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Investigation of groundwater potential zone using Geospatial Technology in Bahir Dar Zuria District, Amhara, Ethiopia

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ABSTRACT

Geospatial technology has been done to identify spatially the extents of highly suitable and moderately suitable areas for groundwater demarcation. Several input parameters (land use, soil type, slope, geology, geomorphology, and lineament) used to maps Groundwater potential assessment. Each thematic map has been reclassified into five classes. Suitable weightages have been given to each class with respect to its groundwater potential influences. Area of all raster formats of all parameters were calculated by GIS environment. All the weighted input parameters have been overlaid using "Weighted Overlay Analysis" tool in ArcGIS 10.3 platform. The results showed that 8.26 Km^2, 441.74 Km^2, 812.86 Km^2, 198.01 Km^2 and 80.57 Km^2 of the study area fall in "Highly suitable, High, suitable, Medium suitable, Low suitable and Very Low suitable" category of groundwater potential respectively.

***Keywords*:** geology, geospatial technology, GIS, Groundwater potential, Ethiopia

1. INTRODUCTION

Geospatial tools have opened new windows in water resource studies. Remote sensing provides multi-temporal, multi-spectral and multi-sensor data about the earth's surface [1, 2].

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Geospatial technology helps in assessment and monitoring of groundwater resources, spatially as well as temporally. Many studies have used geospatial tools to study the groundwater potential of their region of interest [3-12]. Remote sensing data and GIS techniques can provide efficient means to demarcate the groundwater potential zones in countries where rainfall is scarce or unevenly distributed, such as in Northern Ethiopia. The aquifers in Ethiopia are the most complex; they are relatively low storage aquifers and are compartmentalized [2], which could be attributed to the multifaceted geological history. Therefore, groundwater exploration in Ethiopia using conventional methods is time consuming and expensive. There are studies that focused on accessing the groundwater/surface water potential of the Blue Nile [13, 14].In the present study, an integrated approach of Multi Criterial Decision approach and GIS has been used for demarcating the favourable zones for groundwater through geospatial investigation of geology, land use, soil, lineament, slope and geomorphology.

2. STUDY AREA

Study area (Fig. 1) having of 1541 km² is located in and surrounding Bahir Dar district, Amhara region, Ethiopia. This area is situated in Ethiopian highland bound on the north-western escarpment which is founded in the Blue Nile River and Lake Tana basin. Geographically, it is located between 37°10''E-37°40' E and 11°20' N-11°50' N. The basin landscape is part of the western plateau of Ethiopia and includes the escarpments of Gonder, Gojam and the lower plains that form extensive wetlands.

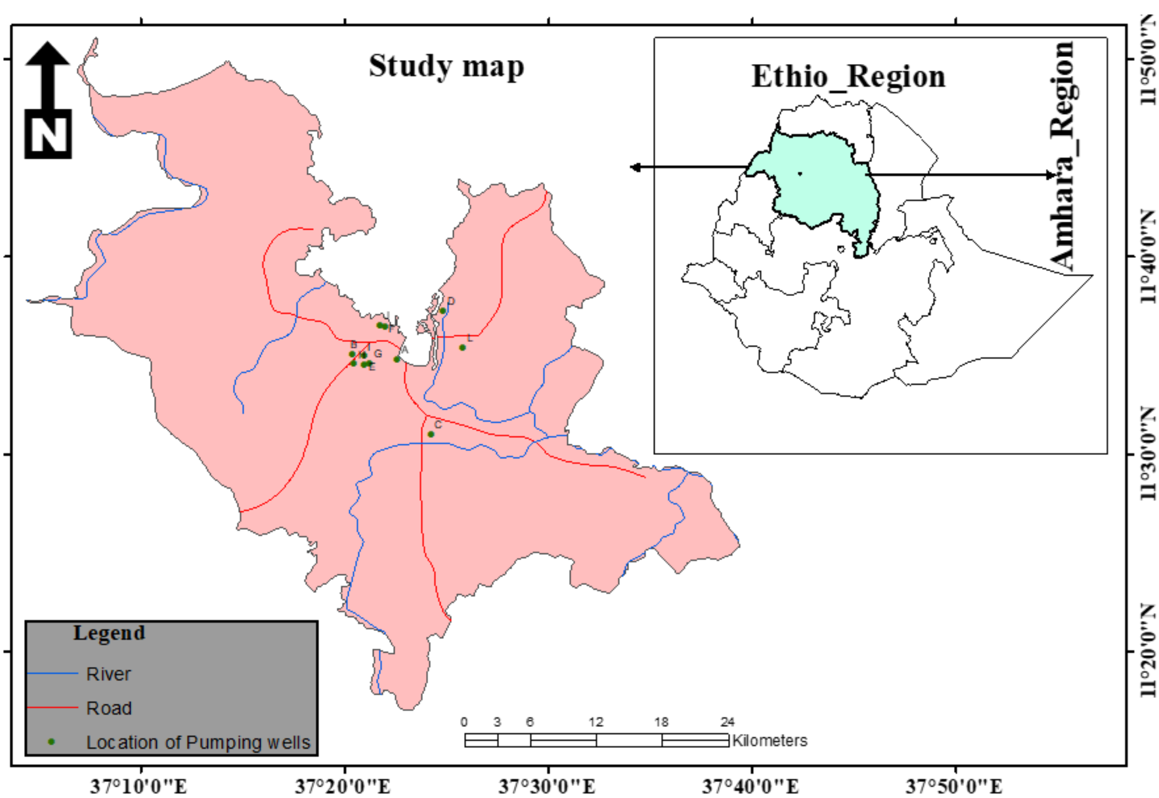

Fig. 1. Location of study area

According to the Ethiopian Meteorology Agency the mean annual precipitation of this area is about 1419mm /55.9 inch per year / and the climate in this area is sub tropical with mean annual temperature is 19.6ºc / 67.2°F /.

