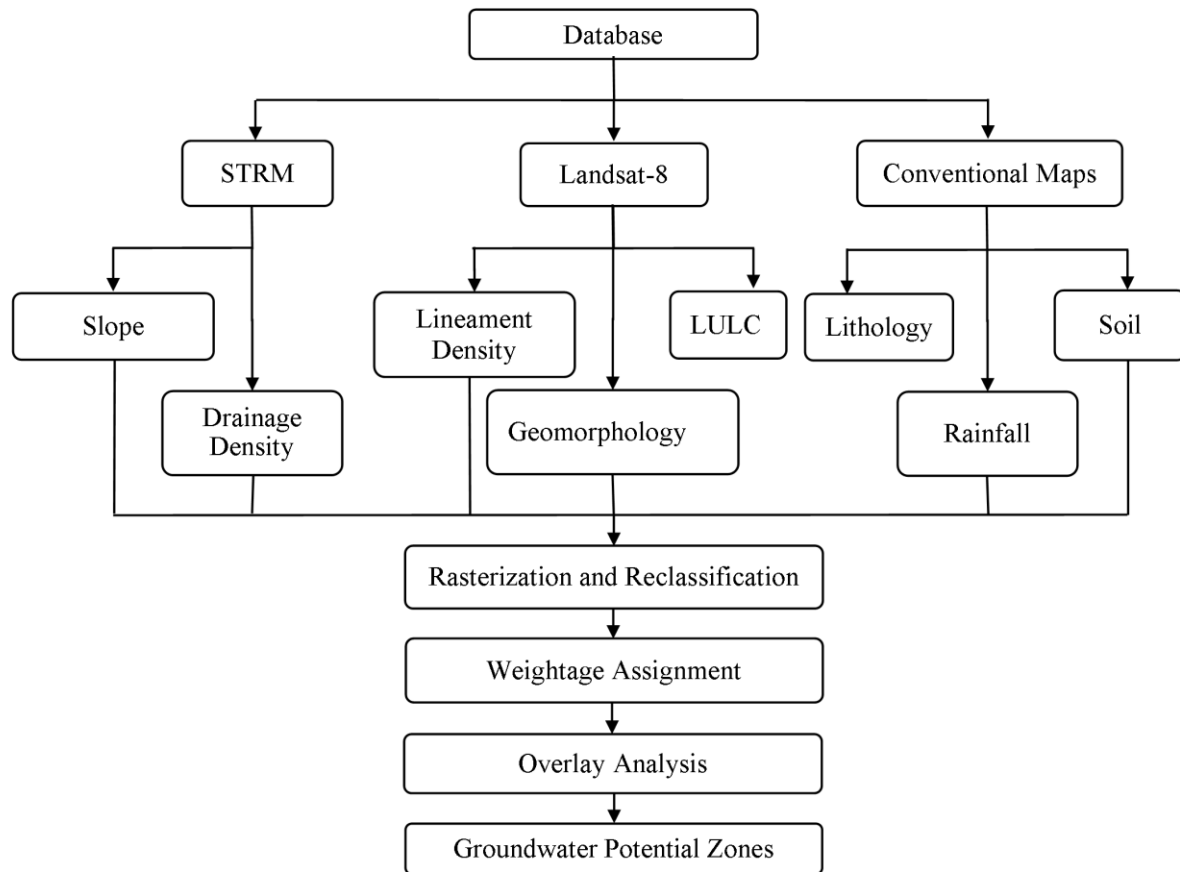


Figure 2. Methodology

the study area is identified and used as input data sets for further processing. SRTM at 30 X 30m resolution was used to generate digital elevation model of the area. Landsat images have been used for the preparation of LULC, lineament density and geomorphology maps. Then the elevation map of the Didessa sub-basin was prepared using Arc GIS. Further, the elevation data was used to generate the slope raster data in each grid cell. In the elevation raster, slope was measured by the identification of maximum rate of change in value from each cell to neighboring cells. The slope classes in the watershed were identified using slope spatial analyst tool in the ArcGIS package. On the other hand, the data related to drainage density were generated indirectly from the watershed slope data. Drainage density is defined as the closeness of spacing of stream channels. Drainage density (Dd) is the measure of the total length of the stream segment of all orders per unit area. The lineaments of the study area were extracted from the Landsat-8 OLI/TIRS image (path 170, row 51 with zero cloud cover) using automated processing LINE tool in PCI Geomatica 2017. Out of the 11 bands of the Landsat-8 OLI/TIRS images, the lineaments were extracted from band 5 due to its quality and the highest number of lineaments delineated. After the lineaments were extracted, further processes of editing the watershed divide line and road features were done in

GIS to ensure the quality of the extracted lineaments. The geomorphological map of the study area was prepared following the Hammond landform classification technique.

