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Groundwater potential zonation mapping using GIS-based MCDM approach in east Gojjam zone, central Ethiopia

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ABSTRACT

Study region: The study area is located in the East Gojjam zone, Amhara, Ethiopia; the area covers the Choke Mount and is surrounded by the Abbay River.
Study focus: The primary focus of the study was assessing the possible groundwater sites in the selected area using the Analytical Hierarchy Process (AHP) with the Geographic Information System (GIS) approach for groundwater exploration and investigation.
New hydrological insights for the region: Water is a very important resource used to the day-to-day activities in our life, which is found naturally on the surface and subsurface of the Earth. The study area is a part of a nation-wide economically significant region in Ethiopia and the Horn. The area is the primary water supply (Choke Mountain) for the Ethiopian Grand Ethiopian Renaissance Dam (GERD) receives the highest water supply from this region. The results of the study show that the groundwater potential zones in the area are mapped as poor, moderate, high, and very high groundwater potential areas. The Validations of the results were made using the borehole log data, and reasonably accepted the rationality of the adopted methodology. The considered parameters, as well as their evaluation of the production of the groundwater potential Map, were confirmed. The produced Groundwater potential map is very important for Irrigation Engineers, domestic water supply studies, agricultural studies, environmentalists, and future groundwater conservation strategies.

1. Introduction

Water occurs in all three phases, as vapor in the atmosphere, soil pore spaces, Liquid and solid form on the surface, and liquid in the subsurface. One of the most important resources that keep life on Earth going is water, which may be found in many different forms, including surface water, groundwater, snow, and meteorological water(Subramani et al., 2024). Groundwater occurs in the saturated zone of variable thickness and depth, below the Earth's surface (Akhtar et al., 2020, Schwartz and Zhang, 2024). Cracks and pores in the existing rocks and unconsolidated materials make up a large underground reservoir where part of the precipitation is stored (Uliasz-Misiak and Misiak, 2024). The worn and fractured zones that make up hard rock aquifers have a high groundwater potential because of their large aquifer networks and ideal recharging conditions (Patel et al., 2024). Groundwater is an important source of water supply. It has been used for a very long time, but only lately has the existence and flow of underground water been recognized as a component of the hydrologic cycle. Numerous variables, including rainfall intensity, geology, soil properties, lineament density, slope gradient, drainage density, land use/land cover (LULC), and topographic wetness index, affect the presence and flow of

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Table 1
Inventory of water at the earth's surface.

Reservoir	Volume (Cubic km x 1000, 000)	Percent of the Total
Oceans	1370	97.25
Ice Caps and Glaciers	29	2.05
Groundwater	9.5	0.68
Lakes	0.125	0.01
Soil Moisture	0.065	0.005
Atmosphere	0.013	0.001
Streams and Rivers	0.0017	0.0001
Biosphere	0.0006	0.00004

Source: https://www.physicalgeography.net/fundamentals/8b.html accessed on October 16/2024

Table 2
Reservoirs.

Reservoir	Average Residence Time
Glaciers	20–100 years
Seasonal Snow Cover	2–6 months
Soil Moisture	1–2 months
Groundwater: Shallow	100–200 years
Groundwater: Deep	10,000 years
Lakes	50–100 years
Rivers	2–6 months

Source: http://www.physicalgeography.net/fundamentals/8b.html

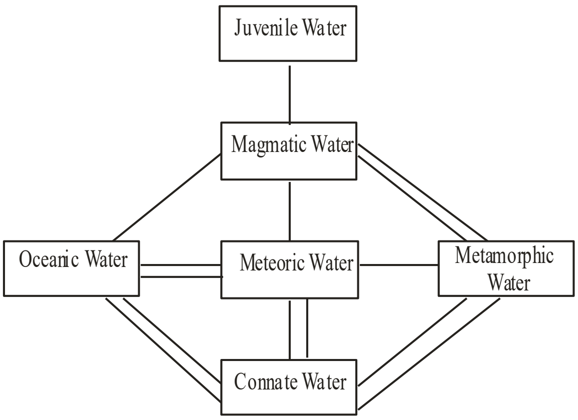

Fig: 1. Different genetic types of water after (White et al., 1963)).

groundwater (Guduru and Jilo, 2022). Precipitation, elevation, lithology, slope, soil, drainage density, lineament density, and land use/land cover (LULC) are some of these datasets (Alharbi, 2023). In many regions across the world, people are suffering from having potable water, and due to this reason, people are affected by waterborne diseases. Ethiopia is known as the water tower in Africa but in most parts of the country, water is scarce for home consumption. The groundwater is utilized through wells and tube wells using various lifting devices, such as those using animal, manual, diesels, or electric power, may be used, to bring the underground supplies to the surface. Because groundwater is an essential natural resource for both industrial and agricultural applications, it has become more important to develop groundwater resources as much as feasible. Planning and developing this resource so requires defining the criteria influencing groundwater resources and evaluating them to forecast groundwater potential (Bekele, 2021, Abebe et al., 2023, Birhanu and Tesfa, 2023).

The rainfall that infiltrates beneath the ground surface passes through the spaces of soil, rocks, and joins. These voids, if interconnected, permit the movement of groundwater to a lower concentration. The recharging and accumulation of groundwater are the main components of a hydrological system. They are caused by water seeping through various soil and rock strata in the drainage basin following rainfall (Raza et al., 2022). But in some rocks and sediments, they may be isolated, and thus, prevent the movement of water between the interstices. Therefore, it is clear that the kind of formation and, by extension, the local geology, determine how groundwater occurs. The possibility of occurrence of groundwater mainly depends upon two geological factors: i.e., (i) the porosity and (ii) the permeability of the rocks and sediments. The porosity of a rock and/or sediment, which is the major geological criterion for the occurrence of groundwater, is a quantitative measurement of the interstices or voids present in the rock and/or sediment. Certain

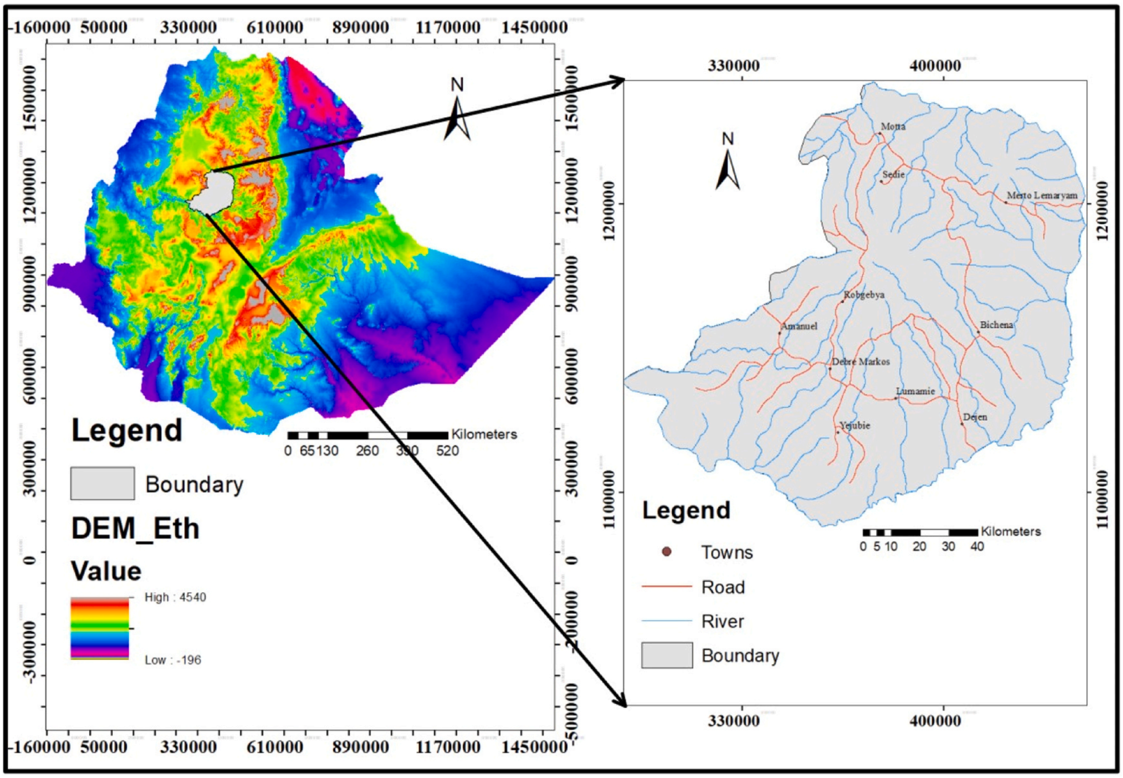

Fig.: 2. Location map of the study area.

