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Evaluation of Groundwater Potential Zone Using Remote Sensing and Geographical Information System: in Kaffa Zone, South Western Ethiopia

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Abstract: This study focused on delineating the groundwater potential and recharge area for Kaffa Zone by the method of remote sensing and ArcGIS 10.4 software analysis techniques. There are six main influencing factors (rainfall, slope, land use/cover, lineaments, drainage density, and Lithology) selected for groundwater recharge zone mapping. The thematic maps were scanned, geo-referenced, and classified as suitable for groundwater using ArcGIS 10.4. The methods to assess the potential zone were using weight overlay analysis and hierarchy of analytical process algorithm. The result obtained the potential of ground water were discussed recharge zones into four major categories: very good, good, and moderate and low. This can help for better planning and management the potential resource of groundwater. The results analyzed the groundwater potential that were subdivided in to low, moderate, high, and very high groundwater potentials areas that cover 1664.1,7682.9, 958.27, and 192.78 km^2 respectively. The prediction accuracy was checked based on the borehole yield observed and predicted data of respective locations within the selected area. The prediction accuracy obtained (68.42%) reflects that the present study's method was produced significantly reliable and precise results.
Keywords: delineation, groundwater potential, overlay, thematic maps

1. Introduction

The groundwater is used as a source for domestic, municipal, agricultural, and industrial activities [1]. It continues to increase mainly due to heavy capital expenditure and maintenance of the production of surface water through the Dams, which are constructed in developing countries [2]. The water demand increased day to day caused different variables, including geological and anthropogenic sources, to change water quality [2][3].

Several methodologies are for locating and mapping groundwater occurrence and distribution, such as surface electrical resistivity, which has produced better results in targeting the groundwater resource [4][5]. Due to its extensive fieldwork, this technique is has a great application. Both the GIS and RS are now considered essential tools for assessing potential groundwater for further studies, particularly in extended and complicated systems [6][7].

The current study focused on assessing potential groundwater zone and recharge zone maps, which would be delineated with integrated RS and ArcGIS 10.4 software, techniques for southwestern Kaffa Zone, S/N/N/P regional state, in Ethiopia. The geographical information system, also known as a geo-based information system is a relatively new technology for assessing groundwater potential. It is a very effective instrument for the processing, analysis, and integration of spatial data sets [8][9].

The following points were studied in accordance with this main objective. The determination of groundwater potential and recharge zone area, thematic maps of Lithology, land use/cover, slope, lineaments, soil texture, drainage density, and geomorphology and rainfall are prepared [10]. Furthermore, the factors that have a greater impact on groundwater potential and recharge zone are identified. Then evaluate and classify the potential groundwater zone and the area recharge zone.

2. Material and Methods

2.1. Study Area

Kaffa zone is found in South Western Regional State, The Zone which was located 738km to the south regional state and 460km apart from Addis Ababa. The zone had geographically, between7^{O} 00' 11.32" to 7^{O} 59' 54.65" N latitude and 35^{0} 59' 48.72" to 38^{0} 00' 3.15" E longitude with an average elevation of 1714 meters above sea level. Based on figures from Ethiopia's central statistical agency in 2007EC (Figure 1), the Kaffa zone has an estimated total population of 874,716, of whom 431,778 are male, and 442,938 are female.

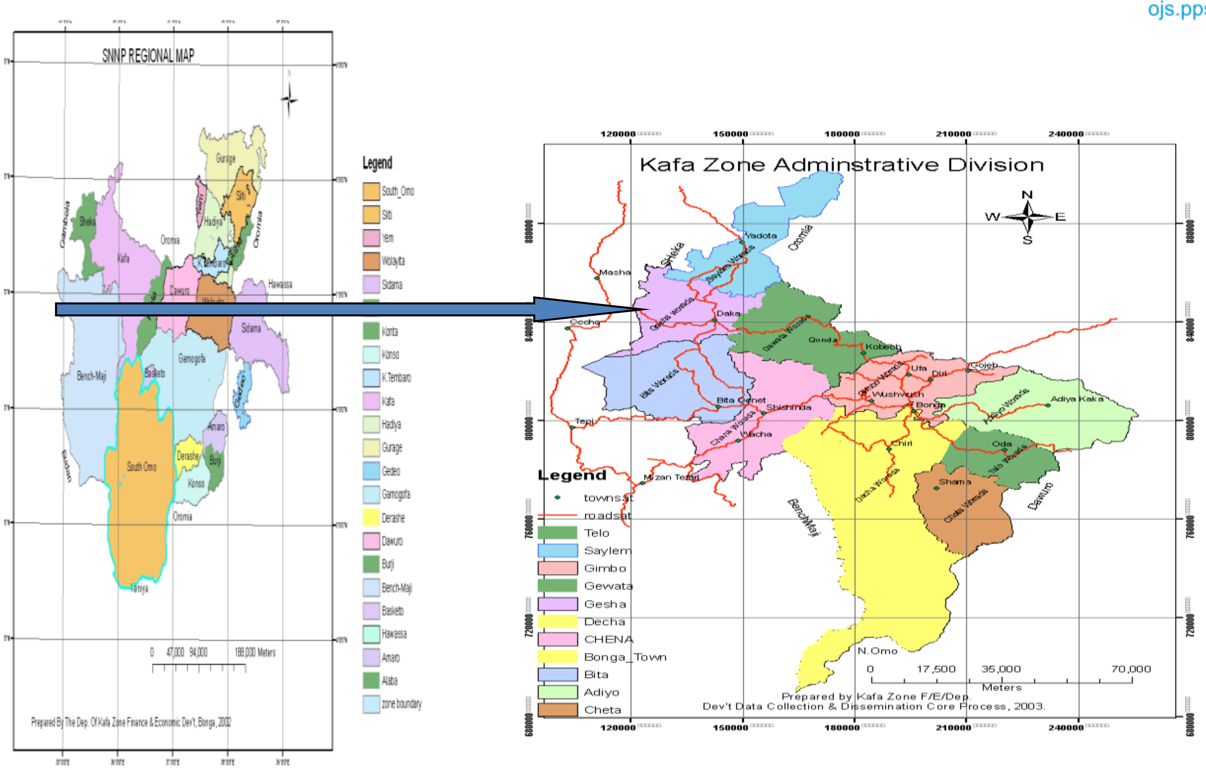

Figure 1. Map of the Study Area

2.2. Methods

To delineate groundwater potential and recharge GIS and RS techniques were applied [11]. This was done in the Kaffa zone of the southwestern region of Ethiopia through an analytical hierarchy process. Methods for this research work include the identification and evaluation of criteria, data collection, preprocessing, input data set, reclassified input layers, pairwise comparison of criteria and weighting with the hierarchical analytical process (AHP), overlay analysis with weight sum overlay analysis in ArcGIS tools, and final value ranking. The overall methods are shown as shown in Figure 2.