3. DATA USED AND METHODOLOGY

In this study six thematic layers (Lithology, Lineaments, Soil, and Geomorphology, Land use land cover, Slope were used. The Lithologies, Soil, Land use and Geomorphology were collected from Ethiopian Geological Survey (EIGS). The lineament density map has been prepared by using kernel density analysis tool in Arc GIS 10.3 respectively. The slope was derived from STR DEM of 30m resolution. These thematic layers were prepared by using Arc GIS 10.3 in Arc GIS environment.

To assess the groundwater potential zones of the given study area, different input parameters were used such as geomorphology, lineament, geology, soil, slope and land use. Those parameters were prepared used geospatial technology. The flowchart of the methodology indicates in Fig. 2 below. All parameters categorized into low, very low, medium, high and very high to develop the groundwater potential maps in the study area.

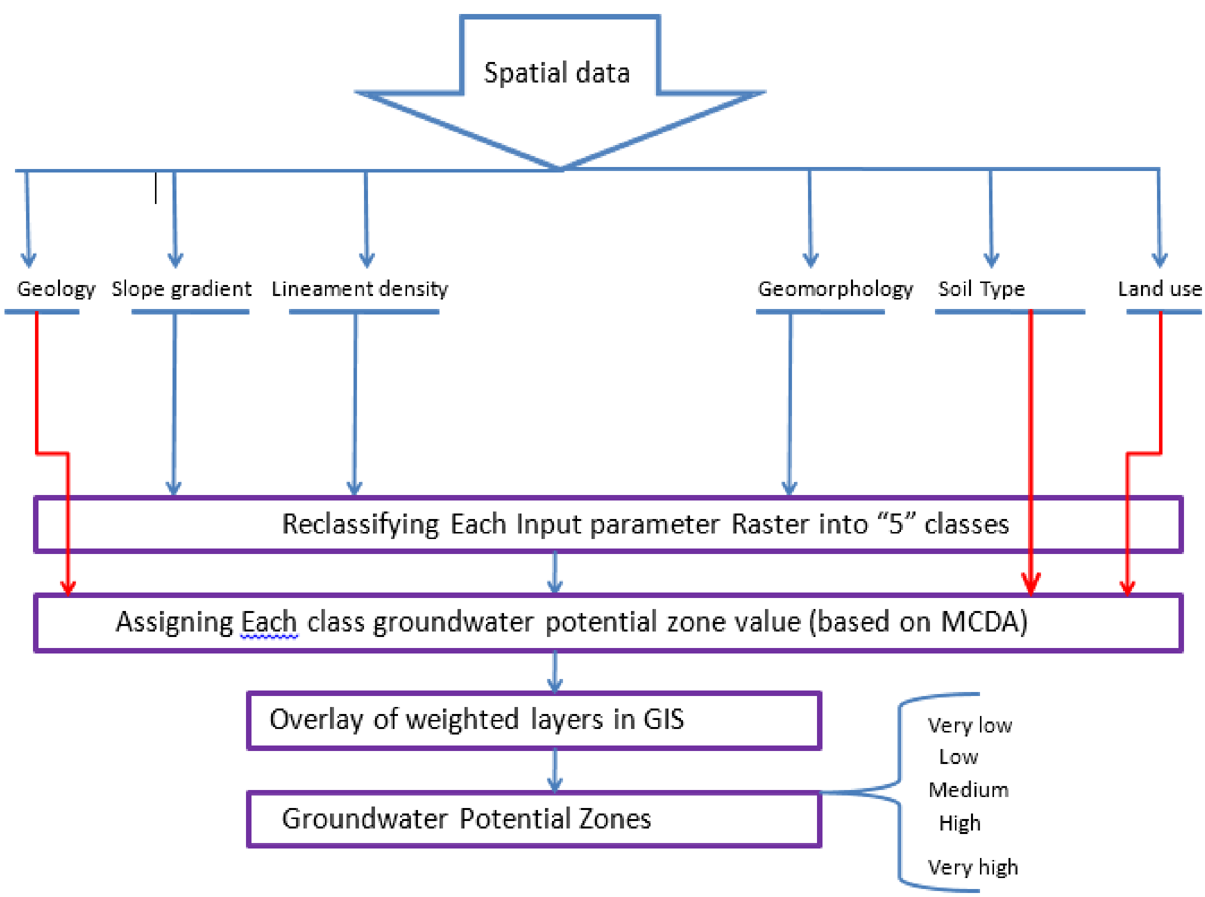

Fig. 2. Framework of the methodology

The weight of individual layers in the overlay analysis to determine the groundwater potential map is computed using analytic hierarchy process (AHP). The method enables pairwise comparison of influencing factors. The methodology used in this paper is summarized as shown in Figure 2.

Slope

The precipitous terrain causes rapid runoff and does not store water easily. The slope of any terrain is one of the factors allowing the infiltration of groundwater into a subsurface (i.e., groundwater recharge). In the gentle slope area, the surface runoff is slow allowing more time for rainwater to percolate, whereas a steep slope area facilitates high runoff allowing less residence time for rainwater to percolate, hence comparatively less infiltration as shown in Fig. 3.