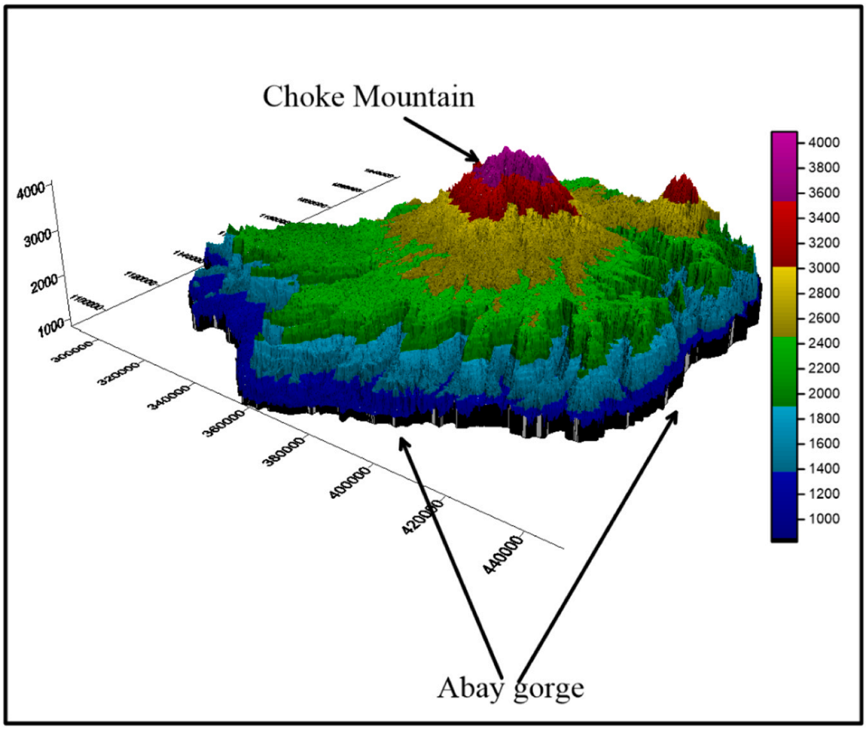

Fig.: 3. Physiographic map of the area.

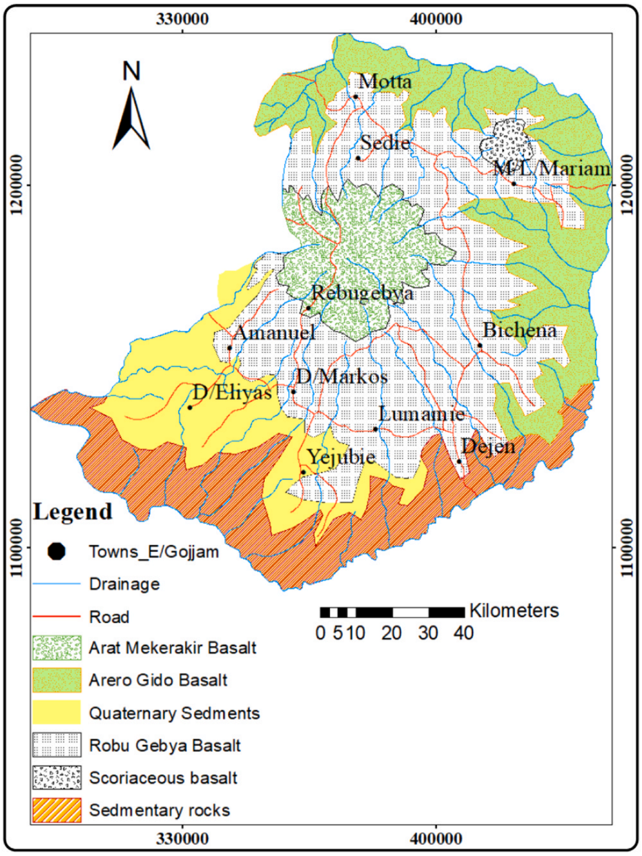

Fig.: 4. Geological map of the study area.

geological formations and arrangements determine the frequency and supply of groundwater supplies. This suggests that the geological structures and formations have a direct bearing on groundwater availability (Subramani and Kamaraj, 2024). Permeability is defined as the ability of a rock or unconsolidated sediment to transmit or pass water through it.

Water can percolate downhill along lines, which act as conduits. A permeable zone is often indicated by its presence. Because of the high rate of penetration, the areas surrounding lineaments and their junction point are ideal locations for groundwater storage. The planetary water supply is dominated by the oceans (Table 1). The seas contain over 97 % of all the water on Earth. The remaining 3 % is stored as freshwater in lakes, glaciers, ice caps, soil, the atmosphere, and living things. One of the most valuable resources is groundwater. It is the world's primary source for agricultural consumption, communities, and industry. Groundwater now makes up over 34 % of the world's water resources and is a significant source of potable water (Verma and Patel, 2021, Zewdie and Tesfa, 2023). Water resource management and conservation have become more important for environmental sustainability as freshwater supply becomes limited in developing countries due to the growing population (Thakuriah, 2023).

The rivers replenish their water supply once every sixteen days on average. Every eight days, the whole amount of water in the atmosphere is replenished. Groundwater, huge lakes, glaciers, and ocean bodies have slower rates of replenishment (Table 2). These reservoirs may need hundreds or even thousands of years to replenish. Human activity is depleting some of these resources, particularly groundwater far faster than it is replenishing them. When resources are used in this way, waterTypical residence times of water found in various becomes almost nonrenewable.

The relationship between various genetic types of water is shown in Fig. 1. Because atmospheric precipitation is a component of the current hydrologic cycle, the majority of the water is of the meteoric kind (Galewsky et al., 2016, Gimeno et al., 2020). It serves as the primary water supply for springs and wells. Connate water, juvenile or magmatic water, and metamorphic water are the other three forms of water that are more interesting to academic studies. Since juvenile water is being introduced into the hydrosphere for the first time, it is sometimes referred to as freshwater (Ward and Whipple, 1918, Goncharuk, 2018). The majority of magmatic water is young and comes from either shallow volcanic eruptions or deep-seated magma. Connate water, which is not in hydraulic continuity with the current hydrological cycle, is the leftover ancient water that has been stored in aquifers. For this reason, it is often referred to as fossil water, even if the name "water" is misleading. It might originate from freshwater or the sea. Connate water, which is often of marine origin, is frequently linked to oil and gas (Fig. 1). Hydrochemical and isotopic data can help identify the different genetic kinds of water (Azzie, 2002, Edmunds and Bogush, 2012).