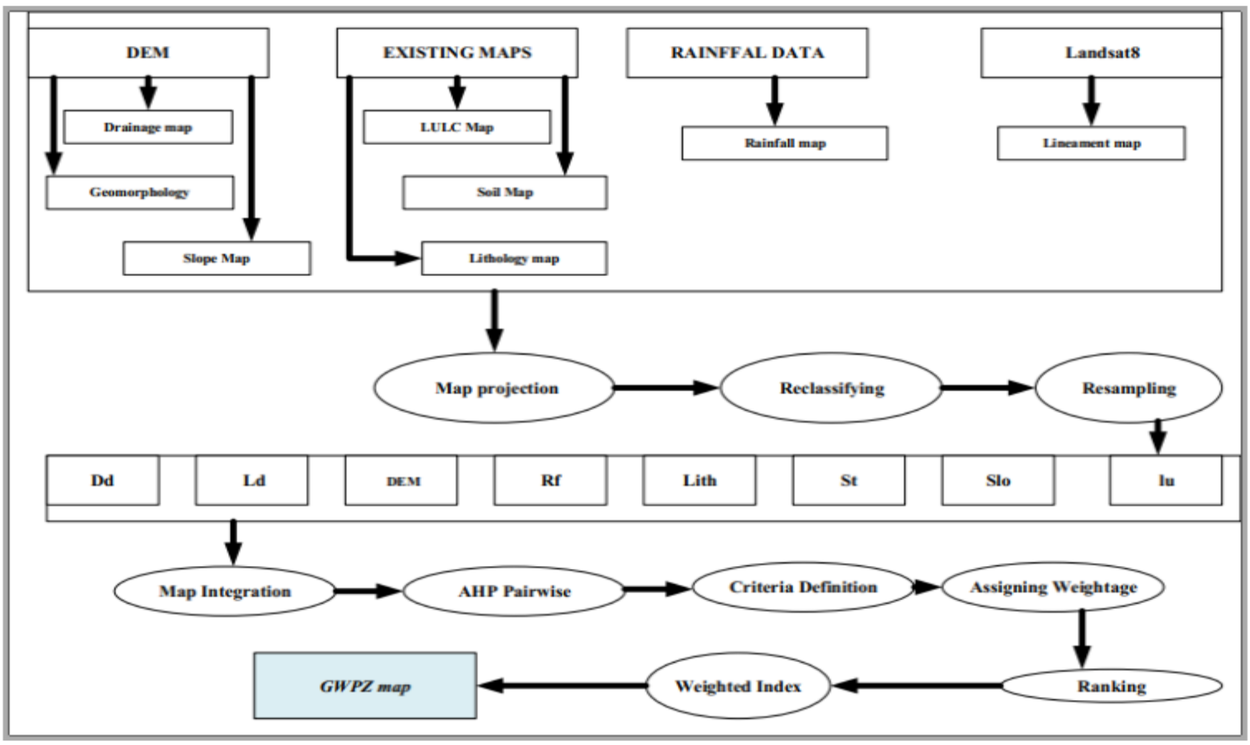

Figure 2. Flowcharts Showing the Methodology

2.3. Materials

2.3.1. Data

Table 1. Data Used

S.No	Data	Purpose	Source
1	DEM 20m×20m), 2014	To generate; slop, drainage density, lineament density	Ethiopian Mapping Agency
2	Rain fall	To evaluate GW recharge in conjunction with RF	Ethiopian National Meteorology Agency
3	Soil	Infiltration capacity	Food and Agriculture Organization
4	Geological data	GW movement	Ethiopian Mapping Agency
5	LULC	Permeability rainfall	Ethiopian Mapping Agency
6	Well data	For validation of model	Keffa Zone Water, Mineral and Energy Burea

2.3.2. Soft wares

Table 2. Tools Used

Materials Used	Company and Location Purpose	Purpose
ArcGIS 10.4.1	ESRI (New York, USA)	For image preprocessing and thematic map-generating
PCI Geomatical 3.4	ESRI (New York, USA)	To generate lineament
HWSC 16	16 ISRIC (Wageningen, Netherlands)	For soil classification
AHP 2.0	ESRI (New York, USA)	Pairwise comparison of criteria and giving weight as well as overlaying

2.4. Input Dataset and Preparation of Thematic Maps

The input layers were prepared for multiple variables such as thematic maps of rainfall, geology, lineaments, elevation, slope, drainage, land use/land cover, and soil) generated primarily from satellite imageries through digital image processing techniques and existing data [12]. During the initial phase of the GIS spatial database creation, the relevant data collected were translated into a digital format using the manual digitization method using ArcGIS 10.4 software in different scales obtained from different organizations.

The following maps were scanned, geo-referenced, and listed using ArcGIS 10.4 as necessary for groundwater. The thematic maps include elevation map, slope map, soil map, land use/land cover map, lithological map, drainage map, rainfall, and line map. The Ethiopia mapping agency data was collected from the DEM (20 to 20 m) and was used to construct maps of drainage density and slope maps. Current geology, soil, land use land cover, and liniment data were converted from '*.shp' format to raster format using a polygon to raster tool, and during conversion, a cell size of DEM (20 to 20 m) and was used to construct maps of drainage density and slope maps. Current geology, soil, land use land cover and liniment data were converted from '.shp' format to raster format using a polygon to raster tool and during conversion a cell size of 20 to 20 m was applied to all maps. Then WGS 1984 Transverse Mercator projected all the maps. The lineament map was transformed to a lineament density (km/km^2) map using the spatial analysis tool's line density tool. As per the central theme's degree of contribution, weights from 1 to 4 scales were allocated to each parameter.

2.5. Identification Criteria for Groundwater Potential and Recharge Zone Mapping

2.5.1. Geology

By regulating the percolation and flow of water to the ground, the forms of geology exposed to the surface are highly influenced by groundwater recharge [13]. Another element that regulates the quantity and consistency of groundwater occurrences in a given region is lithology [14]. The region's lithology is dominated by quaternary sediments and tertiary rocks categorized into the formation and alluvial deposits of groundwater occurrences in a given region is lithology [15]. The lithology of the region is dominated by quaternary sediments and tertiary rocks categorized into the formation and alluvial deposits of ARI, PNmb, ab1, and ja [16]. Both the porosity and permeability of aquifer rocks are influenced by lithology. However, in evaluating and regulating groundwater, each one of those lithological units has no equivalent significance. The result is therefore ordered in the following order: alluvial deposits > sedimentary, > igneous > metamorphic, respectively [17].

Table 3. Geology and Its Aquifer Characteristics

Stn.	Aquifer Characteristics	Rating
Alluvial deposits	Very high	4
Sedimentary	High	3
Igneous rocks	Moderate	2
Metamorphic rocks	Low	1

2.5.2. Slope

The slope is the rate of elevation change and is also a major factor in defining possible zones for groundwater. One of the variables governing water runoff to the ground and measuring future suitability for groundwater is the slope [18]. In contrast to the low slope zone, a high, sloping area causes more runoff and less penetration and has poor groundwater prospects [19][20]. As shown in Table 4, low slopping regions cause less runoff and elevated infiltration rate and have good prospects for groundwater.

2.5.3. Drainage density

The drainage network, dendritic drainage, rectangular, parallel drainage, and coarse drainage are of different forms [18]. The type of drainage network for the study area was the dendritic type that is good for groundwater; classification, as shown in Table 5 has been used for this type of drainage.

Table 4. Slope and Its Aquifer Characteristics

Slope (Degree)	Classification	GW Prospect	Rating
0 – 1	Nearly level	Very good	5
1 – 3	Very gently sloping	Good	4
3 – 5	Gently sloping	Moderate	3
5 – 10	Moderately sloping	Poor	2
>10	Strong sloping	Very poor	1

Table 5. Drainage Density and Its Aquifer Characteristics

Drainage Density (km/km^2)	Description	Ranking in Words	Rating
0.0 – 0.5	Low density	Good	4
0.5 – 1.0	Moderate density	Moderate	3
1.0 – 1.5	High density	Poor	2
>1.5	Very high density	Very Poor	1

2.5.4. Lineament

Lineaments are the structural discontinuity of the earth's surface, such as faults, foliation, joints, and planes of bedding. The mappable linear characterstics present on the surfaces also indicate the area of weakness and structural discontinuities that can be curved, linear and slightly curvedb [21], as defined in table 6, which is most critical for water penetration and movement to the ground.

Table 6. Lineament Densities [20]

Lineament density in (km/km^2)	Classification	Groundwater Potential	Rating
0.00 − 0.34	Very low	Very high	5
0.34 − 0.99	Low	High	4
0.99 − 1.57	Moderate	Moderate	3
1.57 − 2.11	High	Low	2
2.10 − 2.69	Very high	Very low	1

2.5.5. LULC

The land cover of a given area is dependent on geomorphology, agroecology, climate, and activities induced by humans. According to Hussein [22], the factors influencing the occurrence and availability of groundwater suggest that LULC information is an important factor in the storage and recharge of groundwater. The interdependence on groundwater is determined in a particularly quantitative way by land use in an area. To classify and identify the type of LULC, supervised image classification was carried out, and seven classes were identified. These include grassland, cultivation, shrubland, forests, state farms, crops and forests[23]. The 2014 land-sat satellite image with a spatial resolution of 20 m to 20 m was used as a data source to drive the LULC map as described in Table 7.

Table 7. Land Use Land Cover and Its Aquifer Characteristics [24]

Classification	Ranking in Word	Rating
WetLand	Very high	5
Plantation	High	4
Shrubland	Moderate	3
Cultivation land	Low	2
Grassland	Very low	1

2.5.6. Soil texture

Depending on geomorphology, geology, relief, time, and other factors, the characteristics, types, and distribution of soil in a certain area. The relationship between runoff and infiltration rates influences soil properties, which in turn controls the degree of permeability that determines the potential of groundwater. Soil texture is a medium that controls the vulnerability of groundwater, as described in Table 8, which is important in determining the intrinsic vulnerability.