2.3.1 Weight Assessment and Normalization

Because of all parameters do not have an equal effect on groundwater distribution a ranking of each parameter is needed. Weighting each factor and a pairwise comparison matrix were prepared for each map based on Wind and Saaty (1980) scale. The score for the classes in a layer and weights for each factor was assigned and a pairwise comparison matrix has been prepared for each map by using the Multi-Criteria Decision Analysis technique based on AHP (Wind and Saaty, 1980) by considering seven factors (lithology, lineament density, soil, and drainage, rainfall, slope and LULC). On Saaty's scale of 1 to 9, each criterion is compared to the other criteria, proportionate to its relevance in matrices (Table 2). The score for classes in a layer and weights for thematic layers of each factor were calculated using the pairwise comparison matrix was carried out by using AHP techniques (Moges et al., 2019). The relative weight of their relevant classes was taken into account while calculating the cumulative weight of the primary criteria. Map categorization and weight assignment for groundwater potential and

recharge parameters selected for groundwater potential and nine parameters selected for groundwater recharge potential zone. Normalization of assigned weight using AHP (Wind and Saaty, 1980) based on Saaty's scale were considered two themes and classes at a time based on their relative importance to determine the groundwater potentials and recharge zone. Following that, pairwise comparison matrices with given weights to various thematic layers and classes created with the help of AHP and weights normalized by the eigenvector approach. To assess the normalized weights of various thematic layers and their particular classes, the consistency ratio (CR) was determined according to Wind and Saaty, (1980). To compute the CR of various thematic layers and their classes, the following steps were carried out:

1. Square matrix: $A = a_{ij}$ (Equation 1) the element of row i column j was produced and the lower triangular matrix was completed by taking the reciprocal values of the upper diagonal using the formula, $a_{ij} = 1/a_{ji}$

$$A = \begin{bmatrix} \frac{P1}{P1} & \frac{P1}{Pj} & \frac{P1}{Pm} \\ \frac{Pj}{P1} & 1 & \frac{Pj}{Pm} \\ \frac{Pm}{P1} & \frac{Pm}{Pj} & \frac{Pm}{Pn} \end{bmatrix} \quad (1)$$

2. Summation of all columns j in the matrix from (Equation 1) using (Equation 2)

$$\frac{P1}{P1} \dots \dots + \frac{Pj}{Pj} \dots \dots \dots \frac{Pn}{Pn} = \frac{\sum_{i=1}^n Pj}{Pj} \quad (2)$$

3. Divide each element of matrix $a_{ij} = p_i/p_j$ (Equation 2) by (Equation 3) to get normalized relative weight (Equation 5)

$$\frac{\frac{Pj}{Pj}}{\frac{\sum_{i=1}^n Pj}{Pj}} = \frac{Pj}{Pj} \times \frac{Pj}{\sum_{i=1}^n Pj} = \frac{Pj}{\sum_{i=1}^n Pj} \quad (3)$$

4. Averaging across the rows (Equation 6) to get the normalized Principal Eigenvector (priority vector) i.e., Rate (R_i) or weight of row 'i' (W_i). Since it is normalized, the sum of all elements in the priority vector should be one.

$$\frac{W_i}{R_i} = \left[\frac{P_i}{\sum_{i=1}^n P_i} \dots \dots + \dots \frac{P_i}{\sum_{i=1}^n P_i} \right] \times 1/n \quad (4)$$

The judgments of the pairwise comparison within each thematic layer were checked by the consistency ratio (Wind and Saaty, 1980). The proportion of consistency scholars recommended that for matrices having a CR rating greater than 0.1, the method should be repeated until the desired value of $CR = 0.1$ is obtained. The value of CR is computed as (Equation 5)

$$RC = \frac{CI}{R} \quad (5)$$

where, RI is Saaty's ratio index; CI is consistency index. Consistency index is a measure of consistency or degree of consistency of the judgment and computed using (Equation 6).

$$CI = \frac{(\lambda_{max} - n)}{n-1} \quad (6)$$

where, n is the number criterion, the value of RI for n criteria as indicated in Table 2.

To compute λ_{max} , first multiply the normalized value by the respective weight (Equation 6) and then, the values of the product are added together to get λ_{max} (Equation 7)

$$\lambda_{max} = \sum_{i=1}^n W_i \times \left(\frac{P_i}{\sum_{i=1}^n P_i} \right) \quad (7)$$

where, λ_{max} is the largest Eigenvalue of the pairwise comparison matrix. P_i is the priority of the alternative and W_i is the assigned rate/weight.

2.3.2 Overlay Analysis

The final map (Figure 11) was obtained by overlaying all thematic maps using weighted overlay methods after assigning rates for classes in a layer and weights for thematic layers (Kindie et al., 2019; Abiy, et al., 2014; Tamiru and Wagari, 2021), using the spatial analysis tool in are G.I.S 10.7 as shown (Equation 8)

$$GWP = \sum_{i=1}^n W_i \times R_i \quad (8)$$

where, GWP is groundwater potential zone; W_i is the weight for each thematic layer and R_i ; rates for the classes within a thematic layer derived from AHP.