Groundwater is a primary essential element found in the subsurface of the earth across the world. Potential zones for groundwater

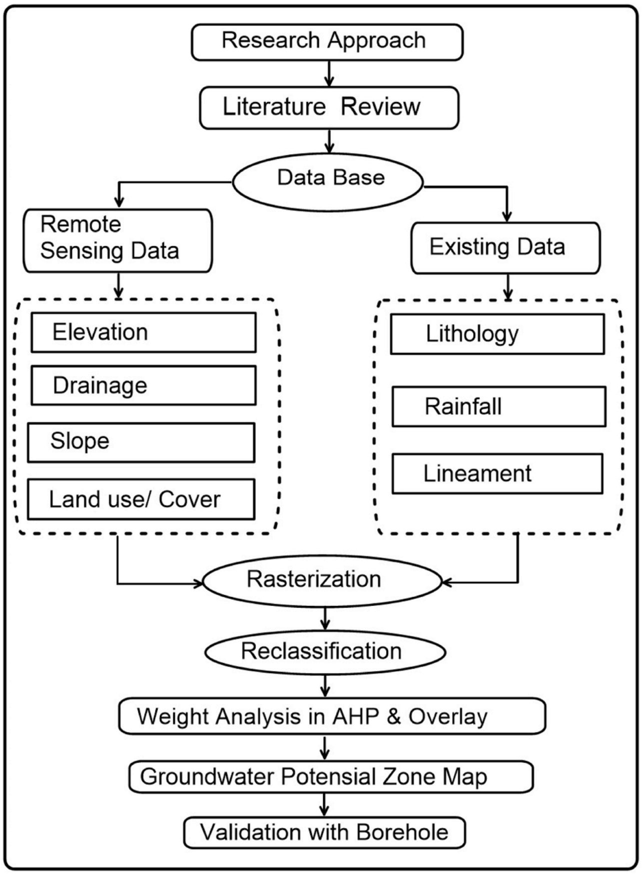

Fig.: 5. Flow chart showing the sequence of the study.

Table 3
Conditioning factors and their respective data sources.

No	Conditioning factors	GIS data type	Scale	Data Source
1	Lithology	Polygon	1:50,000	Geological map of Ethiopia (Tefera et al., 1996), Field observations
2	Lineament Density	Polyline	30 × 30	Geological Map
3	Elevation	Grid	30 × 30	DEM Data (30 ×30 m) ASTER data set
4	Well log	point		
5	Slope	Grid	30 × 30	DEM Data (30 ×30 m) ASTER data set
6	Land use/ cover	Grid	30 × 30	https://livingatlas.arcgis.com/landcover/
7	Drainage Density	Polyline	30 × 30	DEM Data (30 ×30 m) ASTER data set
8	Rainfall	Grid	30 × 30	https://crudata.uea.ac.uk/cru/data/hrg/cru_ts_4.06/

planning and groundwater resource development need mapping. Because the majority of geological and geophysical groundwater techniques involve expensive and time-consuming ground measurements, remotely sensed data in conjunction with a geographic information system (GIS)is a good fit, and the data produced by conventional and ground measurement systems can be readily integrated with it(Sewnet et al., 2016, Tesfa and Sewnet, 2024). While there are several trustworthy geophysical and geological techniques for determining the locations of aquifers and groundwater levels, using these approaches to evaluate the availability of groundwater resources is both time-consuming and prohibitively expensive (Swarnim et al., 2023). When compared to conventional methods, geospatial technology offers a more effective and economical way to detect groundwater potential zones. Conventional approaches depend on time-consuming and costly ground surveys employing hydrogeological, geological, and geophysical instruments (Hagos et al., 2024). Groundwater is now the most significant renewable resource due to industrialization, population increase, and agricultural practices. Despite much study and technical improvement, groundwater studies have remained more insecure due to a lack of direct observation techniques (Ganesan and Subramaniyan, 2024). The need for freshwater has grown significantly in recent decades as a result of the world's population growth, and the need for water for industrialization and agriculture has made water shortages increasingly common (Bogdan et al., 2024). Groundwater is becoming more and more necessary due to factors including climate change, fast urbanization, agricultural water needs, and population increase worldwide (Kom et al., 2024).

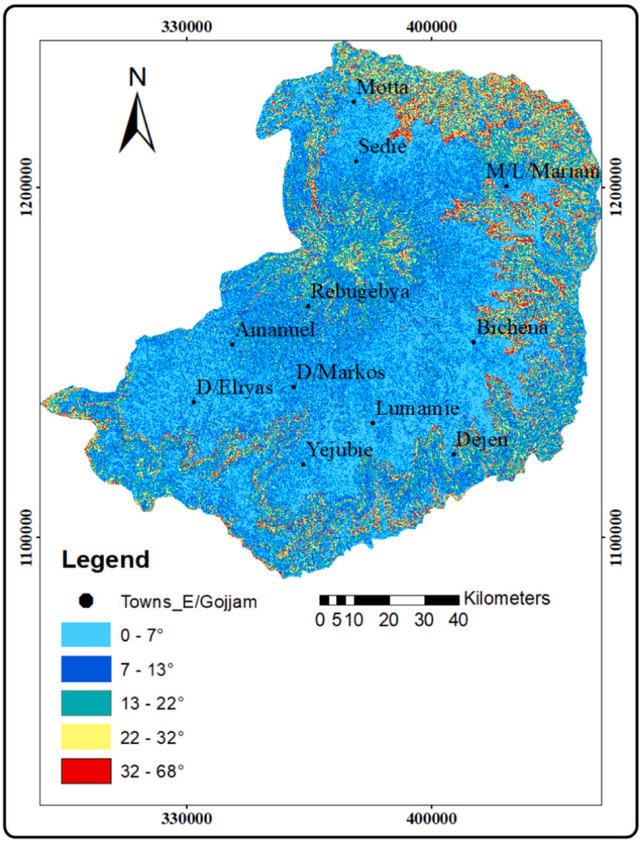

Fig.: 6. Slope degree map of the study area.

Therefore, evaluating possibly accessible groundwater resources using efficient technology should be the primary strategic policy for the majority of nations worldwide to meet the demands of rapidly growing populations and urbanization (Zewdie et al., 2024). Groundwater potential zone (GPZ) detection is greatly influenced by several factors. Important elements that regulate groundwater and help identify possible groundwater locations include lineament, drainage density, precipitation, slope, geology, soil, land use land cover (LULC), and geomorphology (Dwivedi et al., 2024). Several elements, including the climate, geomorphology, land use/cover, physiography, hydrology, geology or lithology structure, lineament density, and soil types of the area, interact to determine the presence, distribution, and flow of groundwater resources (Bulbula and Serur, 2024). The primary source of water storage and a resource for ingeniously addressing water scarcity is groundwater. Depending on a region's hydrodynamics, rainfall, geography, geology, soil texture, gradient, etc., different places have different amounts of groundwater (Rehman et al., 2024). Among the factors influencing groundwater potential are lithology, geomorphology, drainage density, geology, slope, drainage network, land use/cover pattern, and climatic conditions (Ma and Mb, 2024). During the decision-making process, the MCDM-integrated GIS analysis for the groundwater potential index can help decision-makers make more accurate and timely decisions by explicitly providing the information they require (Yıldırım, 2021). The scarcity of potable water is common in the world and it is also a common problem in Ethiopia. The common problematic areas of potable water in Ethiopia are mega cities like Addis Ababa, Harare, Gondar, Mekelle, Debre Markos, and so on. Most of the towns are received from water supply stations with the schedule of waiting more than two weeks. One of the areas having a potable water shortage in Ethiopia is the East Gojjam zone towns under this zone with potable water shortage are Debre Markos, Motta, Bichena, Dejen and so on.