Table 8. Soil Texture and Its Aquifer Characteristics

Classification	Ranking in Words	Rating
Clay	Very poor	1
Clay loam	Poor	2
Sandy clay loam	Moderate	3
Sandy loam	High	4
Sandy and wetland	Very high	5

2.5.7. Geomorphological features

A geomorphological terrain classification is useful, considering both morphological and lithological factors, leading to the delineation of hydro morphological factors. DEM and SRTM data enable a detailed description of landforms useful for groundwater potential to be generated as defined in Table 9.

Table 9. Geomorphology and Its Aquifer Characteristics

Geomorphology Class	Gw Potential	Rating
Hill	Very poor	1
Plateau	Poor	2
Pediment/Pedi plain	Moderate	3
Valley	Good	4

2.6 *Reclassifying and Assigning Ranks*

Different dimensions and ranges have been used for established national standards in determining the value given to each parameter and in determining the degree of attribute desirability of each attribute[15]. Table 10 gives the rationale for assigning a weighting to each polygon of each theme.

Table 10. The Logic of Assigning Weightage

Weight	Logic Value
1	Least contribution to the central theme
2	Low contribution to the central theme
3	Moderate contribution to the central theme
4	High contribution to the central theme

2.7. *Analytical Hierarchy Process*

The analytical hierarchy method (AHP) is a pairwise comparison estimation theory and relies on experts' decisions to extract priority scales[21]. The relation was made on a number 1-9 scale that indicates how many times a layer is significant than the other. The scaling used in AHP is expressed in Table 11. If the matrix formed is equal to bij, aij = wi/wj, where w is the weight of each parameter, I j=1....n of any positive number entering everywhere and fulfilling the reciprocal characteristics, bnij = i/bij, known as reciprocal matrices[24].

Table 11. Saatty's, the Scale of Intensity Relative Importance [22]

The Intensity of Relative Important	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

2.8. *Weight Assessment and Normalization*

Based on Saaty's scale, normalization of allocated weight using AHP was performed by considering two themes and classes at a time based on their relative significance to assess the capacity for groundwater and recharge region. Subsequently, matrices of assigned weights for various thematic layers and their groups are compared pairwise using AHP and weights standardized by the eigenvector approach its matrix was given.

$$A1\begin{pmatrix} a11 & a12\cdots & a1n \\ a21 & a22\ldots & a2n \\ an1 & an2\cdots & an3 \end{pmatrix} aij' = \frac{aij}{\Sigma aij} \text{ for } i,j = 1,2\ldots,n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$W = \begin{bmatrix} w1 \\ w2 \\ w3 \end{bmatrix} \text{and } Wi = \frac{\Sigma aij}{n} \text{for all } n=1,2\ldots n \text{ and}$$

$$W' = \begin{matrix} W1' \\ w2' \\ w3' \end{matrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\lambda max = \frac{1}{n}\left(\frac{w'}{w1} + \frac{w'}{w2} + \cdots \frac{w'}{wn}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where: w= Eigenvector, wi = Eigenvalue of criterion I, and λmax = average Eigenvalue of the pair wise comparison matrix.

The approach of the eigenvector normalizes pairwise comparison matrices of allocated weights to various thematic layers. Via the own principal value and the consistency index[14], the AHP captures the concept of ambiguity in decisions. CR is a consistency calculation, a matrix of pairwise contrast, and it is measured using equations. The consistency ratio is an indicator of the reciprocal matrix's acceptability, measured as follows:

$$CR = CI/RI \text{ , where } CI = (\lambda max - n)/(n-1) \ldots\ldots (4)$$

Such matrixes have the consistency property known as consistency ratio (CR). The matrix should be re-evaluated if the matrix's consistency ratio is greater than 0.1.

Table 12. Random Consistency Index

Matrix Size	RI
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

3. Results and Discussion

3.1 Multi Influencing Factors of Groundwater Potential Zones

The DEM and Slope (slo); which regulates the conversion of rainfall to runoff or remains on the ground surface for sufficient time to infiltrate, Lithology(lith); defines infiltration capabilities of soil and exposed rocks and regulates the flow and storage of water. Lineament Density (Ld); which greatly increases permeability by causing secondary porosity and thus vertical water percolation to recharge the aquifers; drainage density(Dd); which affects the distribution of runoff and groundwater recharge; and top layers of topographical maps (LULC, soil, and geomorphology), rainfall; which is the primary source of groundwater.

3.1.1. Rainfall suitability

There are very high precipitation rates of around 1,853-2,122 mm/year in the northwestern and southeastern portions of the study region. High precipitation of around 1,721-1,853 mm/year is obtained from the central part. The highland foot of the southwest and northeast receives moderate rainfall of 1,565-1,721 mm/year. As shown in Table 13, the southern rift floor receives low rainfall of 1,321-1,565mm/year and is reclassified into four groups, as shown in Figure 3. In the northwest and southeast highland parts, the high rainfall distribution along the high slope gradient directly affects potential groundwater zones' infiltration rate in the downstream central rift floor of the study region.

Table 13. Rainfall and Its Rank as Suitable for Groundwater Potential and Recharge

Rainfall (mm)	Rank in Word	Rating
1321-1565	Low	1
1565-1721	Moderate	2
1721-1853	High	3
1853-2122	Very high	4

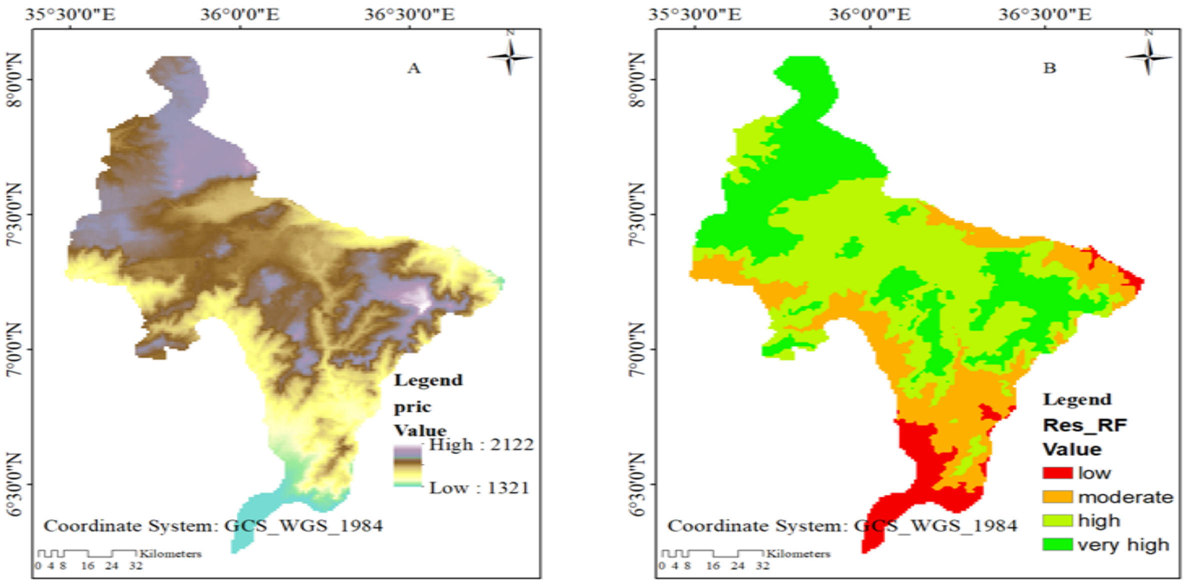

Figure 3. Rainfall Map and Reclassified Rainfall Map

3.1.2. Drainage density suitability

As shown in Table 14, the structural drainage network was used to define groundwater potential and recharge zone characteristics and reclassified them into four categories as shown in Figure 4. Very high drainage density was reported at the southern volcanic mountains and near the mountain feet and very low drainage density was recorded at the northern rift floor area (Gewata, Gesha, Saylem) and moderate and moderate and low drainage density some portions of the central highlands (Gimbo, Adiyo, Chena, Bita). The region where high drainage density values have high runoff and suggest low groundwater possibility.