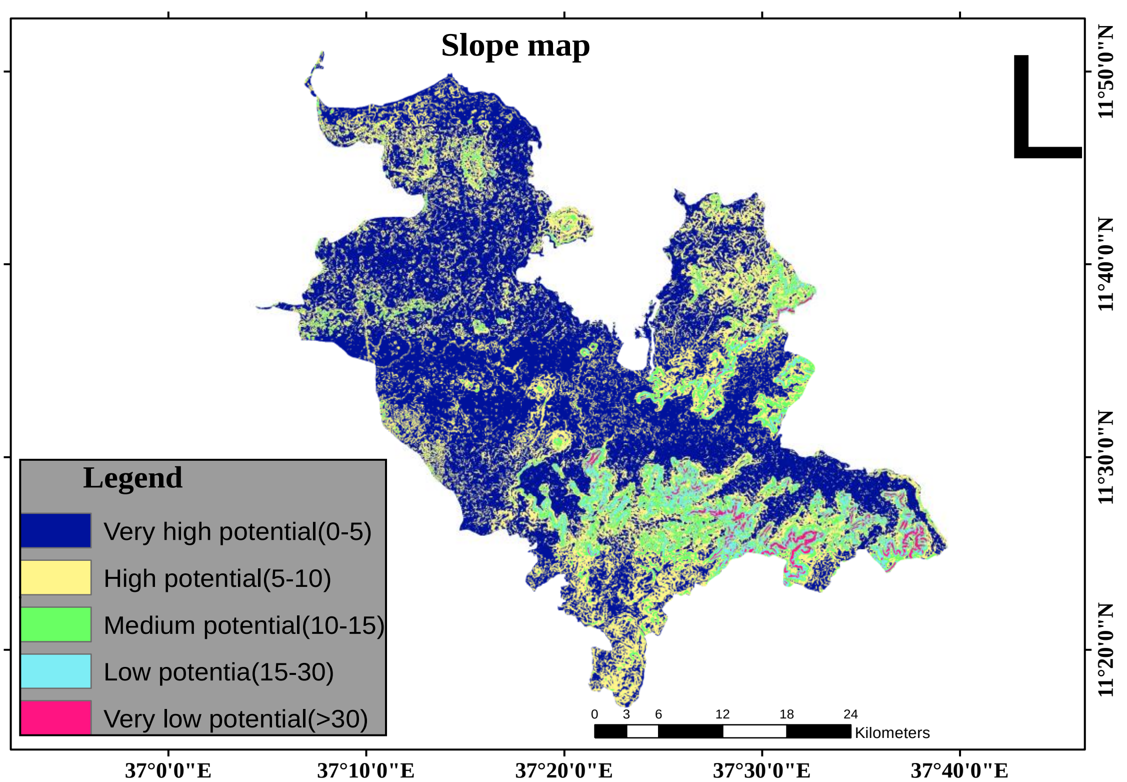

Fig. 3. Slope of the study area

Land Use and/or Land Cover

A land use land cover map of the study area constitutes the natural forest, wetland, woodland, shurbland, grassland, water body and cultivated land as shown in Fig 4. The major part of the area is covered by cultivated land, and with such land use practices, the water requirements are very high, and the permeability of such type of land is less. The weightage was assigned based on the permeability of the particular class (Figure 4).

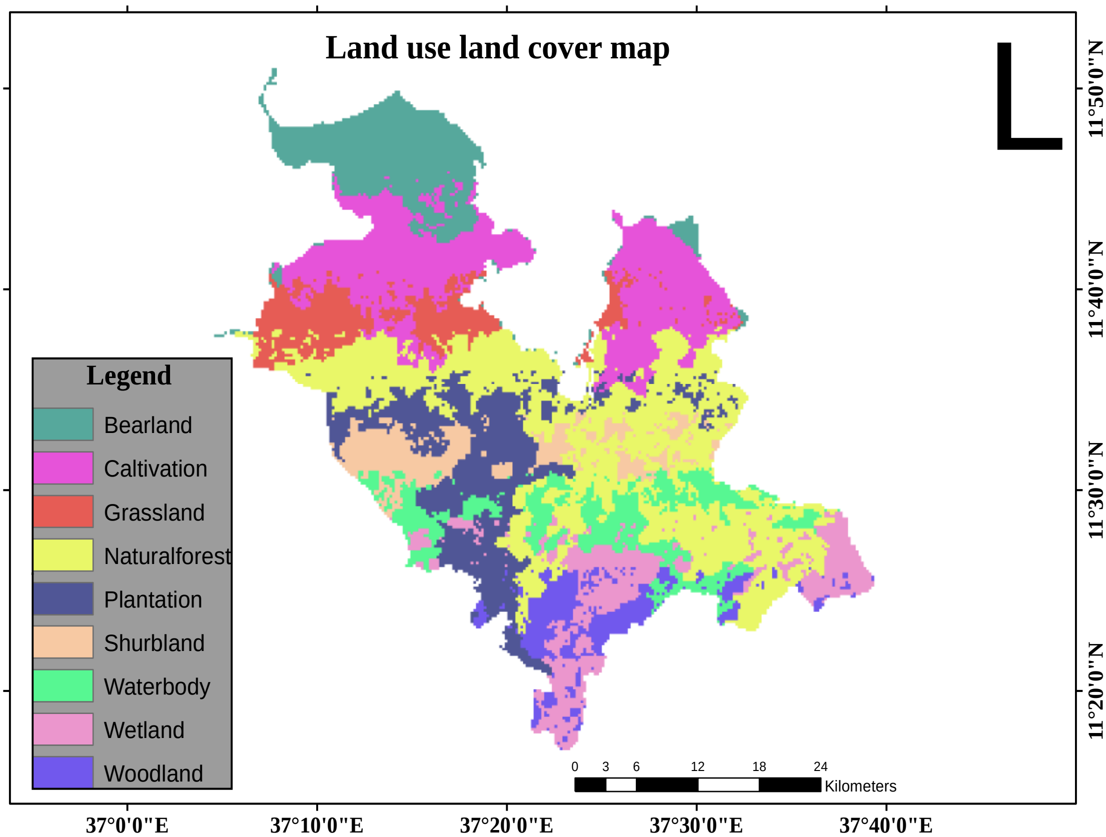

Fig. 4. Land use land cover of the study area

Geology (Lithology)

Tarmaber basalt

On the Ethiopian highlands, the fissure eruptions of the Ashenge, Aiba, and Alaji basalts were followed by central type volcanism which created the large shield volcanoes of the Tarmaber group. They are made of lenticular, often zeolitized, alkali basalts with a large amount of tuffs, Scoriacious lava flows, per alkaline rhyolites, and typical red paleosoils. Dike swarms and acidic extrusions are present. The thickness of the Termaber Basalts reaches 1,000 m close to the volcanic centers. The ages of the Termaber shield volcanoes are Early and Middle Miocene, ranging from 23 to 11 Ma [15], with the exception of the Semien with the base of 30 Ma and the top of 19Ma as shown in Fig. 5.