Table 2. Saaty's scale of relative importance (Wind and Saaty, 1980)

Relative importance	Definition
1	Equal importance
2	Weak or slight
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong
8	Very very strong
9	Extremely importance

3 RESULTS AND DISCUSSION

3.1 Rainfall

Rainfall is the most important factor for the identification of groundwater potential (Duan *et al.*, 2016). The central and northeastern parts of the study area receive very high rainfall of around 1965-2120mm/year; the most central part receives high rainfall of around 1878-1965mm/year. The northwestern and southern parts receive moderate rainfall 1811-18187mm/year. The Northeastern and few eastern parts of the study area receive low rainfall 1713-1811mm/year. The little eastern southeastern and southern parts receive very low rainfalls (1510-1713mm/year). The high rainfall distribution along high slope gradient in the northwest and southeast highland parts directly affects the infiltration rate groundwater potential zones in the downstream central rift floor of the study area. Based on the mean annual rainfall and its contribution to groundwater potential; the relative weight was given for each rainfall class. The rate was determined by the contribution to groundwater potential; high rainfall areas received a greater weight (Figure 3), while low rainfall areas received the lowest weight indicating low groundwater potential.

3.2 Drainage Density

Drainage density is the natural flowing of water runoff to lowland/ common points. It indicates the behavior of surface and subsurface formation, the information of rock, soil permeability, infiltration of water, and surface runoff. Groundwater potential is often weak in places where a higher drainage density is dominant because there is less time for infiltration, whereas areas with a low drainage density allow more infiltration to recharge the groundwater system. Drainage density was prepared from DEM by using line density tool in ArcGIS 10.7 and reclassified into five categories (Figure 4) as very poor = 1 (0-0.02728km/km²), poor = 2 (0.02728-0.07857km/km²), moderate = 3 (0.07857-0.12331km/km²), high = 4 (0.12331-0.170042km/km²), and very high =5 (0.17042-0.2782km/km²). Drainage density is affected by the topographic conditions and the permeability of the geological units. If the slope is flat, the permeability is very high and the drainage density is very low.

3.3 Lineament Density

Lineaments are the simple and complex linear properties of geological structures. The Geomatica module was used to extract faults, cleavages, fractures, and various surfaces of discontinuities such as terraces and ridges arranged in a straight line or a small curve that are identified by remote sensing lineaments extracted from a single image of Principal Component Analysis (PCA) and record the output as a polyline with vector segment (Tadesse *et al.*, 2015). Due to multispectral imaging bands being often highly correlated, Principal Components used to produce uncorrelated output bands,

segregate noise components, and reduce the dimensionality of data sets. This is accomplished by finding a new set of orthogonal axes with their origin at the data mean and which are rotated to maximize the data variance. Landsat images were processed for Principal Component Analysis and eight-bit grayscale lineaments are automatically extracted. Groundwater potential is to be good in areas with a high lineament density. The lineament density was classified into five categories (Figure 5) classified as very poor = 1 (0-0.03234 km/km²), poor = 2 (0.03234-0.08407 km/km²), moderate = 3 (0.08407-0.1304 km/km²), high = 4 (0.1304-0.1767 km/km²) and very high = 5(0.1767-0.2748 km/km²). The large parts of the study areas are classified as moderate lineament density.

3.4 Slope

The slope is the steepness or the change of elevation between two locations and it has a direct influence on groundwater recharge. High slope regions have high runoff and low infiltration rates that are not suitable for groundwater recharge, because water cannot get enough time to infiltrate to the ground. The slope map of the study area was prepared based on the DEM data using the spatial analysis tool in ArcGIS 10.7. Based on this result, the slope of the study area was divided into five classes namely; flat, gentle, moderate, high, and steep slope. The generated map was reclassified (Figure 6) and ranking depend on their groundwater potential and recharge influence. The highest rank was given to flat slope because the flat area can hold water which is very easy for infiltration of water to the ground and the lowest rank was assigned for the steep slope. After all, they result in high runoff and low infiltration which cause low groundwater recharge. For this study, the slopes were reclassified into five categories to groundwater potential zones as very high = 5 (0 - 2.024), High = 4 (2.024 - 3.898), Moderate = 3 (3.898 - 6.297), Poor = 2 (6.297 - 9.82) and very poor = 1 (9.82 - 19.116).

3.5 Soils

Soil is an important factor for delineating the groundwater potential areas. The percolation or infiltration rate of water to the water tables is influenced by soil permeability. Didessa sub-basin is covered by a variety of soil groups. the major soils are Hunitisols which covers (73.77%) and are highly characterized by loam in texture, Hpnitisols (4.66%) with clay texture, Ltleptosols (1.48%) characterized by sandy loam, Hualisols (7.03%), which is loam in texture, Rhnitisols (0.03%) with heavy clay texture character, Dyleptosols (5.73%) which is loamy sand in their texture and Euvertisols (7.3%) characterized by clay texture. The Soils were reclassified into five categories (Figure 7) for groundwater potential zones as very poor = 1 (Heavy clay), poor = 2 (clay), moderate = 3 (loam), high = 4 (sandy loam) and very high = 5 (loamy sand).