2. Descriptions of the study area

2.1. Location

The study area is found in the Amhara Regional State Administration of the East Gojjam Zone, in the northwestern part of Ethiopia. Geographically, the district is described by latitudes of 250000 m to 300000 m and longitudes of 1050000 m to 1550000 m (Fig. 2). An asphalt road that runs from Ethiopia's capital, Addis Ababa, to Bahir Dar, Gondar, and eventually Sudan by crossing the border provides access to the research region. The road portion that begins at Abbay Gorge leads to the study area. One of the Amhara regional state administrative areas, the east Gojjam zone administration is bordered to the west by the west Gojjam zone, to the south and

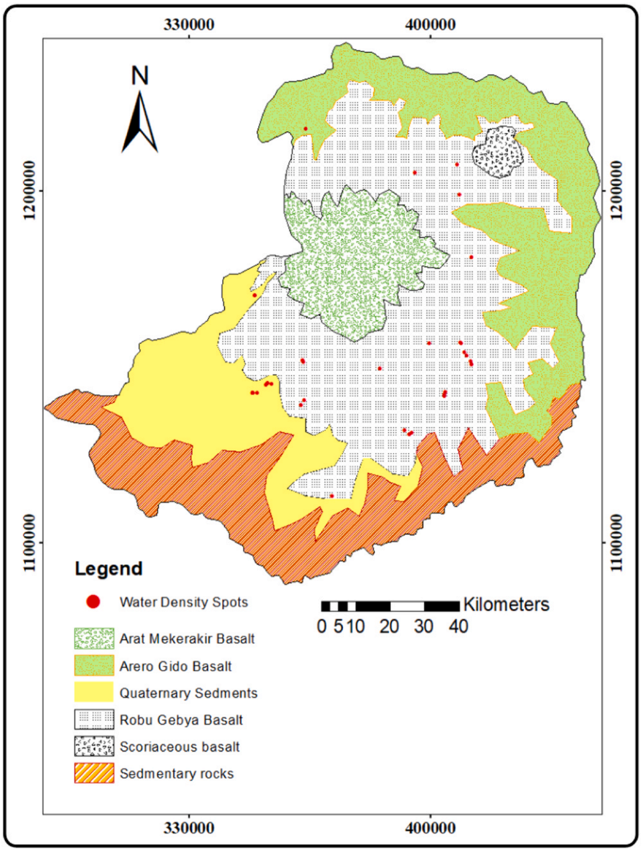

Fig.: 7. Geology/Lithology map of the study area.

southeast by the Oromia regional state, and to the east by the north shewa, which is surrounded by the Abbay river, which forms a belt around most of its territory.

2.2. Physiography and climate

The Amhara regional state has a relatively jagged terrain, with highland regions making up the majority of its physiographic setting (Tesfa and Zewdie, 2023). Choke Mountain is one of the highlands in the study area. The region is quite topographically divided, with an altitude range of 818–4094 m above mean sea level. The most often seen features in the region are conical hills, plane land, and mountains (Fig. 3). The climatic condition of the mountain range is divided into six distinct climate zones, and Choke Mountain's peak, Wurch, is located at 3200 m above sea level in a humid climate with an annual average temperature of fewer than 11.5 degrees Celsius (Simane et al., 2013). The area received an annual rainfall of 1206 mm and 1596 mm minimum and maximum, respectively (Fig. 15).

2.3. Geological setting

The abundant tertiary volcanic that covers the Mesozoic sediments, which are only revealed in the deep incisions of large rivers like Abbay, Jemma, and other minor rivers, characterize the geological context of the studied region. The Paleozoic-Mesozoic sediments are associated with transgression and regression of the sea and Cenozoic volcanic rocks, which are directly overlying the Precambrian metamorphic and Mesozoic sedimentary rocks in Ethiopia (Kazmin, 1973). The research area's primary lithostratigraphic units include Quaternary surface deposits, Cenozoic volcanic rocks, and Mesozoic sedimentary rocks. The primary unit of rock in the Mesozoic sedimentary deposit is sandstone. The geology of the area is described as follows:

Arat Mekerakir Basalt: The choke mountain region, known locally as the Arat Mekerakir Mountains and primarily composed of this kind of basaltic rock, is exposed to this unit. Compositionally, the rock shows plagioclase phyric and olivine plagioclase basalts (Fig. 4). The basalt is dark, porphyritic, aphyric, occasionally vesiculated, and amygdaloidal with silica amygdalas. It is exposed on the summit of Choke Mountain, close to the peak, and is dated at 22.4 Ma (Kieffer et al., 2004). In the northwest of the study area, near Choke Mountain, is the thin layer of exposed basalt known as Choke Peak Basalt (Fig. 4). At the summit of Choke Mountain, it forms a level plateau.

Arero Gido Basalt: This unit is exposed in the northeast part of Merto Lemariam town. Compositional basalt is expressed as olivine

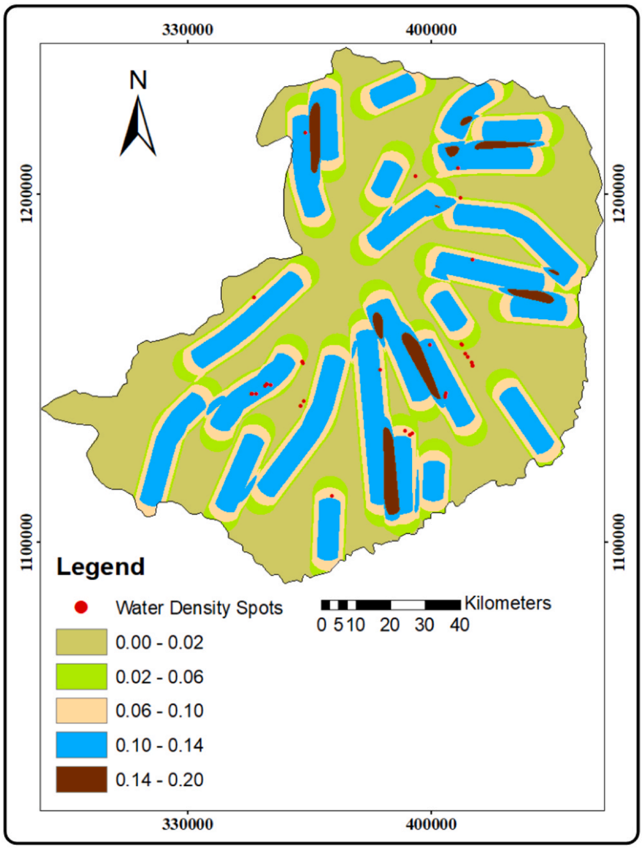

Fig.: 8. Lineament density map.

pyric basalt and olivine plagioclase phyric basalt. This area's uppermost layer is composed of volcanic breccia. This basalt is occasionally interlayered with pyroclastic tuff. This unit's uppermost portion is mostly made up of sandstone or volcanic breccia, which has a basaltic composition. Volcanic breccia, with a maximum thickness of 50 m and a maximum volcanic block size of 40 cm in field observations, dominates the basaltic breccia.

Robu Gebya Basalt: This unit has a variable interval of phenocryst proportion. This unit is located at the foot of the Choke Mountain. The Robu Gebya basalt occasionally has an aphyric texture and is vesiculated and amygdaloidal with silica amygdalas. It is olivine-plagioclase-pyroxene phyric basalt, pyroxene-olivine phyric basalt, and plagioclase phyric basalt.