Ashenge basalt

The oldest fissure basalts on the Ethiopian plateau were described by [16] as the Ashange group in crustal fracture and voluminous volcanoes of tectonic processes (Tertiary volcanic rock of Ethiopia), which is dominantly basaltic in composition. This group consists predominately of alkaline basalts with interblended pyroclastic and rare rhyolites erupted from fissures. Dolerite sills, acidic, gabro-diabase dykes, and other intrusions include them. The flows range in total thickness from 200 to 1,200m. The upper part of the Ashange group is more tuff acetous containing lacustrine deposits including lignite seems and acid volcanic and locally over lays the older part of the group with angular unconformity as shown in Fig. 5.

Alluvial deposit: Alluvial depositis formed tectonically in post-refit sequence from quaternary major stratigraphy of Ethiopia. It consists of silt, sand, clay, and gravel, as well as much organic matter. Alluvial depositis usually most extensive in the lower part of a river's course, forming floodplains and deltas, but they may form at any point where the river overflows its banks or where the flow of a river is checked [17].

Lacustrine deposits: Lacustrine deposite is formed tectonically in Pleistocene from quaternary stratigraphy of Ethiopia which formed in the bottom of ancient lakes which have a common characteristic of lacustrine deposits that a river or stream channel has carried sediment into the basin. Lacustrine deposits form in all lake types including rift graven lakes. Lacustrine deposits are typically very well sorted with highly laminated beds of silts, clays. In regards to geologic time, lakes are temporary and once they no longer receive water, they dry up and leave a formation [18].

They have high yield and easily trap shallow depth. Many of those unconsolidated aquifers are in contact with rivers or other surface waters, which adds significantly to their potential yield when pumped as shown in Fig. 5.

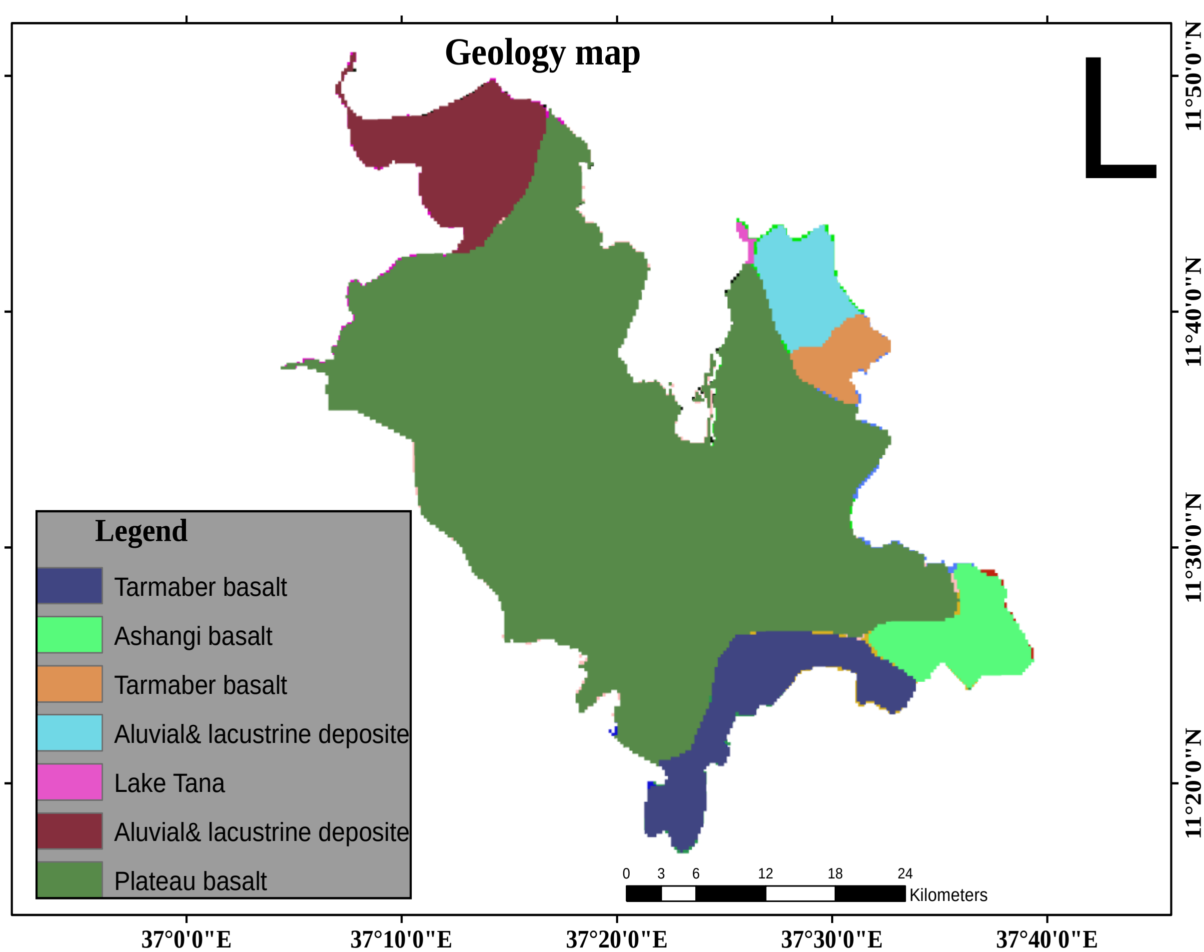

Fig. 5. Geology of the study area

Plateau basalt is an extensive, thick, smooth flow or succession of flows of high-temperature, fluid basalt erupted from fissures, flooding topographic lows, and accumulated to form a plateau. Different types of plateaus can be categorized based on the type of geological processes that caused their formation. Plateaus often have steep slopes on one or more sides or may be partially surrounded by mountains as shown in Fig. 5.