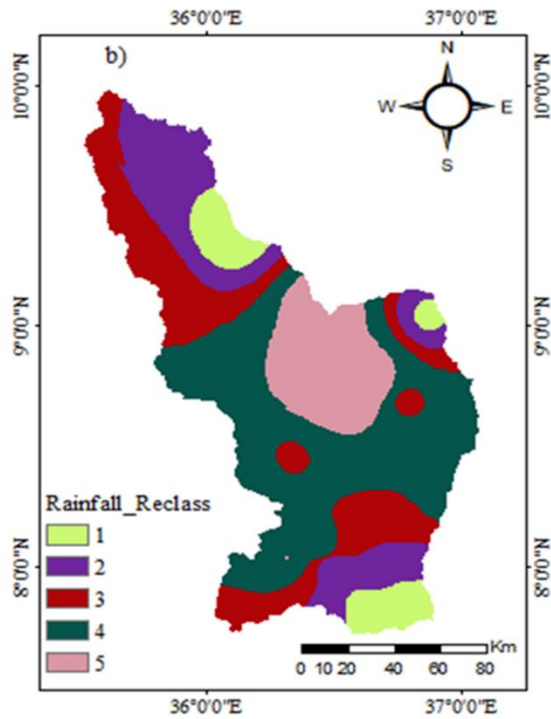


Figure 3. Rainfall

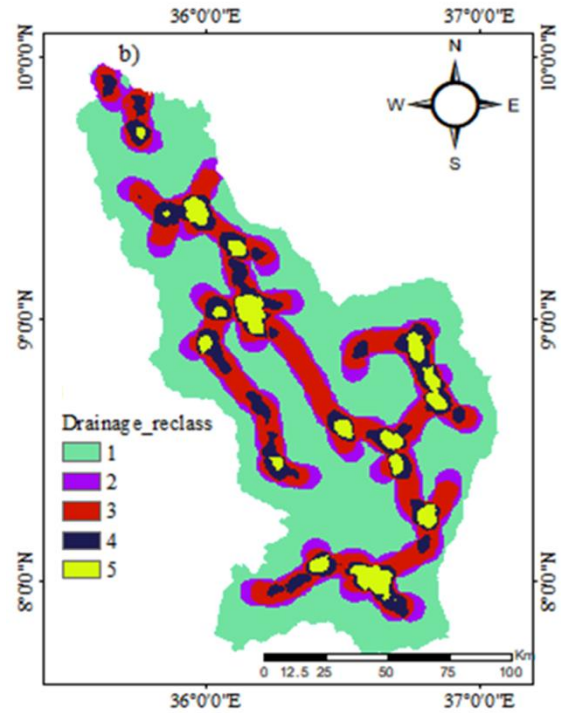


Figure 4. Drainage density

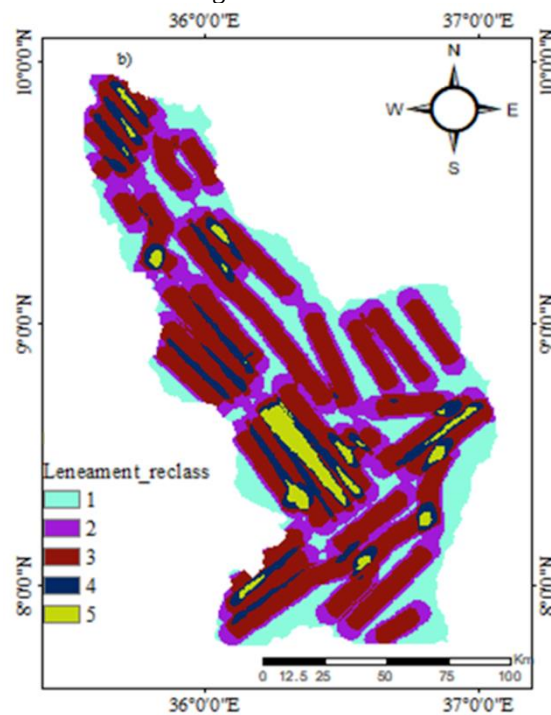


Figure 5. Lineament density

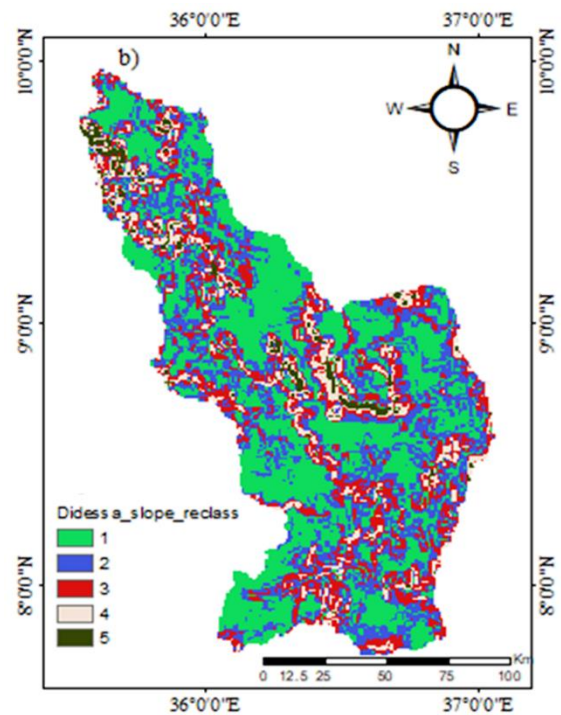


Figure 6. Slope

3.6 Land Use Land Cover (LULC)

LULC have a direct effect on the hydrological process of surface runoff, evapotranspiration, and groundwater potential. LULC types give the necessary information on infiltration. Water body, agricultural land, and the waterlogged area are excellent sources of groundwater potential, while the bare lands and exposed rock surface areas are less important for groundwater potential. A

LULC map was prepared using supervised classification with a maximum likelihood classification from Landsat-8 Operational Land Imager (OLI) Satellite images. Seven dominant LULC namely dominantly cultivated land, shrub land, grassland, dominantly cultivated land, bare land, woodland, and forest are available in the study area. These land use land covers were reclassified into five classes (Figure 8) based on qualitative

categories as very poor = 1 (Bare land), poor = 2 (Agricultural land), moderate = 3 (Woodland), high = 4 (Grassland), and very high = 5 (Forest) based on the rate of groundwater recharge.