Scoriaceous Basalt: This unit showed a cone at the Islamo Mountain and the layer of scoriaceous basalt. It is a representation of the well-known volcanic ash Islamo Mountain. The basaltic agglomerate and volcanic braccia, respectively, separated three massive lava flows to form the volcanic pile (Fig. 4). In comparison to the massive basalt, the scoriaceous basalt is black, heavily vesiculated, and comparatively lightweight. It also contains small olivine-based mantle xenoliths. This unit was completed by covering a thin layer of scoria and scoriaceous basalt covers the uppermost section of this unit, creating a scoria cone.

Sedimentary Rocks: This sandstone unit is known as the top sandstone or Ambaradom formation. In the research region, this unit is primarily exposed along the banks of the Abbay and Jema Rivers (Fig. 4). The rocks exhibit lamination and/or bedding, with varying bedding thicknesses ranging from extremely thin to heavily bedded. The gypsum that complies with blue shale is colored bluish-grey. The gypsum mineral exhibits bedding and occasionally nodules of finely-grained granular aggregates form. Fossil remains are occasionally present in the yellow limestone, which is bedded thickly and thinly and alternated with gypsum. Fine-grained silt- and sand-sized layers, closely spaced microchannels, and clay-sized minerals filling the channels are the expressions of the laminations. The reddish-gray, bedded sandstone is light gray.

Quaternary Sediments: Slope deposits have occurred in the topographies with steep and moderate slopes. In the southern portion of the area, these sediments are found as a mapable unit south of Dejen town and north of the Abay River (Fig. 4). The slope deposits range from enormous to locally stratified sediments, and they are friable. These sediments contain a variety of sizes that consist of boulders, pebbles, cobbles, clay, and silt. The observed larger size of thickness in the study area was 5 m. The limestone, gypsum, and basalt units combined to produce the boulders.

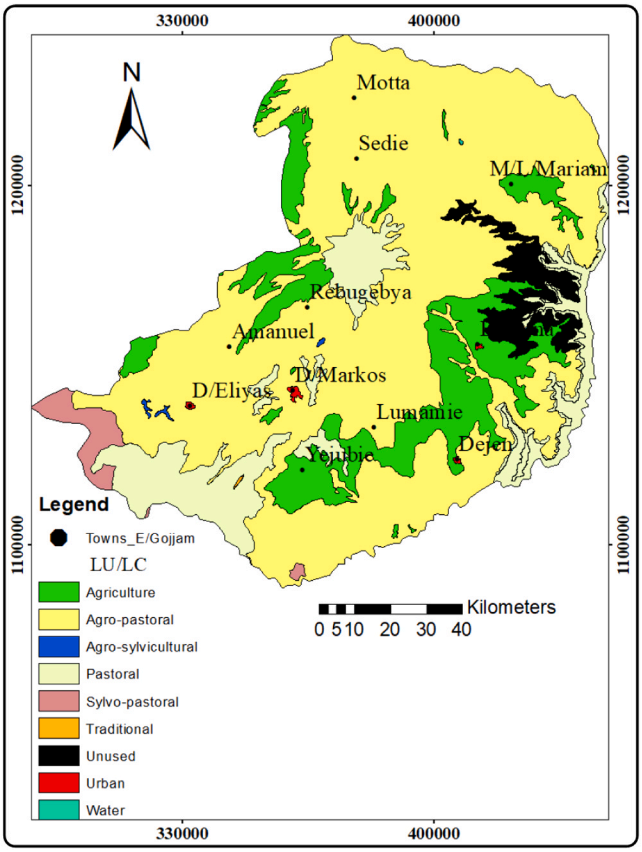

Fig.: 9. Land use/cover map of the study area.

3. Methodology and approaches

AHP is a popular and reliable method for defining groundwater potential zones around the world. This approach has been effectively used in several research projects (Lalngaihawma et al., 2024). An AHP-based multi-criteria decision-making technique was used with the chosen driving factors in the groundwater potential areas. The analytical hierarchy process (AHP) was chosen for this study among several other multicriteria decision-making techniques due to its broad applicability (Tesfa, 2025). Based on the expert's experience and knowledge, the relative value of each component may be compared to generate a pair-wise comparison matrix (Vishwakarma et al., 2021, Tesfa and Woldearegay, 2021).

The methodology of the study followed by this study was:

1) A thorough field survey of the places, GPS data, photos, expert interviews, lithological data, topographic surveying, hydrogeological conditions, and creation of base maps of groundwater potential zones.
2) The study area for groundwater potential zones was mapped using a GIS window, which was also utilized to create maps of the factors and analyze the groundwater potential zones mapping (Fig. 13).
3) The AHP tool was first created by (Saaty, 2004) as a multicriteria decision-making technique. It is a process that uses paired comparisons to create ratio scales.

The values of each column in the pairwise matrix were summed to get the layers and sub-layers of the driving factors for the occurrences and distribution of groundwater (Eq. 1)

$$\mathrm{Lij} = \sum_{j=1}^{n} \mathrm{aij}) \tag{1}$$

Where, aij = factor layer. Lij=

Each element in the row was divided by the total of each matrix column to create the normalized pairwise matrix (Eq. 2).

$$\mathrm{Xij} = aij \Big/ \sum_{j=1}^{n} \mathrm{aij}) \tag{2}$$

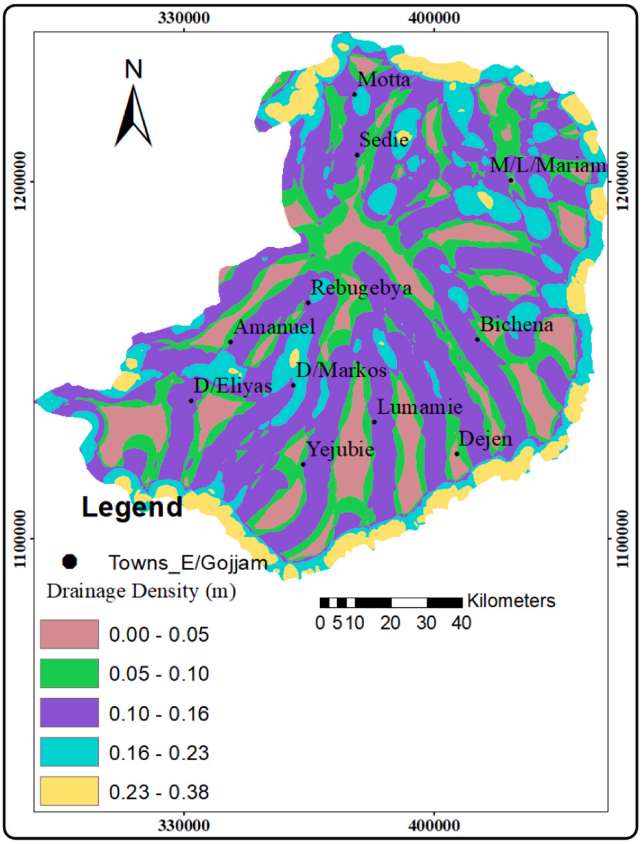

Fig.: 10. Drainage density map.

Using (Eq. 3) to divide the total of the normalized row of the matrix by the number of factor layers (N), the standard/mean final weights of the factor layers were found.

$$\mathrm{GWP} = \sum\nolimits_{i=1}^{n} \mathrm{WiRi}) \tag{3}$$

Where RI is graded for the classes inside a thematic layer derived from AHP, Wi is the weight for each thematic layer, and GWP is the groundwater potential. Moreover, the depth to groundwater level of the research area was ascertained using secondary data gathered from thirty-eight active boreholes and manually dug wells. The groundwater level thematic layer was created by importing and interpolating the spatially related groundwater level data using the IDW technique. Fig. 5

3.1. *Selection of variables*

Groundwater movement transportation and storage can be affected by many factors. These factors are also affected by different zones and environments from place to place. Based on the purpose and the nature of the study area the following variables are selected, Lithology, rainfall, Slope, drainage density, well logs, altitude, and lineament density, land use/ cover. Several sources provided the data for this investigation (Table 3). To evaluate groundwater potential zonation, primary and secondary data from several sources were gathered (Table 3). The prepared and collected input data are derived from a range of inherent and triggering properties of the region. Lastly, an assessment of groundwater potential zones was produced by adding up all of the assessments for all of the driving components.