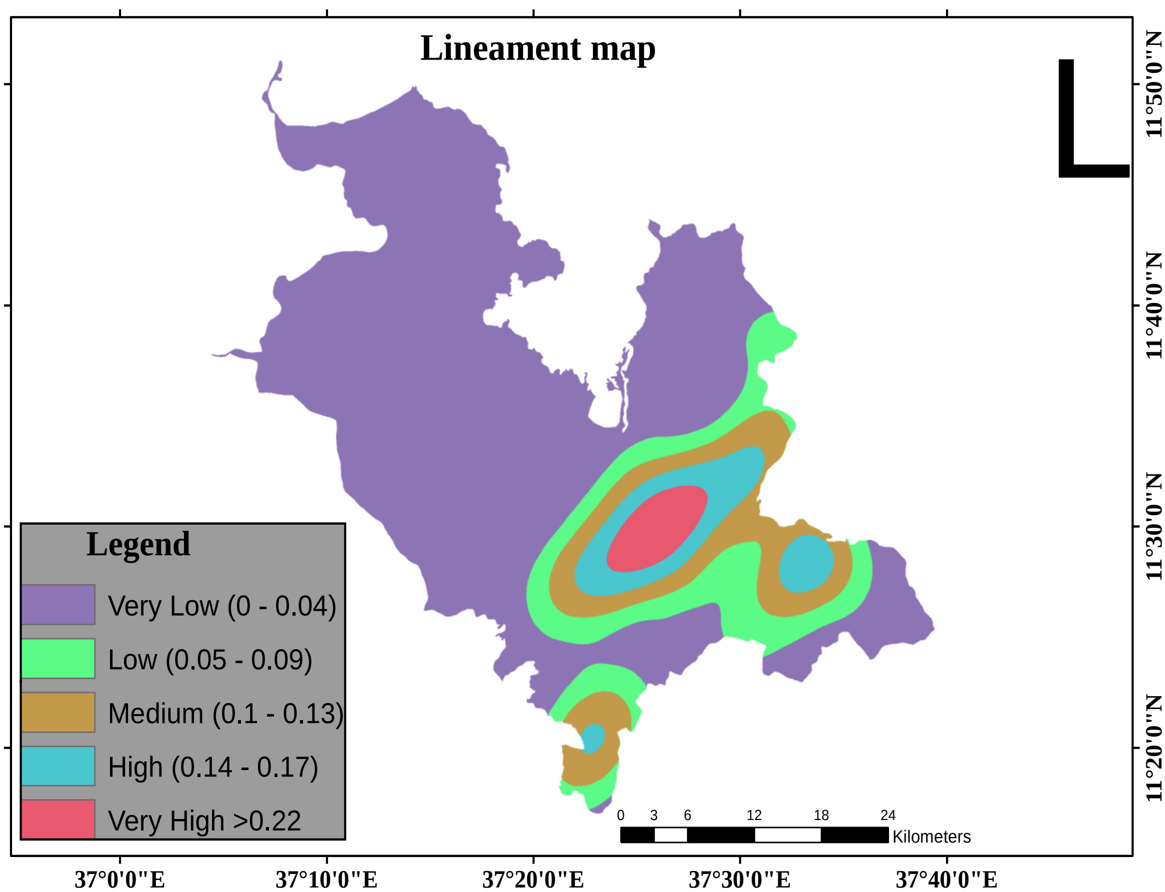

Fig. 6. Lineament of the study area

Lineament Density

Lineaments like joint, fracture and fault were developed by tectonic activity, lineaments are hydro geologically very important and may provide the pathways for groundwater movement [19]. Presence of lineaments may act as a conduit for ground water movement with results in increased secondary porosity and therefore, can serve as groundwater prospective zone [20]. Lineaments give a clue to movement and storage of ground water and therefore, are important guides for ground water exploration. Groundwater movements [21]. Lineament density map was prepared by using kernel density method (Fig. 6).

Geomorphology

Geomorphology of the area is one of the most vital features in the delineation and evaluation of groundwater resources [22, 23]. The geomorphology map of the study area (Fig. 7) consisting of nine geomorphological class.