3.7 Geomorphology

Geomorphology is the study of earth structures and landforms. It mainly depends on geological formation. From a geomorphological study point of view, the identification and characterization of diverse landforms and structural elements in the study region are very significant as they are required for groundwater potential. If the hydrogeological settings convey water for a geomorphological unit a slope based landform, low mountainous, and flat plains are markers for the presence of groundwater. The geomorphological map shows seven landform features namely: High altitude plains, Low plateaus, Mid altitude plateaus, High-altitude plateaus, Low altitude mountains, Mid altitude mountains, and High altitude mountains. These geomorphologies were reclassified into five units (Figure 9) as very poor = 1 (high mountains), poor = 2 (Hills), moderate = 3 (low mountains), high = 4 (plateaus), and very high = 5 (plains) based on the rate of groundwater recharge.

3.8 Lithology

The presence of groundwater in an aquifer is determined by the geological settings' lithology and permeability. Water is stored in the aquifer when the lithological formation holds and conveys the percolating water. The amount and volume of water stored in the geology is a function of the hydrogeological settings of the area. The water can only be stored if there are enough void areas between the geologic units. The aquifer is assumed to be potential when there are enough spaces in the hydrogeological settings. Porosity and permeability are frequently sufficient in lithological units with uniform grain sizes. Groundwater recharge occurs when precipitation from surface runoff lakes and streams percolates into the subsurface. The study area's dominant lithology classes are Termeber, Adigrat Sandstone, Blue Nile Basalts, Marshsoils, Fluvium, Colluvium and Lateritecon Amba Alija Rhyolite, and the corresponding classes to the groundwater potential zones are very poor = 1, poor = 2, moderate = 3, high = 4 and very high = 5, respectively (Figure 10).

3.9 Groundwater Potential Zones

In locations like the Didessa Sub-basin, where rainfall is erratic, mapping the groundwater prospect zone is critical. Farmers in the study area are required to dig and construct bore wells in order to meet home water needs and maintain agricultural productivity through irrigation. The goal of this research was to find useful information and the optimum locations for groundwater investigation. Groundwater availability and distribution are always determined by a multitude of hydro-

morphological conditions that affect soil infiltration and aquifer recharge (Hussein *et al.*, 2016).

The groundwater potential zone map of the study area (Figure 11) was prepared through the integration of various thematic layers including rainfall and characteristics of terrain features such as geology, geomorphology, and slope. The entire watershed classified into very low, low, moderate, high, and very high groundwater prospect zones.

High groundwater prospect zone is widely distributed across most parts of the Subbasin. The total area covered by category is 66% (18532.2 km²) of the total area of sub-basin. The very high groundwater prospect zone is occupying 4.6% (1289.4Km²) of the area. This result is reveals with the findings by Wudad *et al.* (2021), Kindie *et al.* (2019), Melese and Belay (2021), Tamiru and Wagari (2021), Hussein *et al.* (2016), Debele (2020), Hussein *et al.* (2016), Bashe (2017) and Bawoke *et al.* (2020) who reported high infiltration and aquifer recharge rates in areas with flat slope, deep soil, and alluvial deposits. The river banks, wetlands and lake fringes of the Didessa Sub-basin also exhibited very good groundwater potential zones.

Appropriate weights were assigned to all thematic layers and their individual features after understanding their importance in influencing groundwater potential. Scores and weights were assigned to all thematic layers based on their roles in groundwater potential including infiltration, aquifer transmission, and storage. The scores and weights assigned to the individual features of the nine themes considered in this study are summarized in Table 4.

The analysis of thematic layers (rainfall, soil texture, slope, runoff depth, LULC, lineament, geomorphology, drainage density, and lithology) and the values of the parameters are given based on the Saaty scale as shown in Table 3. Based on the pairwise comparison matrix, the relative weight matrix and normalized Principal Eigenvector were calculated. The relative weight for thematic layers was assigned according to their relative importance.

The weights were normalized based on equation five (Equation 5), which are calculated by averaging the values in each row to get the corresponding ranking, which gives the results of normalized weights of each parameter as presented in Table 3. From the result, observed rainfall has the highest value rather than other parameters. Because, it indicates high rainfall has the possibility of high groundwater recharge thus high groundwater potential zones, while low rainfall indicates low groundwater recharge thus low groundwater potential zones. The main source of groundwater in the area was the rainfall of the northwestern and southeastern highlands in the study area due to mountain blocks and slopes.