4. Results

4.1. *Assignment of weights*

By dissecting the intricate characteristics of groundwater-controlling factors, the AHP of MCDM eliminates ambiguities (Tesfa, 2022, Asmare and Tesfa, 2022, Asmare et al., 2023). The decision-making components were organized hieratically, and the normalized weights of each component were established to produce a comprehensive and distinct image of the work's goals with a high degree of confidence and certainty (Zewdie et al., 2024). Table 2 shows the pairwise comparison matrix of seven selected variables and their

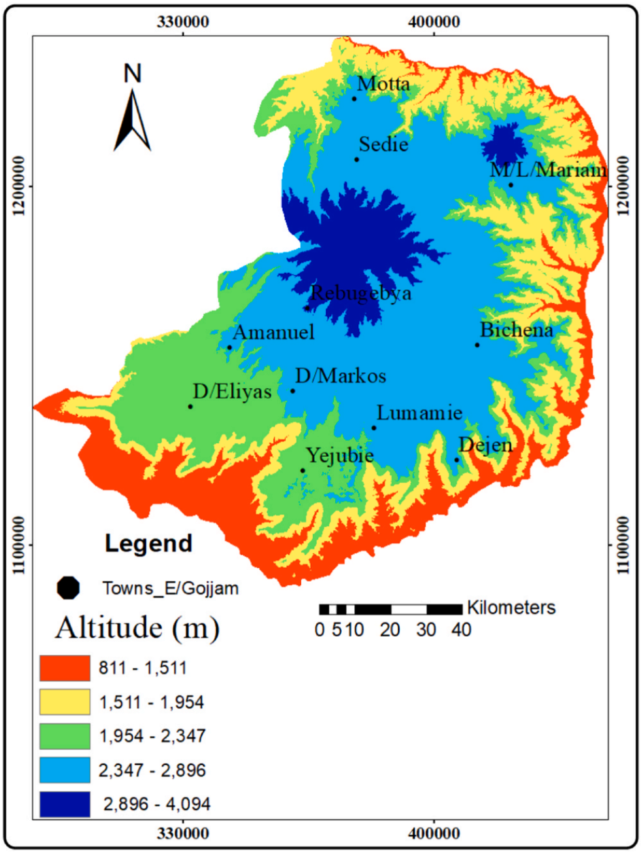

Fig.: 11. Altitude/ elevation map of the study area.

relative weights. Weights have been allocated, taking into consideration the relative influence of each variable on groundwater potential through particular judgment based on expert opinion and literature review. Maximum weight is assigned to geology and minimum weight to relief and drainage density.

4.2. Slope degree

Using GIS, the research area's slope degree was derived from the DEM. Escarpment or cliff (32°–68°), severe slope (22°–32°), moderately steep slope (13°–22°), mild slope (07°–13°), and extremely gentle slope (07°) are the different slope classes (Fig. 6). Slopes with steep 22–32 % and extremely steep 32–68 % gradients are primarily located in the area southern region. Lower weights are allocated to steep and extremely steep slope sections, indicating strong runoff and little infiltration, whereas higher weights are assigned to gentle and very gentle slope areas, indicating low runoff and longer residence time for water to percolate down.

4.3. Geology/lithology

During the field visit, it might be challenging to differentiate some rocks from others due to the severely worn and disintegrating rock masses that define the lithology of the research area. It was shown that rock strength and geologic boundaries are frequently weathered. Thus, one additional aspect can take into account that water can be easily percolated and stored in this condition (Fig. 7). Geologically, the study is composed of formations of basalt, Scoriaceous basalt, quaternary sediments, and several local unconformities. According to rock characteristics, high weight is assigned to sedimentary rock and quaternary sediments. These formations have excellent groundwater possibilities and range in depth from 1.5 to 4 m with a decent yield.

4.4. Lineament density

The area is filled with many lineaments, which provide secondary porosity that allows water to flow into aquifers. These are particularly common in basaltic rocks. Regarding density, the majority of the area has a relatively low lineament density. The lineaments and their intersections are advantageous for storing groundwater since groundwater intensity decreases with distance from lineaments. The lineaments and their intersections are advantageous for storing groundwater since groundwater intensity decreases

Table 4
Boreholes.

ID	Well Name	Easting	Northing	static water level(m)	Specific yield L/S
1	Bichena Well−1	410534	1153242	71	15
2	Bichena well−2	409969	1154229	70	15
3	Bichena well−3	408992	1156642	71	20
4	Robgebeya-Enerata	362966	1151880	3	7
5	Robgebeya-Wonka	352304	1144921	43	15–20
6	Shelel-Machakel	348978	1170426	3	3
7	Shebel Berenta-Suha	411920	1150783	68	20
8	Bichena−4-Enemay-Suha	408704	1157092	76	25
9	Ayirara/Arara Well	411827	1181269	0	0
10	Abay Cement Yetemen-Enemay	404165	1141624	64	10
11	Abay Cement Yetemen-Well2	404245	1142888	110	5
12	Abay Cement Factory-Well3	404158	1142081	104.85	3
13	D/Markos-Well3-Lekelekite	348588	1142531	7	30
14	D/Markos-Well4	349651	1142565	6.4	2–3.
15	D/Markos-Well1-Wenqa	352796	1145405	43	10
16	D/Markos-Well2-Wenqa	353930	1145298	0	0
17	D/Markos-Well1-Wenqa	352796	1145405	43	10
18	D/Markos-Adisena-Gulit1	348310	1142751	6	18
19	D/Markos-Adisena-Gulit2	348310	1142751	13	10
20	Debre Werk-Well1	398815	11766641	16	2
21	Dejen Town- Enebie	394498	1131362	76	15
22	DMU-Well6-Aneded Amber	370521	1334031	4	5
23	Wejel-Sefer−01Awabel	393947	1130892	6	15
24	Enebsie Kol Shallow Well	407760	1207640	3	1
25	Goncha Siso-Enegodie	408412	1199104	4.65	2
26	Shebel Berenta-Gedayasu	411650	1151752	68	20
27	Gindeweyin-Laymikael	395529	1205388	5	8
28	Robugebiya-Gozamen-Enerata	362966	1151880	3	7
29	Robugebiya-Wenqa	352304	1144921	43	15
30	Machakel-Shelel	348978	1170426	3	2–3.
31	Shebel Berenta-Suha	411920	1150783	68.8	20.6
32	Yoyin Wuha-Bibugn-Enatinesh	363843	1217825	44	1.5
33	Wejel-Sefer−01Awabel	393947	1130892	11.1	10.5
34	Yedebena-Awabel	392457	1131955	30	0.5
35	Yechite-Kork	371358	1113367	24	1.5
36	Yesenbet-Awabel	385392	1149553	3	16
37	chiferge No.3	365575	1135826		0.063
38	Durbetie Well	282448	1254947	4.41	11

with distance from them. For this reason, high-density zones receive more weight than low-density zones (Fig. 8).