3.1.3 Slope suitability

The study area's slope was divided into four classes namely, flat, gentle, moderate, and steep slope. The generated map was reclassified, and ranking depends on their groundwater potential and recharges influence, as shown in Figure 5. The highest rank was given to a gentle slope because the gentle area can hold water that has very easy for infiltration of water to the ground and the lowest rank was assigned for steep slope because they result in high runoff and low infiltration cause low groundwater recharge as shown in Table 15. Furthermore, 95 percent of the study areas were categorized under very low slope/gentile, 4.3 percent are medium slope, and 0.7 percent were under a very steep slope.

Table 14. Drainage Density and Its rank as Suitable for Groundwater Potential and Recharge

Drainage Density(km/km2)	Groundwater Prospect	Rating
0.000 - 0.303	Very high	4
0.303 - 0.576	High	3
0.576 - 0.770	Moderate	2
0.770 - 0.990	Low	1

Furthermore, 95 percent of the study areas were categorized under very low slope/gentile, 4.3 percent are medium slope and 0.7 percent were under the very steep slope.

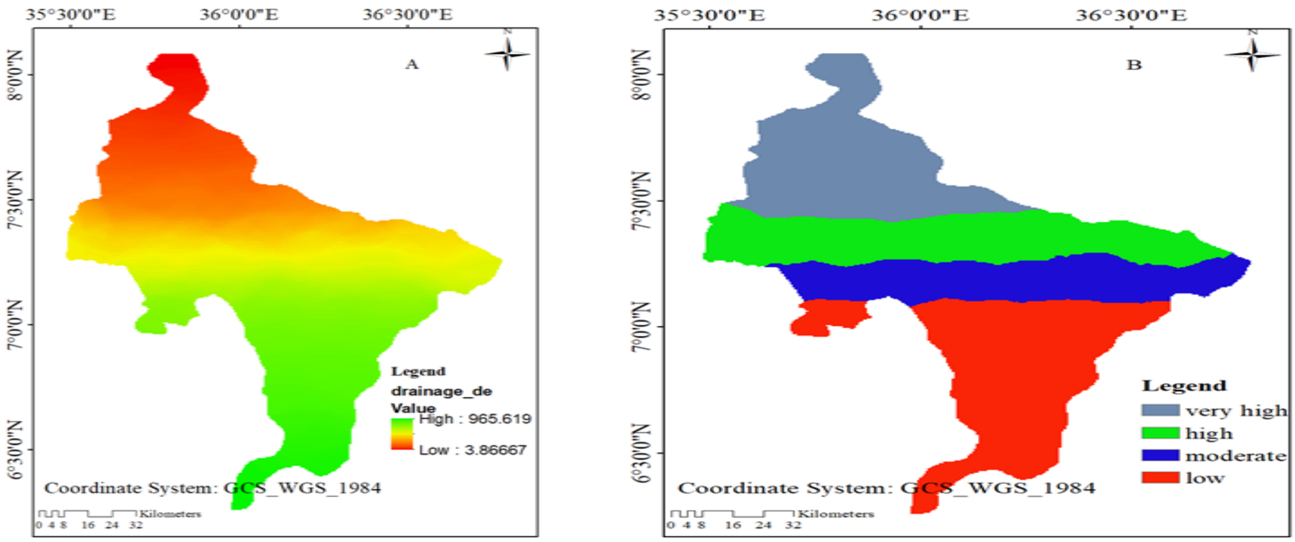

Fig 4. Drainage Density Map and Rec-Drainage Density Map

Table 15. Slope value of and Its Rank as per Suitable for Groundwater Potential and Recharge

Slope (Degree)	Classification	Groundwater Infiltration Potentiality	Rating
0.00	Flat	Very high	4
0.00-89.60	Gentle slope	High	3
89.60-89.92	Moderate slope	Low	2
89.92-90.00	Steep	Very low	1

3.1.4. Lineament density suitability(Ld)

The directions of the study area's lineaments were towards the direction of the tributaries and wetlands, which suggests that the direction of aquifers mostly tends to be aligned with the surface water bodies. The lineament density was done by the line density in ArcGIS tools and classified into four categories 0 − 0.11, 0.11− 0.14, 0.14− 0.19, and 0.19 − 0.25 km/km^2 as presented in table 16. The lineament density was relatively high in the west and southwest of the study area compared with the other areas and very less at the west northern, northeastern, central southeastern of the study area, as shown in Figure 6. The place having very high lineament density, the infiltration rate of the groundwater was more, and the place was low lineament density; the infiltration rate of the groundwater was less.

3.1.5. Soil texture suitability

The soil texture of the study area is reclassified into four classes based on (FAO 1998), and their hydrological soil group (HSG) properties are described by Universal Soil Data Analysis (USDA). The soil classification, there are 15 major soil groups in the study area, including dystricnitisols, eutricchambisol, verticcambisol, dystricgleysols, calcic xerosols, chromic luvisols, chromic vertisols, dystricfluvisols, eutricfluvisols, eutricnitisols, gypsicvertisols, leptosols, orthicarcisols, orthicsolonosols, phaeozems and the most dominant of the study area is dystricnitisols. Generally, the study area's soil type is summarized in Table 17 and reclassified as per suitable for groundwater potential in Figure 7.