The consistency index was computed to overcome for the formula of consistency ratio and this was done

based on equation 9, which results in $CI = 0.120$. Then, the consistency ratio was computed as per equation 8 and the computed result of $CR = 0.085$ which is less than 0.1 and the given weights were valid for further analysis. The values of weights taken after the AHP analyses were used in the weighted overlay analysis for each criterion were fixed as 0.327, 0.242, 0.112, 0.1065, 0.0757, 0.064, 0.046, and 0.026 for rainfall,

geomorphology, lineament density, drainage density, slope, soil, LULC, and lithology, respectively. Therefore, groundwater potential areas were obtained by the combination of all layers using the overlay analysis method in Arc GIS 10.7 (Equation 9):

$$GWPZ = 32.76 \times Rf + 24.22 \times Gm + 11.18 \times Ld + 10.65 \times Dd + 7.57 \times Sl + 6.4 \times St + 4.6 \times LULC + 2.6 \times lith \quad (9)$$

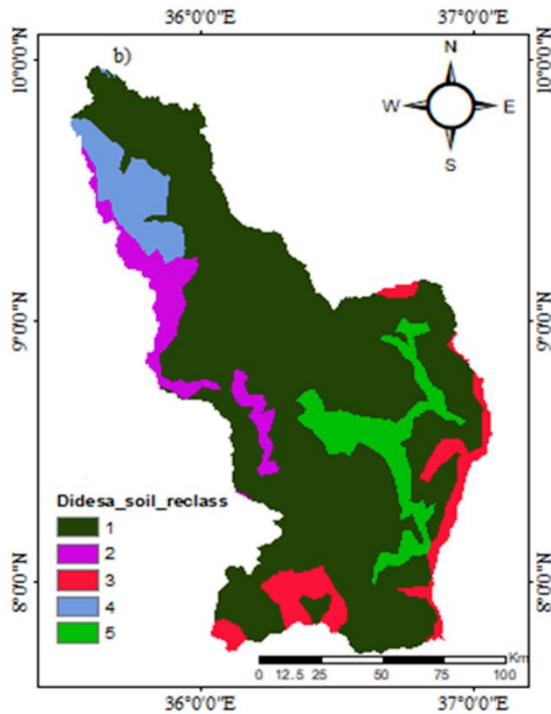


Figure 7. Soil

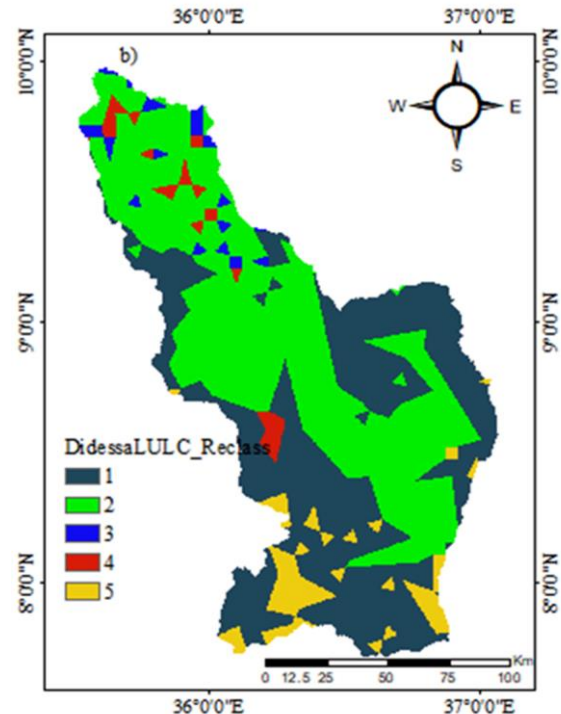


Figure 8. Land use land cover

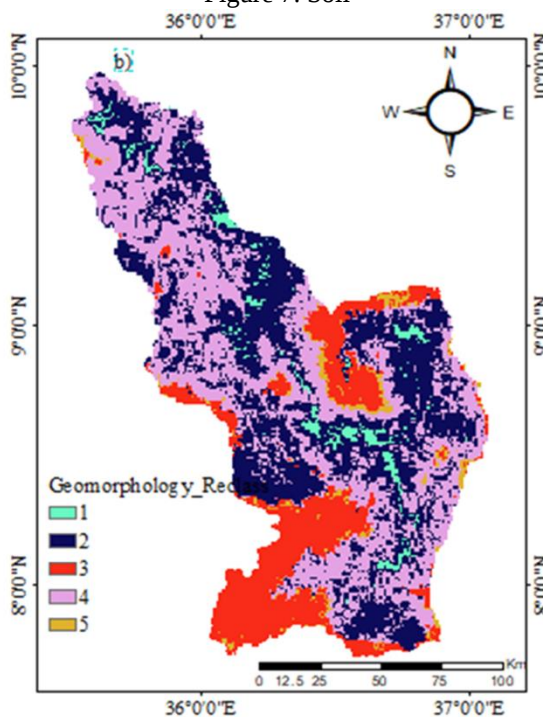


Figure 9. Geomorphology

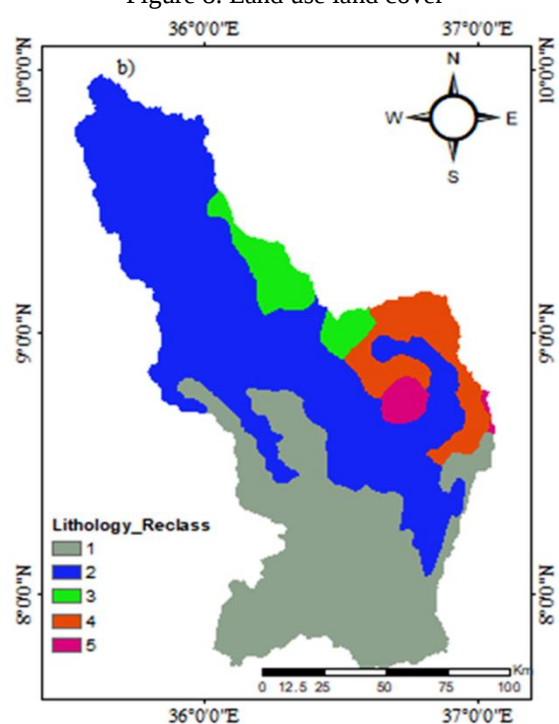


Figure 10. Lithology

Table 3. Pairwise comparison matrix

Parameters	Rf	GM	Ld	Dd	Sl	St	LULC	Lith
Rf	1	2	3	5	6	4	6	7
GM	0.5	1	2	3	5	5	6	7
Ld	0.333	0.5	1	0.5	2	4	2	3
Dd	0.2	0.333	2	1	2	2	2	3
Sl	0.167	0.2	0.5	0.5	1	2	3	4
St	0.25	0.2	0.25	0.5	0.5	1	3	4
LULC	0.167	0.167	0.5	0.5	0.333	0.333	1	4
Lith	0.143	0.143	0.333	0.333	0.25	0.25	0.25	1
Total	2.76	4.543	9.583	11.333	17.083	18.583	23.25	33

Table 4. Scores and weightages

Theme	Dominant effect	Suitability	Scores	Weightages
Rainfall (mm/year)	1967.75 - 2120.67	Very High	5	0.327
	1871.88 - 1967.74	High	4	
	1791.99 - 1871.87	Moderate	3	
	1691.56 - 1791.98	Low	2	
	1538.62 - 1691.98	Very Low	1	
Geomorphology	Low Plateaus	Very High	5	0.242
	Low Plains	High	4	