4.5. Land use and cover

Patterns of land use and cover have a significant impact on the occurrence of groundwater. The resource for creating the land use and land cover map of the research area may be accessed at https://livingatlas.arcgis.com/landcover/ (Fig. 9). One important determinant of groundwater potential zones is land use and cover. Groundwater may be found in forests, waterways, and agricultural areas; it can also be found in built-up areas and arid areas. Although agricultural land is widely dispersed throughout the area, it is mostly concentrated in the southwest, west, central, northeast, and eastern regions. Mostly comprised of built-up terrain are the villages and town of Debre Markos. Water bodies receive the highest weight since they are the primary recharge zones; the lowest weighting is assigned to forests, croplands, bare ground, and built-up areas, all of which have extremely poor permeability and infiltration capability. One key indication of possible groundwater zones is land use/cover (LU/LC). Groundwater may be effectively stored in forests, lake bodies, and croplands; it can be less effectively stored in built-up areas and arid regions.

4.6. Drainage density

The total length of unit area streams per unit drainage area is known as the drainage density. Zones with little groundwater potential are identified by high drainage density values, which are advantageous for runoff, and vice versa. The groundwater in a given region is a major factor in determining how vulnerable rocks and soil are to collapse. The existence of streams and rivers, the state of the subsurface water, the saturation level of the rock and soil, and the drainage pattern of the region are all considered aspects of an area's hydrological features. A 100-meter buffer zone in a GIS window was used to create a stream distance map from the area's drainage pattern map (Fig. 10).

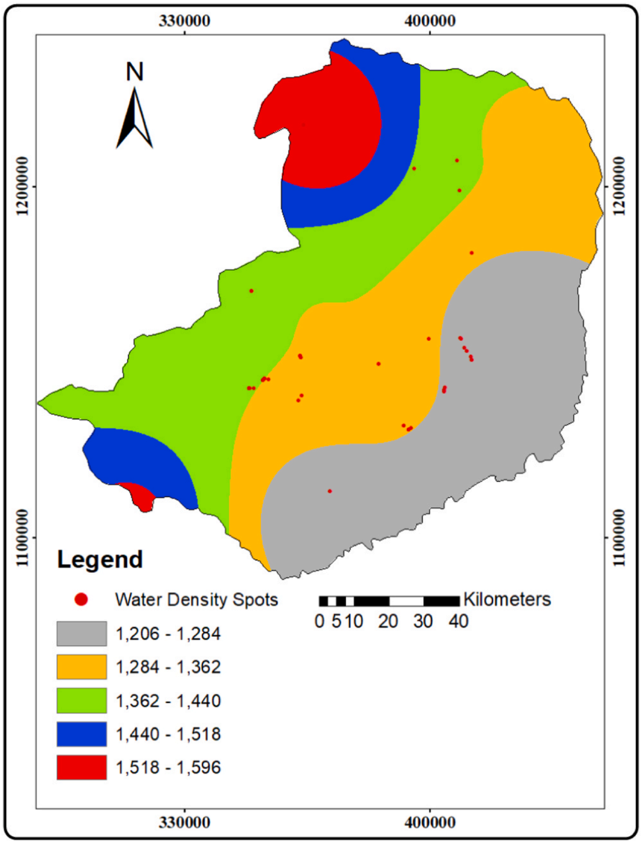

Fig.: 12. Map showing rainfall/precipitation of the study area.

4.7. *Altitude/elevation*

The altitude map of the study area was created using the DEM map, and it was divided into five classes based on the elevation above mean sea level: 818–1511, 1511–1954, 1954–2347, 2347–2896, and 2396–4094 m (Fig. 11). The research region is encompassed by an altitude/elevation range of 2347–2896 m above sea level at its highest, and by an elevation range of 2896–4094 m at its minimum. However, the influence of the other eight criteria taken into account will determine its actual position. As a result, extremely low relief receives maximal weight, which diminishes with elevation. But in reality, where it stands relies on how the other eight criteria that are taken into account affect it. As a result, the lowest relief (~0.018) receives the most weight, decreasing with increasing elevation (Table 4 & Fig. 11).

4.8. *Rainfall/precipitation*

Rainfall is essential to the ecosystem of plants. But in the East Gojjam zone, excessive summer and fall rainfall and recharging the groundwater table are to be raised. The precipitation data for the 10 years of rainfall in the East Gojjam zone region, from 2011 to 2020, were sourced from https://crudata.uea.ac.uk/cru/data/hrg/cru_ts_4.06/. Because the precipitation has a major impact on the groundwater recharge potentials for the groundwater in the area (Fig. 12). Maximum weight is allocated to areas with extremely high rainfall, and very low weight to areas with extremely low rainfall, due to the direct correlation between groundwater potential and rainfall. Based on a 10-year average, the study area's average annual rainfall was 1206 and 1596 mm. Given that groundwater potential is closely correlated with rainfall, zones with extremely high rainfall (Table 4 & Fig. 12).

4.9. *Borehole logging*

The Amhara Regional State Water Bureau provided information from 39 boreholes, including borehole depth, aquifer type, thickness, and geologic elements that comprise the aquifers, borehole yields, and static water levels during the rainy and dry seasons (Table 4). The frequency of bore and deep wells has increased the rate of exploitation for both agricultural and residential uses (Silwal et al., 2023, Zewdie and Tesfa, 2023). This dataset is used to validate the GWP zonation using the borehole yield data and to prepare the groundwater potential zone map of the area. Table. 5, Table, 6

Table: 5
Pair-wise comparison matrixes of selected factors for groundwater potential.

Lineament Density Sub-Class	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	Value
[1] 0.00 – 0.02	1.00	2.00	4.00	5.00	6.00					0.45
[2] 0.02 – 0.06	0.50	1.00	2.00	3.00	5.00					0.26
[3] 0.06 – 0.10	0.25	0.50	1.00	2.00	3.00					0.14
[4] 0.10 – 0.14	0.20	0.33	0.50	1.00	2.00					0.09
[5] 0.14 – 0.20	0.17	0.20	0.33	0.50	1.00					0.05
Geology	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	Value
[1] Sedimentary Rocks	1.00	2.50	4.00	4.00	6.00	7.00				0.42
[2] Scoriaceous basalt	0.40	1.00	2.00	3.00	5.00	5.00				0.24
[3] Quaternary Sediments	0.25	0.50	1.00	2.00	3.00	3.00				0.14
[4] Robu Gebya Basalt	0.25	0.33	0.50	1.00	2.00	2.00				0.09
[5] Arero Gido Basalt	0.17	0.20	0.33	0.50	1.00	2.00				0.06
[6] Arat Mekerakir Basalt	0.14	0.20	0.33	0.50	0.50	1.00				0.05
Slope Degree	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	Value
[1] 32 – 68	1.00	2.00	2.50	3.00	4.00					0.38
[2] 22 – 32	0.50	1.00	2.00	3.00	3.00					0.26
[3] 13 – 22	0.40	0.50	1.00	2.00	3.00					0.18
[4] 7 – 13	0.33	0.33	0.50	1.00	2.00					0.11
[5] 0 – 7	0.25	0.33	0.33	0.50	1.00					0.07
Drainage Density	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	Value
[1] 0.23 – 0.38	1.00	2.00	3.00	5.00	6.00					0.44
[2] 0.16 – 0.23	0.50	1.00	2.00	3.00	5.00					0.26
[3] 0.10 – 0.16	0.33	0.50	1.00	2.00	3.00					0.15
[4] 0.05 – 0.10	0.20	0.33	0.50	1.00	2.00					0.09
[5] 0.00 – 0.05	0.17	0.20	0.33	0.50	1.00					0.06
Elevation (m)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	Value
[1] 818 – 1511	1.00	1.00	2.00	3.00	4.00					0.32
[2] 1511 – 1954	1.00	1.00	2.00	3.00	4.00					0.32
[3] 1954 – 2347	0.50	0.50	1.00	2.00	3.00					0.18
[4] 2347 – 2896	0.33	0.33	0.50	1.00	2.00					0.11
[5] 2896 – 4094	0.25	0.25	0.33	0.50	1.00					0.07
Land use & Cover	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	Value
[1] Water	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	0.31
[2] Agriculture	0.50	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	0.22
[3] Agro - pastoral	0.33	0.50	1.00	2.00	3.00	4.00	5.00	6.00	7.00	0.15
[4] Agro - sylvicultural	0.25	0.33	0.50	1.00	2.00	3.00	4.00	5.00	6.00	0.11
[5] Traditional	0.20	0.25	0.33	0.50	1.00	2.50	3.00	4.00	5.00	0.08
[6] Pastoral	0.17	0.20	0.25	0.33	0.40	1.00	2.50	3.00	4.00	0.05
[7] Sylvo - pastoral	0.14	0.17	0.20	0.25	0.33	0.40	1.00	2.00	3.00	0.04
[8] Urban	0.13	0.14	0.17	0.20	0.25	0.33	0.50	1.00	2.00	0.03
[9] Unused	0.11	0.13	0.14	0.17	0.20	0.25	0.33	0.50	1.00	0.02
Rainfall (mm)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	Value
[1] 1206 – 1284	1.00	2.00	4.00	5.00	6.00					0.45
[2] 1284 – 1362	0.50	1.00	2.00	3.00	5.00					0.26
[3] 1362 – 1440	0.25	0.50	1.00	2.00	4.00					0.15
[4] 1440 – 1518	0.20	0.33	0.50	1.00	2.00					0.09
[5] 1518 – 1596	0.17	0.20	0.25	0.50	1.00					0.05