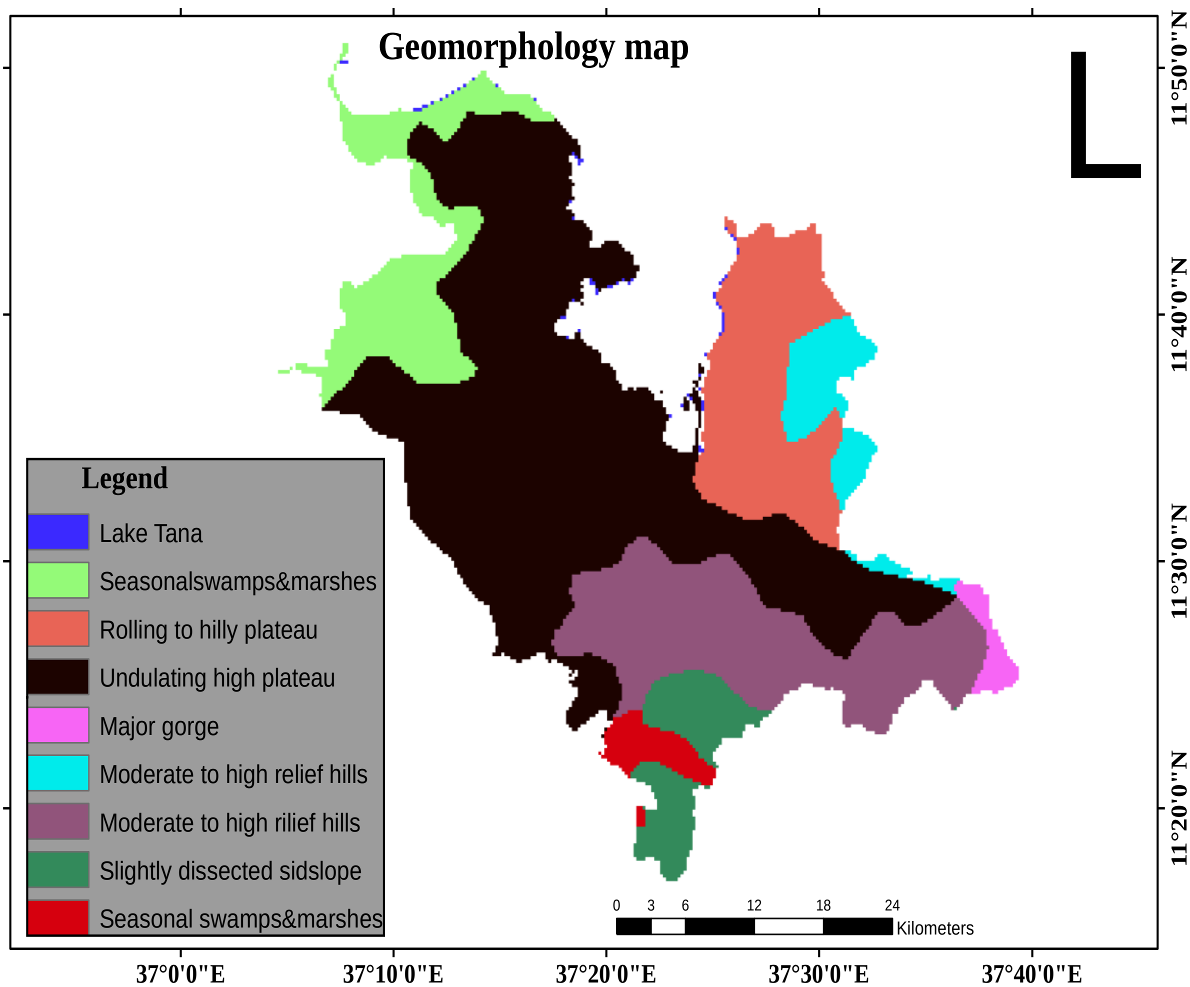

Fig. 7. Geomorphology map of study area

Soil Type

The soil forming factors, climate, parent rock, vegetation, fauna and physiography are responsible for the type of soil formed and plays an important role on groundwater recharge through infiltration and loss through run-off. The type of soil and permeability affects thewater holding and infiltrating capacity of a given soil.Soil type is the base for all information that is required for the groundwater analysis of any catchment. In the study area, seven types of soils are available as shown in Fig. 8. The weightage given was based on the permeability of soil type. The highest and lowest weights were assigned based on the infiltration capacity of soil type in the given study.

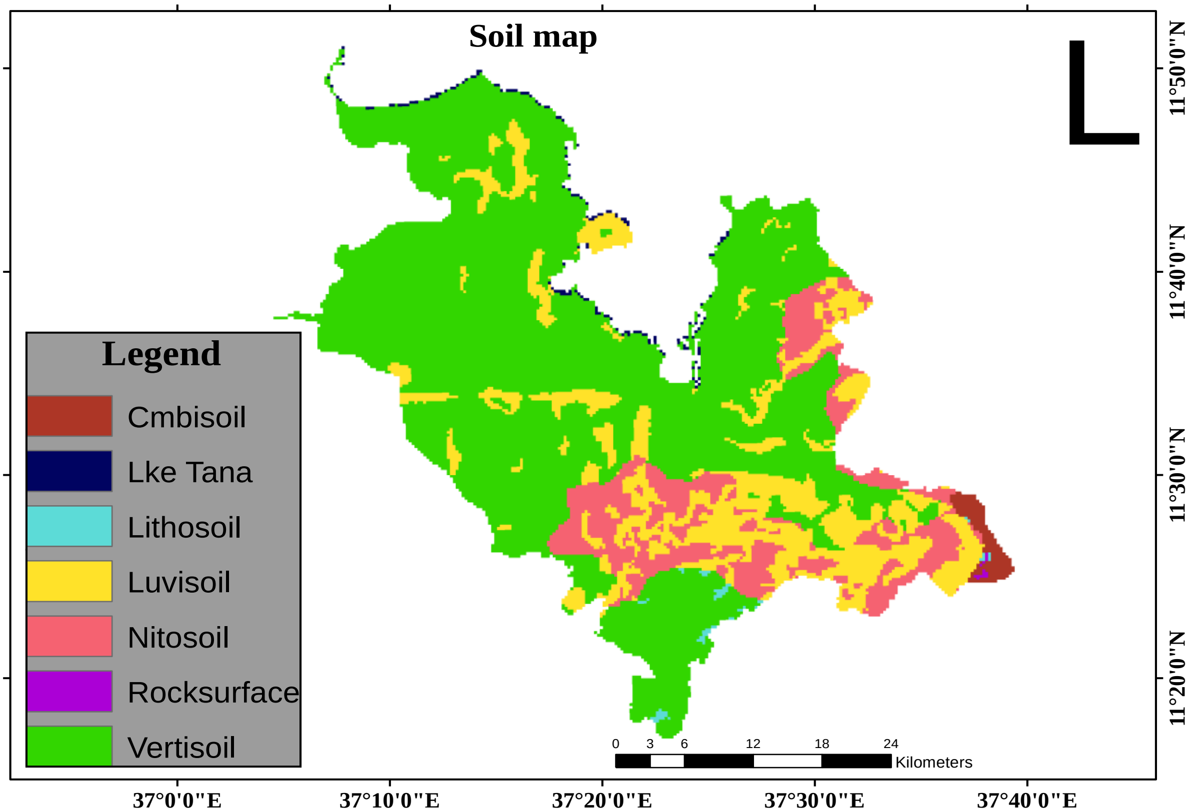

Fig. 8. Soil Type of the study area.