	Mid Plateaus	Moderate	3	
	Mid Plains	Low	2	
	Low Mountains	Very Low	1	
Lineament Density (Km/Km ²)	0.176 - 0.274	Very High	5	0.112
	0.13 - 0.176	High	4	
	0.084 - 0.13	Moderate	3	
	0.032 - 0.084	Low	2	
	0 - 0.032	Very Low	1	
Drainage Density (Km/Km ²)	0 - 0.28	Very High	5	0.106
	0.028 - 0.079	High	4	
	0.079 - 0.123	Moderate	3	
	0.123 - 0.17	Low	2	
	0.17 - 0.27	Very Low	1	
Slope (degree)	0.0 - 2.02	Very High	5	0.0757
	2.02 - 3.89	High	4	
	3.89 - 6.3	Moderate	3	
	6.3 - 9.82	Low	2	
	9.82 - 19.11	Very Low	1	
Soil Texture	Loamy Sand	Very High	5	0.064
	Sandy Loam	High	4	
	Loam	Moderate	3	
	Clay	Low	2	
	Heavy Clay	Very Low	1	
LULC	Forest	Very High	5	0.046
	Grassland	High	4	
	Woodland	Moderate	3	

Lithology	Agricultural land	Low	2	0.026
	Bare land	Very Low	1	
	Taramber	Very High	5	
	Basalt	High	4	
	Fluvium	Moderate	3	
	Colluvium	Low	2	
	Marshsoils	Very Low	1	

Table 5. Normalized pairwise comparison matrix

Parameters	R	Sl	GM	Ld	Dd	St	LULC	Lith	Wt	Wt %
Rf	0.3623	0.44	0.31	0.44	0.35	0.215	0.26	0.21	0.32	32.76
GM	0.1812	0.22	0.21	0.26	0.29	0.269	0.26	0.21	0.24	24.22
Ld	0.1207	0.11	0.1	0.04	0.12	0.215	0.09	0.09	0.11	11.2
Dd	0.0725	0.073	0.21	0.09	0.12	0.108	0.09	0.09	0.11	10.65
Sl	0.0605	0.044	0.05	0.04	0.06	0.108	0.13	0.12	0.08	7.57
St	0.0906	0.044	0.03	0.04	0.03	0.054	0.13	0.12	0.07	6.4
LULC	0.0605	0.037	0.05	0.04	0.02	0.018	0.04	0.12	0.05	4.6
Lith	0.0518	0.031	0.03	0.03	0.01	0.013	0.01	0.03	0.03	2.6
Total	1	1	1	1	1	1	1	1	1	100

Rainfall, slope, lineament density, and geomorphology hold the highest value relative to the other parameters. The weight assigned for rainfall was greater than the weight of others, which influence the occurrence of groundwater potential and recharge zone than other parameters. The result indicated that about 2.1% of the study area classified (Figure 11) as low 27.35% classified as moderate, 66% as high potential, and 4.6% were classified as very high groundwater potential.