Table: 6
Par ways comparison factor weight, λ max, CI, and CR.

Factors	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**	**[7]**	**[8]**	**Weight**
[1] Rainfall	1.00	3.00	4.00	5.00	6.00	7.00	8.00		0.40
[2] Lithology	0.33	1.00	2.00	3.00	5.00	6.00	7.00		0.23
[3] Lineament Density	0.25	0.50	1.00	2.00	3.00	3.00	4.00		0.13
[4] Altitude	0.20	0.33	0.50	1.00	2.00	3.00	4.00		0.09
[5] Slope	0.17	0.20	0.33	0.50	1.00	3.00	4.00		0.07
[6] Drainage Density	0.14	0.17	0.33	0.33	0.33	1.00	4.00		0.05
[7] LU/LC	0.13	0.14	0.25	0.25	0.25	0.25	1.00		0.03
	2.2	**5.3**	**8.4**	**12.1**	**17.6**	**23.3**	**32.0**		**1.00**
λ max = 7.39 CI = 0.065 CR = 0.049									

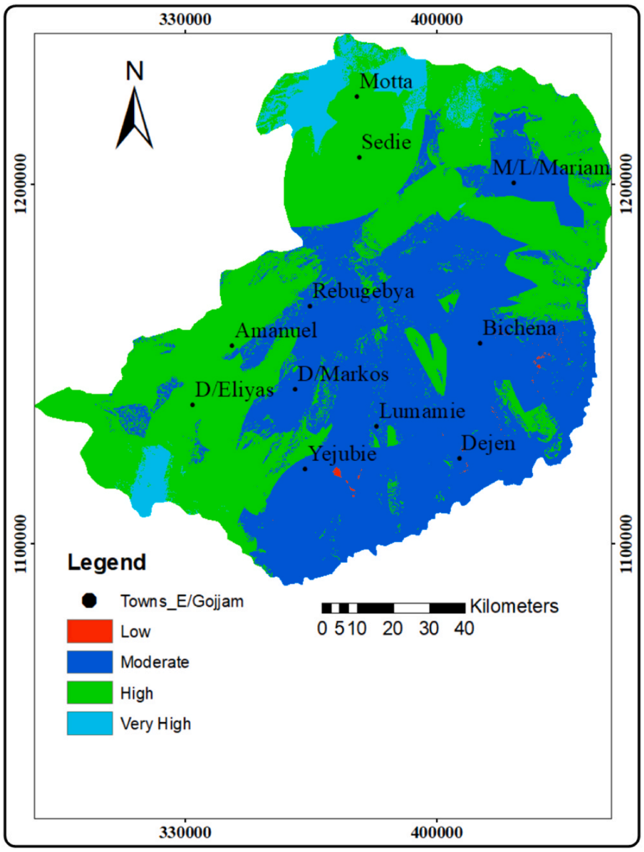

Fig: 13. Groundwater potential zonation map of the area.

AHP analysis of selected factors

4.10. Groundwater potential zonation mapping

The groundwater potential map of the study area was developed using a multicriterial decision-making approach with the AHP and GIS windows.. Fig. 13

5. Discussion

In this study, seven parameters (geology, lineament density, slope, Altitude, drainage density, rainfall, and LULC) that mostly influence the groundwater occurrence in the study area have been carefully considered to assess the groundwater potential zone in the East Gojjam zone administration. After successfully assigning the weight to each factor using AHP for each feature of the thematic layer was computed using Eqs. (1 to 3). Groundwater potential zonation mapping using selected factors was used, and the resulting map is classified into four zones low, moderate, high, and very high classes. According to the Groundwater potential zonation maps and field observations, the highest Groundwater potential zonation was observed in the northern and southwest of the study area. The research area's rainfall chart shows that, on average, 1401 mm of rain falls there annually. This suggests that the region has a great capacity for transitivity and storability because of the delicate character of the geological units. Based on field observation of the study area, it was found that the Groundwater potential zonations are affected by the nature of geological materials.

6. Conclusions

The study utilized GIS-based multi-criteria decision-making techniques, which were the most effective for identifying GPZ in the study area. This method was very important in minimizing time and costs while facilitating decision-making on groundwater management.

It is essential to identify and evaluate groundwater resources to raise local knowledge and minimize any losses brought on by water scarcity. Finding regions with significant groundwater potential has become a top priority on a regional and worldwide scale.

To create a Groundwater potential zonation map in the East Gojjam Zone administrative region, integrating GIS and AHP was conducted using the MCDM technique/ methodologies. The results indicate that 5.3 % of the region was classified as very high potential, 45.8 % as high, 48.8 % as moderate, and 0.1 % as low potential zones. Agriculturalists, irrigation planners, industrialists, environmentalists, and academic research organizations can all benefit from the current study's findings. Because of this, the research has certain inherent limitations that may be mitigated by employing advanced data mining techniques, high-resolution data collection, and accounting for temporal oscillations in the dataset as well as The researcher recommends that all the data like well logs, geological logs, and all reports are must be0 kept and outsourced for further researchers to be used as secondary and primary data.

Based on the conclusions and findings, the medium to high potential area would require careful planning and monitoring of groundwater as well as restrictions of an activity that increases the vulnerability of groundwater to pollution such as dumping domestic and municipal waste in the highly vulnerable zones. Therefore, these findings significantly advance the sustainable planning and development of local water resources by helping to develop new projects and expand existing ones that use groundwater in the research region.

CRediT authorship contribution statement

Chalachew Tesfa: Writing – original draft, Visualization, Supervision, Software, Project administration, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Demeke Sewnet:** Writing – review & editing, Validation, Resources, Methodology.

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Declaration of Competing Interest

I am delighted to submit the manuscript, *Groundwater Potential Zonation Mapping Using GIS-Based MCDM Approach in East Gojjam Zone, Central Ethiopia*, of the original research paper for publication. I believe these findings will be of interest to the readers of your journal. I declare that this manuscript is original, has not been published before, and is not currently being considered for publication elsewhere. I declare that no conflicts of interest are associated with this publication, and there has been no significant financial support for this work that could have influenced its outcome.

Data availability

Data will be made available on request.

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