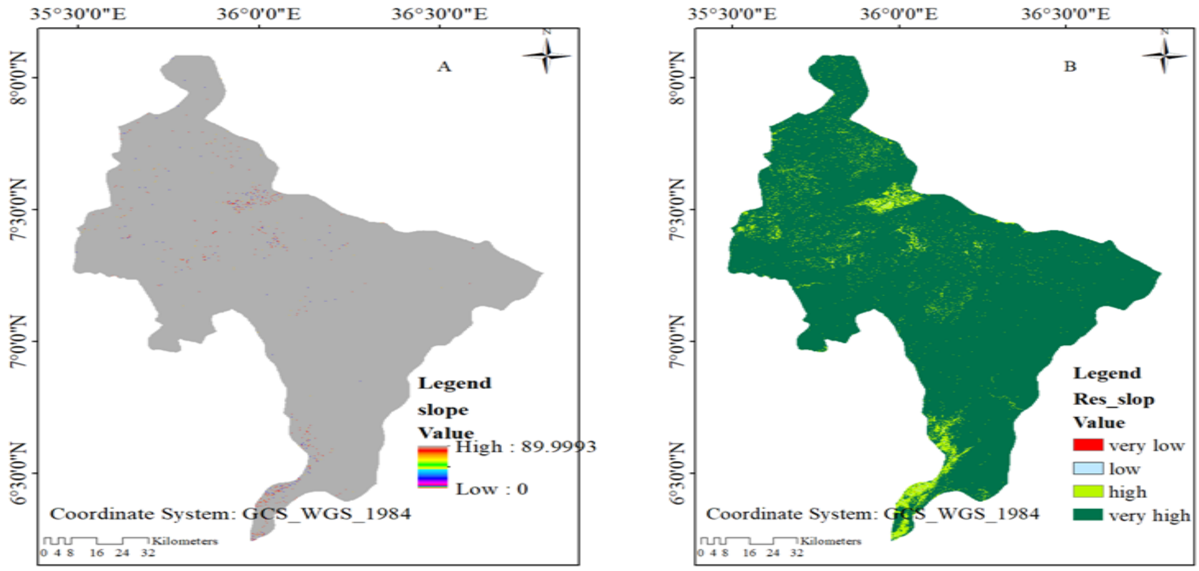

Figure 5. Slope Map and Rec-Slope Map of the Study Area

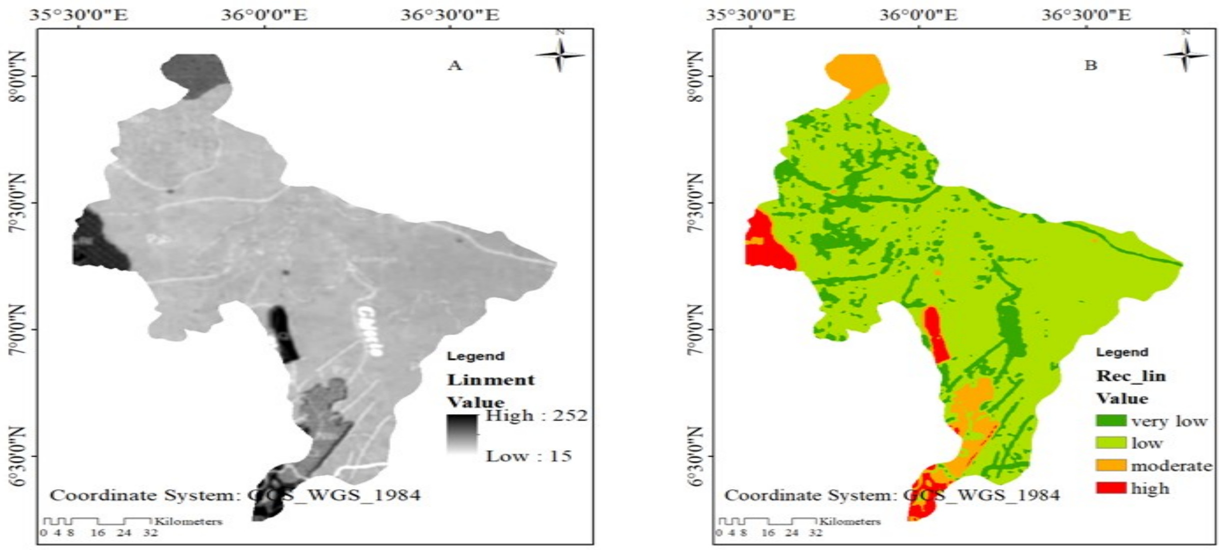

Figure 6. Liniment Map and Reclassified Liniment Map

Table 16. Lineament Density as Suitable for Groundwater Potential

Ld (km/km2)	Ld (word)	GW Suitability	Weight
0.00 - 0.11	Very low	Low	1
0.11- 0.14	Low	Moderate	2
0.14 - 0.19	Moderate	Good	3
0.19 - 0.25	High	Very good	4

3.1.6. Land-use/land-cover suitability

Land-use/land-cover has a direct effect on the hydrological process of surface runoff, evapotranspiration, and groundwater recharge. The water body, agricultural land, and the wet area were excellent groundwater sources, while the bare lands and exposed rock surface areas are less significant for groundwater recharge, as shown in Table 18. The study area's land-use/land covers were taken from data, and the area highly covered Forest, grassland, Woodland, Crop plantations, alpine vegetation, Cultivation, and bushland. Accordingly, (50.60, 17.83, 9.92, 9.84, 9.26, 2, less than 1) percent of part of Kaffa Zone is covered by forest, grassland, Woodland, Crop plantations, alpine vegetation, Cultivation, and bushland, respectively. The central and lowland of the study area is covered by forest, Cultivation, and cropland, mainly cover the pediment slopes along escarpment margins, as shown in figure 8. Cultivation, andbushland respectively. The central and lowland of the study area is covered by forest,Cultivation,and cropland mainly cover the pediment slopes along escarpment margins as shown in Figure 8.

Table 17. Soil Type and Its Weight as Suitable for Groundwater

Soil Type	Soil Texture	Infiltration Rate (mm/hr)	Weight
Nitisols	Clay loam	5 -10	2
Acrisols	Clay loam	5 - 10	2
Leptosols	Clay loam	5 - 10	2
Phaeozems	Clay loam	5 - 10	2
Gleysols	Clay(H)	1 - 5	1
Cambisols	Clay(L)	1 - 5	1
Vertisols	Clay(L)	1 - 5	1
Solonchak	Loam	10 - 20	3
Xerosol	Loam	10 - 20	3
Fluvisols	Loam	10 - 20	3
Luvisols	Sandy clay	20 - 30	4

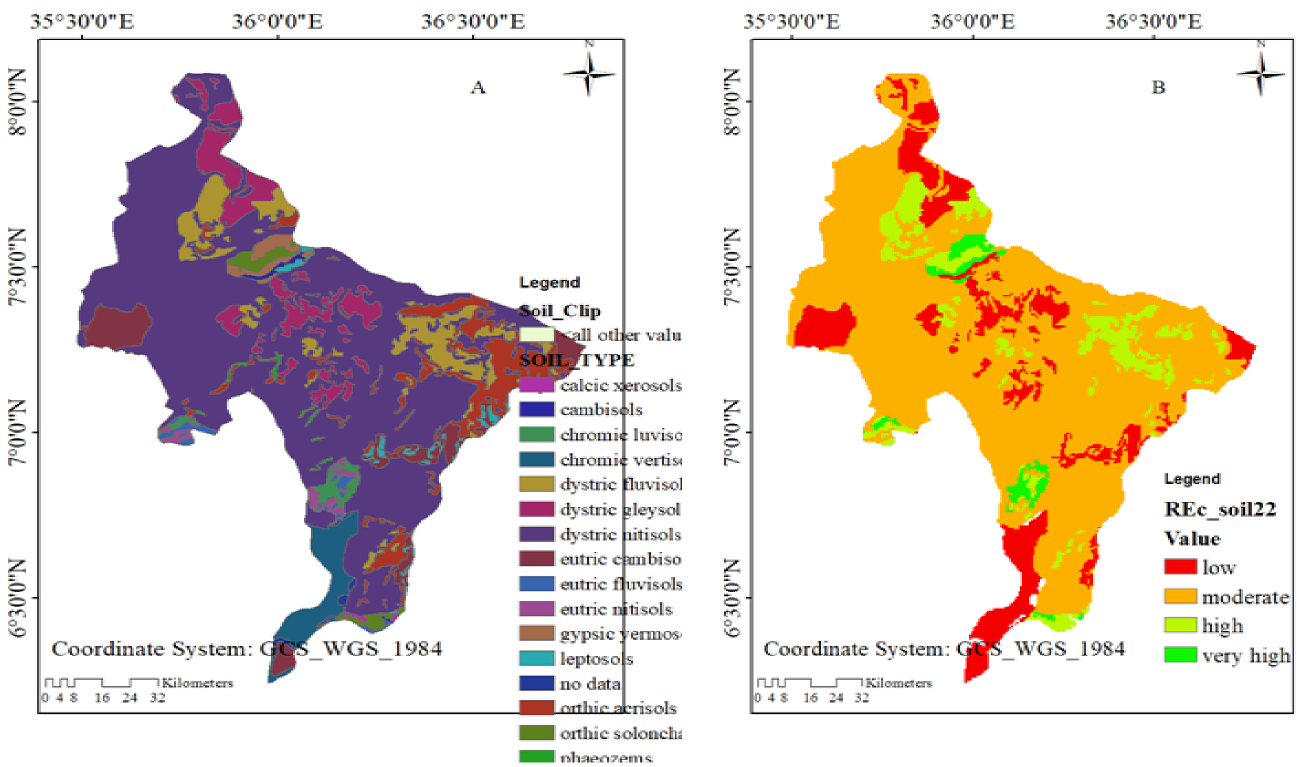

Figure 7. Soil Map and Rec-Soil Map of the Study Area

Table 18. LULC and Its Weight as per Suitable for Groundwater (W=weight)

LULC	Category	W
Bushed Shrumbbed grassland	Grassland	1
Dense bush land/moderately cultivated	Bush land	3
Dense woodland	Woodland	4
Disturbed High Forest	Forest	4
Intensively cultivated	Cultivated land	3
Moderately cultivated	Cultivated land	3
Open grassland	Grassland	1
Perennial crop cultivation	Cultivated land	3
Riparian woodland or bushland	Woodland	4
State farm	Cultivated	3