4. RESULT AND DISCUSSION

Land use land cover

Land use map of the study area (Fig. 4) consists of several classes, viz., cultivation (904.5 km^2), Shurbland (403.32 km^2), natural forest (40.16 km^2) as shown in Fig 4 and Table1. Land use is one of the important criteria for identifying groundwater potential zones. Suitable weights were given to each class and their areal extents were calculated using "Zonal Statistics" in GIS (Table 1).

Table 1. Area covered under different range of parameter of Land use land cover.

Land use class	Categories	Area km^2	Area%
cultivation	Very low productivity	904.5	58.70
Shrub land	Medium productivity	403.32	26.17
natural forest	High productivity	40.16	2.61

wetland	Very high productivity	59.02	3.83
Bare land	Very low productivity	13.4	0.87
waterbody	Very high productivity	23.9	1.55
grassland	Low productivity	60.3	3.91
woodland	Medium productivity	23.6	1.53
plantation	High productivity	12.8	0.83

Geomorphology

Surface water is one of the important aspects of developing and determining the landscapes of any area; hence hydro geomorphic approach is necessary for planning purpose about groundwater exploration [3]. The geomorphology of the study is very much correlated with the lithology and geological formation. RS and GIS studies provide an opportunity for scientific analysis and observation of numerous geomorphic units with multispectral coverage of landscape [24].

The geomorphology categories of the study area analysed as shown in Fig 7 and Table 2. The maximum area coverages favours to undulating high plateau (746.2 Km^2) and the lowest area coverages lake (4.7 Km^2).

Table 2. Area covered under different range of parameter of Geomorphology.

Geomorphology class	Categories	Area km^2	Area%
lake	Very high productivity	4.7	0.3
Seasonal swamps and marshes	Very high productivity	148.8	9.7
rolling to hilly plateau	Low productivity	196	12.7
undulating high plateau	Moderate productivity	746.2	48.4
major river gorge	Very low productivity	17.2	1.1
moderate to high relief hills	Low productivity	64.5	4.2
moderate to high reief hills	Very low productivity	260.1	16.9
sligtly dissected sides slope	Moderate productivity	74.8	4.9
seasonal swamps and marshes	Very high productivity	28.8	1.9

Geology

Geology is also one of the input parameter factors in delineating the groundwater potential zones. Six different lithologies have been observed in the study area (Fig. 5). Their areal extent has been determined using "Zonal Statistics" in geographic information system domain (Table 3). Geology of Bahir dar zuria is dominated by Plateau basalt with an aerial extent of 1176.19 Km^2 (76.32%), followed by Aluvial and lacustrine deposite (164.52 Km^2, 10.67%), and other units together cover in the study area as indicated in Fig 5 and Table 3.

Table 3. Area covered under different range of parameter of Geology.

Geology class	Categories	Area km^2	Area%
Tarmaber basalt	High productivity	105.82	6.87
Ashangi basalt	Low productivity	65.16	4.23
Tarmaber basalt	High productivity	27.13	1.76
Aluvial and lacustrine deposite	Very High productivity	164.52	10.67
Lake Tana	Very High productivity	2.18	0.14
Plateau basalt	Medium productivity	1176.19	76.33

Slope

The slope of the study area has been estimated from Digital Elevation Model (DEM) data as shown in Fig. 3 and Table 4. Flat or gentle slope is suitable for increasing the infiltration amount from rainfall. Otherwise, in steep slope area where the infiltration capacity is very minimum whereas runoff is maximum. From the analysis, slope ranges from 0-5 percent rise covers high area coverage which is 57.67% (889.08 Km^2) and 1.10% (16.97 Km^2 covers in the slope of >30.

Table 4. Area covered under different range of parameter of Slope

Slope categories	Categories	Area (Km^2)	Area (%)
0 - 5	very high	889.08	57.67
5 - 10	high	470.90	30.55
10 - 15	medium	109.06	7.08
15 - 30	low	55.53	3.60
>30	very low	16.97	1.10

Lineament

Lineaments are the natural linear feature like: faults, joints and fractures which can visualize and interpreted directly from remotely sensed data [3]. The following equation has been taken into consideration for calculation the Lineament Density [3]. As shown in the table 5, lineament density class ranked as very low, low, medium, high and very high with the areal extent of 10851.77 Km^2, 1797.85 Km^2, 1499.39 Km^2, 878.38 Km^2 and 387.98 Km^2 respectively.

$$LD = \frac{SI}{A},$$

where, 'LD' is the lineament density, 'SI' is the Length of the lineament and 'A' is the area.

The total area falling in different range of lineament density is given in Fig 6 and Table. 5 which show that most part of the study area have very low lineament density. So very low lineament density indicates very low infiltration rate, where as the high lineament density areas indicate high infiltration (Table. 5) thus a potential zone for groundwater development.

Table 5. Area covered under different range of parameter of Lineament.