4 CONCLUSION

In this study, the result of groundwater potential zones by using GIS and remote sensing techniques through AHP decision methods were identified and delineated based on the influential factors for groundwater potentials. Eight parameters were selected which have more affected the occurrence of groundwater potential zone before overlay analysis. It is possible to construct important criteria that have a stronger impact on the result than other criteria by applying quantitative weights. The AHP approach allows decision-makers to give judgments to reduce complexity in decision-making processes. The result of the consistency ratio in this study was 0.08 for the groundwater potential zone and the value was accepted for further analysis.

The delineated groundwater potential zones classified into four zones namely low, moderate, high, and very high. The low zone shows the low suitable area for groundwater prospects. A very high zone, on the

other hand, indicates the best location for groundwater potential. The effective parameters in the area for groundwater potential zone are rainfall, slope, geomorphology, lineament density and drainage density in pairwise comparison matrix analysis indicates that all parameters are significant. The values of weights taken after the AHP analyses were used in the weighted overlay analysis for each criterion were fixed as 0.327, 0.242, 0.112, 0.1065, 0.0757, 0.064, 0.046, and 0.026 for rainfall, geomorphology, lineament density, drainage density, slope, soil, LULC, and Lithology, respectively. Therefore, groundwater potential areas were obtained by the combination of all these layers using the overlay analysis method in Arc GIS 10.7. The important factors result show that rainfall and geomorphology have a higher weight and lithology has the lowest weight for identifying the potential of groundwater in the study area. The result indicated that about 4.6% (1289.4km²) of the study area were classified as very high potential, 66% (18532.2km²) classified as high potential, 27% (7683km²) as moderate potential, and 2.1% (587.5km²) were classified as low groundwater potentials. This indicates that the AHP, GIS and Remote Sensing integrated approach for identification of groundwater potentials gives an acceptable result. Hence, it is fair to conclude that this result can be used for the planning of new groundwater based projects and expansion of the existing project in the sub-basin.

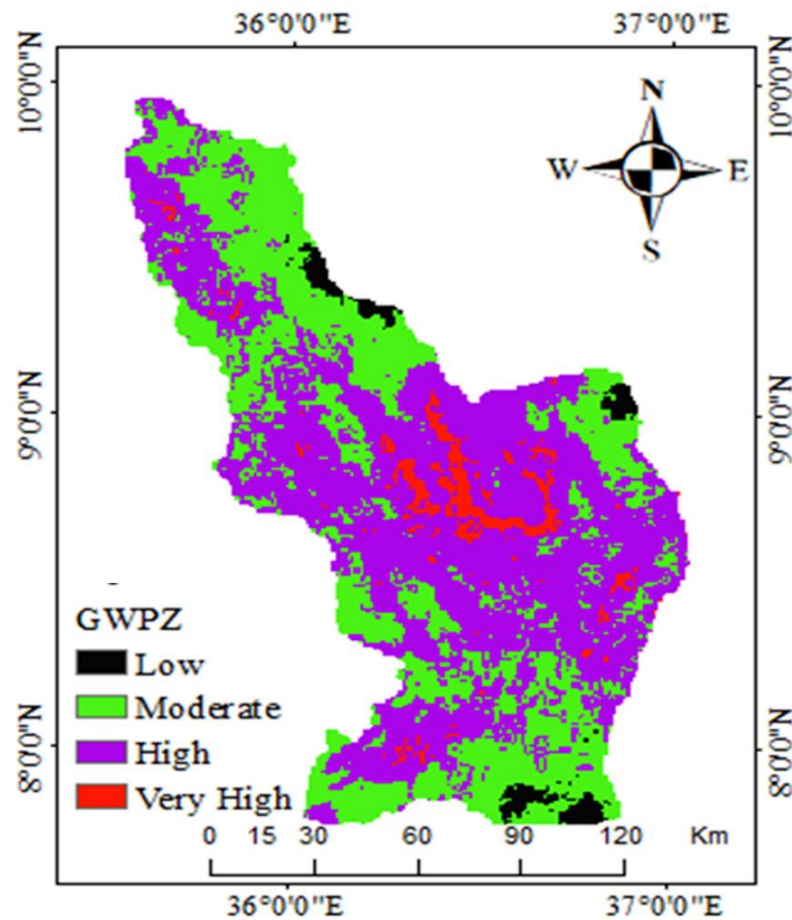


Figure 11. Groundwater potential zones

ACKNOWLEDGEMENTS

The author is highly indebted to the College of Engineering and Technology and Department of Hydraulic and Water Resources Engineering, Wolkite University for providing all kinds of necessary facilities and support during the present study.

CONFLICT OF INTEREST

The author declares no potential conflicts of interest with respect to the research, authorship and publication of this article.

ABBREVIATIONS

AHP: Analytical Hierarchy Process; **Dd:** Drainage Density; **GIS:** Geographical Information System; **Gm:** Geomorphology; **GWPZ:** Ground Water Potential Zone; **IDW:** Inverse Distance Weighting; **Lith:** Lithology; **LULC:** Land Use Land Cover; **Rf:** Rainfall; **RS:** Remote Sensing; **Sl:** Slope; **SRTM:** Shuttle Radar Topographic Mission; **St:** Soil Texture; **USGS:** United States Geological Society; **Wt:** Weight.

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