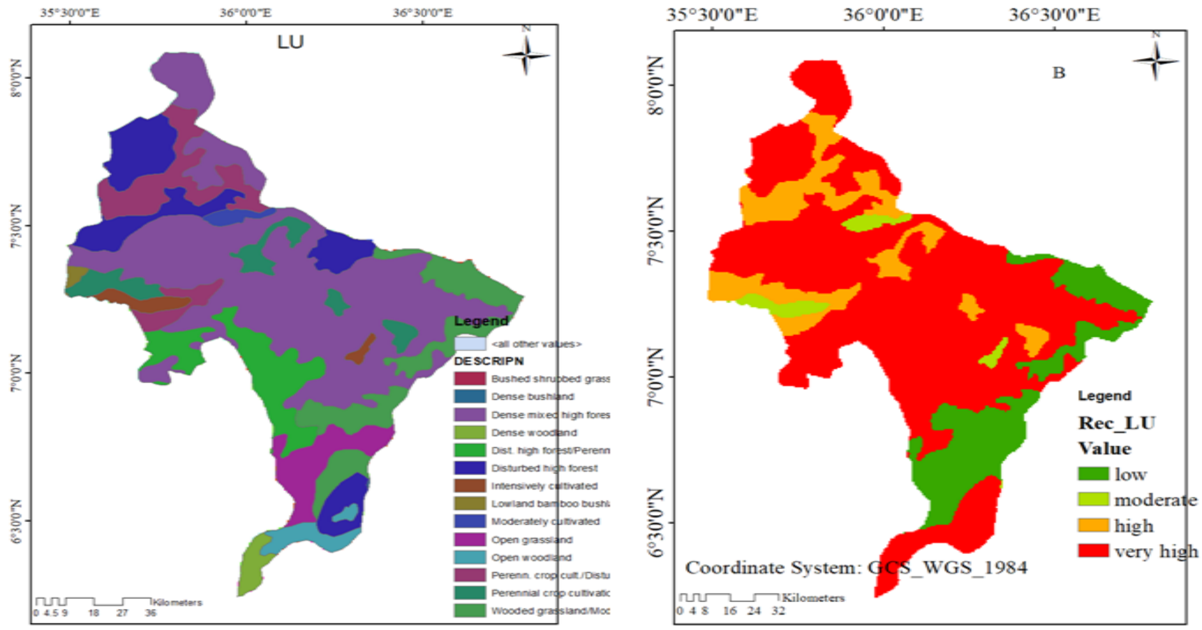

Figure 8. LULC Map and Rec-LULC Map of the Study Area

3.1.7 Digital elevation and surface analysis suitability

Shuttle radar topographic mission (SRTM) elevation data was used for the present study to get surface data. The resolution of this data was 20m×20m. This elevation data was analyzed in remote sensing and GIS software, i.e., ArcGIS 10.4 Software, to get a digital elevation model (DEM), slope, and area aspect. In the DEM, the highest elevation was 3,348 m, and the lowest elevation was 447 m, as shown in Table 19. However, the maximum area was covered by low elevation, which indicates the maximum possibility of groundwater. In the slope study, the maximum slope was 95degree Figure 9. The maximum portion of the study area was covered by the gentle and level slope (0 to 89.99 degrees).

Table 19. Elevation and Its Weight as Suitable for Groundwater

Elevation (m)	Elevation (word)	GW suitability	Weight
447 - 1133	Very low	Very good	4
1133 - 1696	Low	Good	3
1696 - 2151	Moderate	Moderate	2
2151 - 3348	High	Low	1

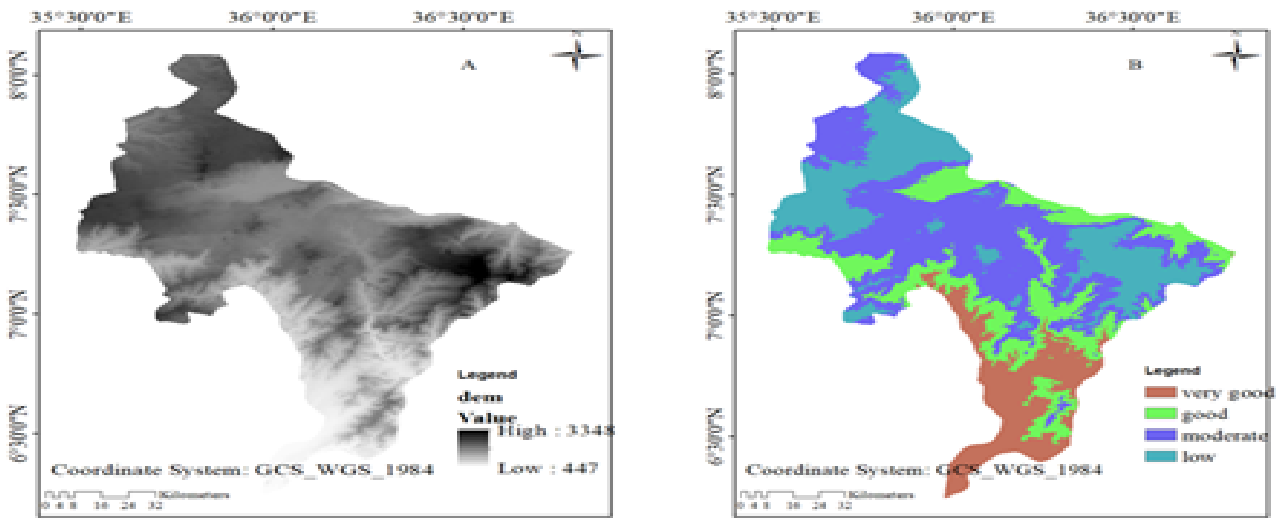

Figure 9. DEM Map and REC-DEM Map

3.1.8. Geological suitability

Lithological stratigraphy of the Kaffa Zone area was taken from a geological map of Ethiopia that was investigated by the Ethiopian geological survey. The study area consists of volcanic and sedimentary rock units. The study area was predominant with the

Paleogene group (Pjb) followed by Mokennen basalt (PNmb), Alkaline basalt, Alluvial and lacustrine deposit mostly in small mounds or linear domes in the study area. All geological classes were reclassified based on their groundwater recharge potential, and They were good, moderate, and low. The area distribution of the rock types in the study area is shown in Figure 10. It shows that about 78.52% of the study area was covered by Pjb followed by 8.76% PNmb, 4.16% NB, and very less area was covered by plateau, granite, and Alluvial. However, each one of those lithological units has no equal significance in determining and controlling groundwater.

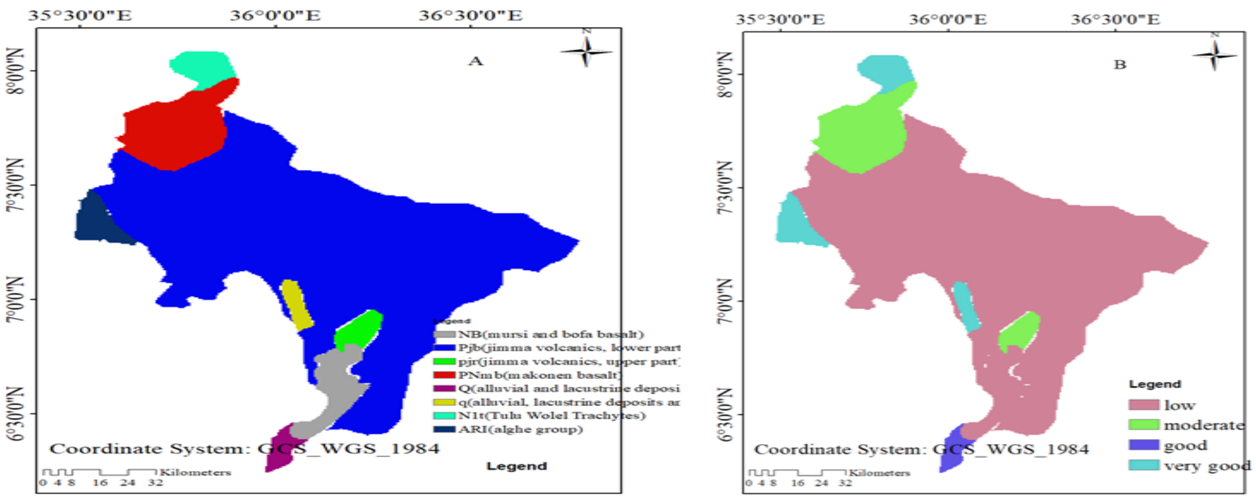

Figure 10. Geological Map and REC Geological Map of the Study Area

3.2. Mapping Groundwater Potential Zone

Finally, after the successful integration of all the thematic maps, an output raster map was obtained. Moreover, that map indice the potential groundwater zones. Earlier, ranks from 1 to 4 were assigned for individual classes of rainfall, geology, DEM, slope, soil, land use/ land cover, drainage density and lineament density layers based on the influence on groundwater potential and recharge zone. Hence the final output map was also obtained with 4 classes. As per the rank assignment, value 4 indicates a very high groundwater potential area, 3 indicates a high groundwater potential area, 2 indicates moderate groundwater potential area and 1 indicates Low groundwater potential area as presented in Figure 13.