Lineament density class	Categories	Area (Km^{-1})	Area (%)
0 – 0.04	Very Low	10851.77	70.40
0.05 – 0.09	Low	1797.85	11.66
0.1 – 0.13	Medium	1499.39	9.73
0.14 – 0.17	High	878.38	5.70
0.18 – 0.22	Very High	387.98	2.52

Soil Type

Soil type is also one of the most determinant factors in estimating the groundwater. Ten different soil types have been observed in the study area (Fig. 6). Their areal extent has been determined using "Zonal Statistics" in geographic information system domain (Table 6).Soil type of Bahir dar zuria is dominated by vertisoil with an aerial extent of 1045.19 Km^2 (67.78%), followed by luvisoil (284.31 Km^2, 18.08%), and other units together cover in the study area as indicated in Fig. 3 and Table 6. Based on the hydraulic properties of the soil, the soil classes were accordingly ranked using AHP proposed by [25].

Table 6. Area covered under different range of parameter of soil type.

Soil class	Categories	Area km^2	Area%
cambisoil	High productivity	15.88	1.03

lake	High productivity	10.19	0.66
lithosoil	Low productivity	4.88	0.32
luvisoil	High productivity	284.31	18.44
nitosoil	Moderate productivity	180.63	11.71
rocksurface	Low productivity	0.88	0.057
vertisoil	Low productivity	1045.19	67.78

Groundwater Potential Assessment Zones

Each input parameters were converted into raster file and assigned appropriate groundwater potential values based AHP (Saaty 1980) in a GIS environment. The final output shows the spatial distribution of groundwater potential zones of the Bahir Dar Zuria shown in (Fig. 9). The final vales of the map reclassified into five classes, viz., "Very High", "High", "Medium", "Low" and "Very Low" as shown in Fig. 9 and Table 7.

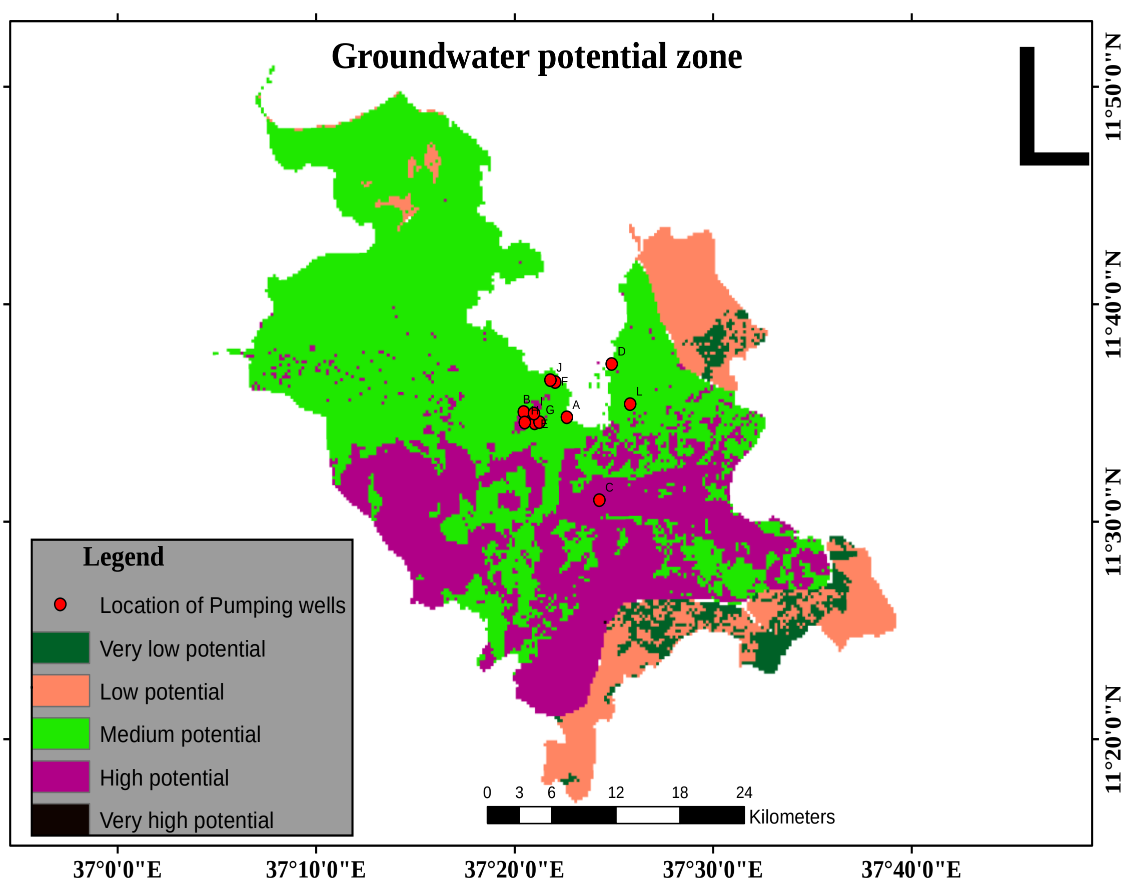

Fig. 9. Groundwater potential map of the study area

Table 7. Area covered Groundwater Potential Zone.

No.	Groundwater Potential Area	Area (Km^2)	Area (%)
1	Very Low	80.57	5.23
2	Low	198.01	12.85
3	Medium	812.86	52.73
4	High	441.74	28.66
5	Very High	8.26	0.54

5. CONCLUSION

The geographic information system with multi criteria decision approach has been applied in the Bahir Dar Zuria, Amhara, Ethiopia, to delineate groundwater potential zones. A total of six input parameters were prepared in the GIS tool. Each input parameters were assigned values and overlaid using the 'weighted overlay' tool in the GIS environment. The output shows that 8.26 Km^2, 441.74 Km^2, 812.86 Km^2, 198.01 Km^2, 80.57 Km^2 of the study area are in the very high, high, medium, low and very low of groundwater potential zone respectively. This study shows the large spatial variability of ground water potential across the study area indicates due to variability in the geomorphology, geology, soil, land use and land cover, slope and lineament in the study are

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