Table 20. Pairwise Comparison Matrix

Parameter	RF	Geo	Slop	Ld	DD	DEM	Soil	LU
RF	1	2	3	5	6	4	6	7
Geo	0.5	1	2	3	5	5	6	7
Slop	0.33	0.5	1	0.5	2	4	2	3
Ld	0.2	0.33	2	1	1	2	2	3
DD	0.16	0.2	0.5	1	1	2	3	4
DEM	0.25	0.2	0.25	0.5	0.5	1	3	4
Soil	0.16	0.167	0.5	0.5	0.33	0.333	1	4
LU	0.14	0.143	0.33	0.33	0.25	0.25	0.25	1
Total	2.76	4.543	9.58	11.8	16.08	18.583	23.25	33

Table 21. Pairwise Comparison Matrix for All Variable

Parameter	RF	Geo	Slop	Ld	DD	DEM	Soil	LU	Wt	Wt(%)
RF	0.362	0.440	0.313	0.422	0.374	0.215	0.258	0.212	0.324	32.458
Geo	0.181	0.220	0.209	0.253	0.311	0.270	0.258	0.212	0.239	23.920
Slop	0.121	0.111	0.104	0.042	0.124	0.215	0.086	0.090	0.111	11.173
Ld	0.073	0.073	0.209	0.085	0.062	0.107	0.086	0.090	0.098	9.821
DD	0.061	0.044	0.052	0.085	0.062	0.108	0.129	0.121	0.082	8.265
DEM	0.091	0.044	0.027	0.042	0.032	0.054	0.129	0.121	0.067	6.726
Soil	0.061	0.037	0.052	0.042	0.021	0.018	0.043	0.121	0.049	4.931
LU	0.052	0.031	0.035	0.028	0.016	0.013	0.010	0.030	0.027	2.702

3.2.1. Weight assessment

To determine the groundwater potential zone, the pairwise comparison matrix was carried out by using AHP techniques. To compute the cumulative weight of the main criteria, the relative weights of their corresponding classes were considered.

Map Categorization and weight assignment for factors selected for groundwater potential and eight parameters selected for groundwater potential zone. Categorization and weight assignment for groundwater potential zones. Normalization of assigned weight using AHP; based on Saaty's scale, considering two themes and classes at a time based on their relative importance to determine the groundwater potentials zone. After that, pairwise comparison matrices of assigned weights to different thematic layers and their classes were constructed using according to (Saaty's, 1980). AHP and weights normalized by the eigenvector approach. The consistency ratio (CR) calculated to examine the normalized weights of various thematic layers and their classes to compare the importance of two-layer maps show that one of them has more influence on the groundwater occurrence than the other. Weights assigned to each theme's classes based on their influence on groundwater potential as described in table 20.

3.2.2 Weight normalization

The weights were normalized based on equation five, which was calculated by averaging each row's values to get the corresponding ranking, which gives the results of normalized weights of each parameter as presented in table 21. From the result, observed rainfall has the highest value rather than other parameters. 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 groundwater source in the area was the rainfall of the northwestern and southeastern highlands the study area due to mountain block and slope.

3.2.3 Principal eigen vector

To check the weight assigned to each parameter in table 15, the normalized principal eigenvector value (λmax) is computed depending on equations 2 and 3 to drive the consistency ratio equation 8. This was done by multiplying the weight of the first criterion, for example, rainfall = 32 (as shown in Table 23) with the total value found in the pairwise comparison matrix, for example, Rainfall =2.76 Table 20. This was applied for the rest of the seven factors as per equation 4. Finally, the summation of these values gives the consistency vector ($\lambda_{max}$of = 8.84), as shown in table 22 for calculating the consistency index.

Table 22. Normalized Principal Eigenvectors

Parameter	Normalized Principal Eigenvectors
RF	0.895847356
Geo	1.086711488
Slop	1.070725092
Ld	1.162161801
DD	1.329387111
DEM	1.249919965
Soil	1.146646715
LU	0.891959073
Λmax	8.8333586

The consistency index was computed to overcome the formula of consistency ratio, and this was done based on equation 4, which results in CI = 0.120. Then, the consistency ratio was computed as per equation 4 and the computed result of CR = 0.085 was less than 0.1 and the given weights were valid for further analysis. Groundwater potential zone map (GWPZM) was computed after checking all criteria as follows in equation 5:

GWPZM = 32RRf + 23.92 RGeo +11.17RSL+ 9.82RLd + 8.27RDD + 6.72RDEM + 4.93RSt + 2.7RLu……………………………………(5)

Where, RRf: Reclassified Rainfall Map, RGeo: Reclassified Geology Map, RSl: Reclassified Slope map, Rst: Reclassified Soil Texture Map, RLd: Reclassified Lineament density Map, RDd: Reclassified Drainage density Map, RLulc: Reclassified Land-use/land-cover Map and RLith: Reclassified Lithology Map. Rainfall, slope, lineament density, and geology hold the highest value relative to the other parameters. The weight assigned for rainfall was greater than the weight of others, which influences the occurrence of groundwater potential and recharges zone than other parameters. The result for groundwater potential zones was classified into very high, high, moderate and low Figure 11. The integration of all thematic maps did the result of the groundwater potential of this study area to delineate groundwater potential zones. The results are categorized into four categories, namely as very high, high, moderate, and low of groundwater potential zone. Low groundwater potentials cover 1664.1 km^2 of the study area; moderate groundwater potential covers 7682.9 km^2 of the study area. Hence, high to very high groundwater potentials cover 958.27km^2 and 192.78 km^2, respectively to the southern, northeastern, and central lowland of the study area as shown in Figure 11.

3.3 Groundwater Recharge

The groundwater recharge zone investigation considers the analysis of thematic layers like rainfall, slope, land use land cover, drainage density, liniment density, and geology; which the same maps used for groundwater

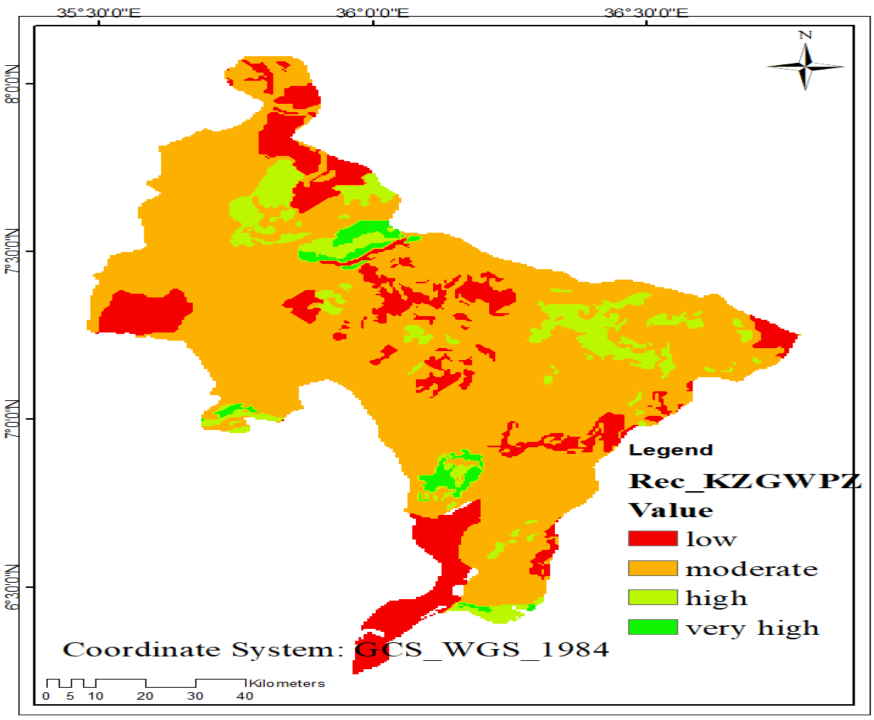

Figure 11. Groundwater Potential Zone Map

Potential zone are mapping. The parameter values were given based on the Saatty scale as shown in Table 12. As per the pairwise comparison matrix, the relative weight matrix and normalized principal eigenvector were calculated for getting the relative weights of the variables. The influence percentage of thematic layers and the rank for its parameters were assigned based on the research's judgment or knowledge of expertise gained through similar work on groundwater recharge mapping. Determination of the relative importance and each thematic map's weight of each thematic map with another paired-comparison matrix was done by saatty importance scale. In this pairwise comparison matrix, the weight of the consistency ratio value of groundwater recharge was computed and the result is less than 0.1 for all experts. This indicates that all experts' weightings are consistent and suitable for the implementation.

3.3.1 Weight analysis

The relative weight importance between criteria was assigned according to a numerical scale from 1 to 6, as shown in table 11, and it is assumed that the selected parameters were equally important or more important than other selected parameters. In this research, the relative weight was assigned for delineating and mapping of groundwater recharge of thematic layers.

Table 23. Pairwise Comparison Matrix Analysis

Parameters	RF	Slop	LU	DD	ld	Geo
RF	1.00	3.00	5.00	7.00	7.00	9
Slop	0.30	1.00	3.00	5.00	7.00	9
LU	0.20	0.33	1.00	3.00	5.00	7
DD	0.14	0.20	0.33	1.00	3.00	5
Ld	0.14	0.14	0.20	0.33	1.00	3
Geo	0.11	0.11	0.14	0.20	0.333	1
Total	1.93	4.78	9.676	16.5	23.33	34

3.2 Weight Normalization

The weights were decided based on the local field experience, as well as expert opinions. Thus, the weights assigned to different thematic maps and their features were normalized by using Saaty's AHP. The corresponding ranking, which gives the normalized result. normalization process reduces the subjectivity associated with the assigned weights of the thematic maps and their features. The weights were normalized based on equation one, which was calculated by averaging each row's values to get the

Table 24. Pairwise Comparison Matrix and Normalized Weight Analysis

Parameter	RF	Slop	LU	DD	Ld	Geo	Wt	Wt%
RF	0.51813	0.626697	0.516742	0.423396	0.300004	0.264706	0.441613	44.1613
Slop	0.17253	0.208899	0.310045	0.302425	0.300004	0.264706	0.25977	25.9769
LU	0.10362	0.069563	0.103348	0.181455	0.214289	0.205882	0.146361	14.6360
DD	0.07409	0.04178	0.034415	0.060485	0.128573	0.147059	0.081068	8.10675
Ld	0.07409	0.029873	0.02067	0.020142	0.042858	0.088235	0.045978	4.5978
Geo	0.05751	0.023188	0.014779	0.012097	0.014272	0.029412	0.02521	2.521
Total	1	1	1	1	1	1	1	100

The weights of each parameter As presented in result, As presented in the result, the weights of each parameter (rf, slo,Lu and Dd) had the highest value rather than other parameters. Because it indicates, it had the possibility of high groundwater recharge zones.

3.3.3 Normalized principal eigen vectors

To check the weight assigned to each parameter in Table 22, the normalized principal eigenvector value (λmax) was computed depending on equations 4 and 5 to drive the formula of consistency ratio from equation 5. This was done by multiplying the weight of the first criterion i.e, rainfall value was 44.16 as shown in Table 23 with the total value that was found in the pairwise comparison matrix i.e, rainfall was 1.93 in a Table 22. This calculation was applied for the rest of the eight factors as per equation 6.

Table 25. Normalized Principal Eigen Vector

Parameter	Normalized Principal Eigen Vectors
RF	0.85231382
Slop	1.24351824
LU	1.4161878
DD	1.34028984
Ld	1.07281291
Geo	0.85714002
Λmax	6.78226263

Finally, the summation of these values gives the consistency vector (λmax of = 6.78) as shown in Table 24 for calculating the consistency index.

The consistency index was calculated based on equation 8 and equation 9 to which results from CI = 0.04. Then, the consistency ratio was computed as per equation 8 and the computed result was CR = 0.03 which was less than 0.1and the given weights were accepted for further analysis. Groundwater Recharge zone map (GWRZM) was computed after checking all criteria as follows:

GWRZM= 44.16Rf + 25.97slo + 14.63LU + 8.11Dd + 4.160Ld +2.52Geo……………(6)

Rainfall, Slope, Land use land cover and drainage density hold the highest value relative to the other parameters. The weights assigned for Rainfall were greater than the weight of others, which influence the process of groundwater recharge than other parameters. The delineated groundwater recharge zone of the study area has also been classified into four classes; namely ‘highly suitable', ‘suitable', ‘moderate', and ‘non-suitable' for recharge zone and represented as 4, 3, 2 and 1 respectively in Figure 13.

3.4. Validation of Groundwater Potential Zones

Delineation of groundwater potential and recharge zone by integrated GIS and remote sensing techniques have a close agreement with the available point source inventory data as shown in Figure 7. However, there were high yields of groundwater potentials in some areas. This may happen when the rift faults in the area have caused variable degrees of displacement on rock formations coming to lateral contact to different rock types that have high permeability and as a result, the lacustrine deposits to that areas. Thus, the groundwater potential zoneswere validated with well yield data of 16 boreholes and 3 dug wells with the depth ranging from 65 to 254 m as presented in Table 26.

Table 26. Well Data

Woredas	Kebele	X	Y	Z	Source	Yield (L/s)	Depth (m)	Category
Bonga	Hospital	206055	811941	1670	Deep well	27.0	65	4
Shishonde	Chena	194444	801212	1880	Deep well	6.0	110	2
Adiyo	Mera	206815	799582	2012	Deep well	8.0	155	4
Adiyo	Boka	206811	799579	2083	Deep well	10.0	180	2
Saylem	Imiriki	149804	867717	2408	Deep well	10.0	200	2
Bonga	Kayikela	193993	810562	1722	Deep well	5.0	65.9	1
Cheta	Bashi	206227	762231	1726	Deep well	6.0	180	2
Cheta	Bashi	779491	208743	1686	Deep well	10.0	250	2
Decha	Oogiya	184652	756642	1081	Deep well	24.0	180	4
Bita	Bita Genet	123637	823560	1836	Deep well	12.0	220	3
Decha	Cheri	188292	788898	1841	Deep well	4.5	190	1
Decha	Awurada	184648	756638	1866	Deep well	34.0	254	4
Sayilem	Techibi	147351	857086	2381	Deep well	23.5	163	4
Decha	Boba	182977	783740	1820	Deep well	5.0	158	1
Sayilem	Shunga	147357	857051	2300	Deep well	5.0	158	1
Sayilem	Yadoota	147340	857082	2294	Shallow well	8.5	220	2
Sayilem	Yadoota	149553	873824	2308	Shallow well	0.29	160	1
Sayilem	Yadoota	149556	873830	2311	Shallow well	0.32	150	1

It is observed that high potential zones were located in the northwestern part of the study area and the southeastern part of the Sayilem, Bonga, Decha, and Adiyo. A cross-validation study has been carried out in this area to ensure that the groundwater potential zone was as per the field data reported by Keffa Zone water, Mineral, and Energy (2019). The good yield of 34l/s capacity is found in the very high potential zone. For verification of resulted map secondary field data collected from 16 observation deep well and 3 shallows well from these three, seven, three and five wells fall in the low, moderate, high and very high groundwater potential zone respectively in table 25; the existing data shows three, three, five, and five wells fall in the low, moderate, high and very high groundwater potential zone respectively in table 25, and the total variation of the model and the existing data was four wells. Thus: the accuracy of the prediction is estimated as follows: Total number of boreholes = 19, number of boreholes where there was an agreement between , the expected and the actual yield = 13, number of boreholes where there was a disagreement between, the expected and the actual yield = 6, the accuracy of the prediction = (13/19) *100 = 68.42 %. The prediction accuracy obtained as 68.42% reflects that the method applied for present study's method produced significantly reliable and precise results.

4. Conclusions

The result of groundwater potential and recharge zone using GIS and remote sensing techniques through analytical hierarchy decision methods were using GIS and remote sensing techniques through analytical hierarchy decision methods and delineated based on the influential factors for groundwater potential and recharge zone. In this research, eight parameters were selected which have more effects on the occurrence of groundwater potential and six parameters were selected for the recharge zone before overlay analysis.This approach allows decision-makers to give judgments to reduce complexity in decision-making processes. The results of the consistency ratio in this study were 0.085 and 0.03 for groundwater potential and recharge respectively. In this case, the consistency ratio results for both groundwater potential and recharged zone was less than 0.1 and the value was accepted for further analysis. Very high potential areas present in alluvial plains, lacustrine sediments, the fracture valleys, and valley fills, which coincide with the low slope and high lineament density of the study area. Very low groundwater potential falls in the area volcanic landform, bare lands, high slope, and high drainage density. Very high groundwater recharge was identified to the northeastern and central-eastern highlands of the study area in high rainfall, high drainage density, high lineament density, and structural landforms.

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