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Research Article

Identification and Mapping Groundwater Potential Zones Using Geospatial Analysis for Genale-Dawa Bale Sub-Basin, Oromia, Ethiopia

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Abstract

Groundwater is one of the most crucial natural water supplies because of continuously directly or indirectly supports many domestic, agricultural, and industrial activities but is now being degraded due to various causes. *Therefore, this study aimed to iddentfy and map the factors that determine groundwater potential and produce a groundwater potential zones map for Genale-Dawa Bale Sub-Basin.* Accordingly, in this study, ten (10) factors affect groundwater potential at varying degrees namely: rainfall, geomorphology, LULC, lithology, soil texture, slope, elevation, topographic wetness index, drainage, and lineament density were used. Criteria weights and rankings were assigned based on expert opinion, literature review, and field survey experience, using Analytical Hierarchy Process (AHP) and ArcGIS 10.3 software to map potential groundwater zones. The results show that thematic factors such as rainfall, geomorphology, LULC, lithology, soil texture, slope, topographic wetness index, elevation, drainage density, and lineament density affect groundwater potential with weight values of 24.2%, 18.7%, 10.7%, 13%, 7.9%, 6.9%, 3.8%, 3.8%, 5.4%, and 5.7% respectively in the study area. Maps of groundwater potential zones classified into five categories: very low 366,001.80 ha (24.36%), low 249,151.07 ha (16.58%), moderate 271,817 ha (18.09%), high 278,343.13 ha (18.53%), and very high 337,194.06 ha (22.44%) for the Bale Zone and the Genale-Dawa Sub-Basin. The low to very low groundwater potentiality has been seen on the map at different distances due to the presence of hills and steep slopes, rock outcrop surfaces, clay soil textural class, low rainfall areas, very high drainage density, low lineament density, bare land are the main reasons. The validation analysis revealed a 91% confirms the very good agreement between the groundwater inventory data and the developed groundwater potential zone. The groundwater potential zones assessment and map of the current research results serve as a baseline information for planners, decision-makers, and adopters of sustainable management options, to identify suitable sites for groundwater exploration, and initial for further studies. Further studies, detailed water chemistry surveys, geophysical surveys at potential drilling sites, and grade analysis should recommended.

Keywords

Remote Sensing (RS), MCDA (AHP) Genale-Dawa, Bale Zone, Groundwater Potential, Geospatial, Weight Overlay Analysis

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1. Introduction

Water resource especially groundwater is a valuable component of the natural hydrological process, as it is stored below the water table in the voids of rocks and soil in the main areas of the earth's crust [11, 32]. In many regions of the world, groundwater is the main source and is extensively used for drinking, household, industrial, and agricultural needs [34, 25]. It is the safest and most dependable supply of water, utilized for household, agricultural, industrial, and municipal needs. Ethiopia, one of the most hydrologically promising nations in East Africa, is thought to contain a sizable groundwater potential reserve [66]. Lithology, geomorphology, drainage density, geology, slope, drainage network, land use/land cover pattern, and meteorological conditions are some of the variables that affect groundwater potential [12, 88, 37].

Thus, it is essential to evaluate and map the zones that have the potential for groundwater using GIS and remote sensing. Regarding the management and development of groundwater, in-depth knowledge of aquifers and their potential mapping is essential. The groundwater potential zones can be mapped and assessed using a variety of approaches. Numerous nations have evaluated groundwater potential zones mapping using different techniques [54, 62, 35, 45]. However, the traditional methods, including hydrogeological fieldwork and geophysical surveys, take time and are too expensive [6].

Recent years have seen an increase in the use of geographic information systems (GIS) and Remote Sensing (RS) for mapping, generating valuable data quickly and inexpensively, and identifying groundwater potential zones that provide massive scale in space-time and save time and money [22, 42, 28]. It can produce data in the spatial and temporal domains, which has a significant role in successful analysis, prediction, and validation. It can also give all the parameters that affect a region's groundwater potential zones. Like huge amount and quality of data processed in geospatial software produces groundwater potential zones [49, 68].

Additionally, by combining multi-criteria decision analysis (MCDA) with RS and GIS approaches, AHP has been successfully implemented in various studies for groundwater recharge potential zone mapping and water resource management [52, 87]. Numerous studies with encouraging findings have effectively combined RS, GIS, and AHP methods to map groundwater potential zones [4, 67, 70, 59].

In Ethiopia, groundwater is not adequately used due to higher development and operational cost and a lack of understanding of the resource dynamics [40]. The LULC, climate change, brought challenges and loss of available surface water which alarmingly increases the demand for groundwater [97, 2, 41]. The dramatic increment in human population, the LULC change, the dry of deep and shallow springs and wells, and limited research studies brought unwisely utilization and declines in groundwater potential in Bale Zone, Genale-Dawa Sub-basin create competition over surface available water sources for multi-purpose.

Additionally, alleviating problems in water demand and failure related to groundwater exploitation is vital within the study area. Furthermore, the lack or limited research-based study using the integrated geospatial techniques (GIS and RS) with multi-criteria decision analysis (MCDA – AHP) is a main limitation for the planner, decision-makers, investment, management options, selecting suitable sites for drilling new boreholes, and current status of groundwater potential in Bale Zone, Genale-Dawa Sub-basin.

2. Materials and Methods

2.1. Description of the Study Area

The research region is located 430 kilometers from Addis Ababa, the capital city of Ethiopia, in the Oromia Regional State's Bale Zone in the southeast of the country. The Genale-Dawa basin contains the Bale Zone Genale-Dawa Sub-Basin. According to Figure 1, the research area covers 1,510,426.32ha and is located between the latitudes of 5°57'40"N and 7°33'30"N and the longitudes of 39°53'50"E and 41°19'50"E. The majority of the districts, including Agarfa, Dinsho, Sinana, Gobba, Goro, Ginnir, Dawe Kechane, Gasara, Gololcha, Berbere, Delomana, Sawena, and Raitu, are covered by this Bale Zone Genale - Dawa Sub-basin, which has elevations ranging from 670 m to 4463 m above mean sea level (amsl).

2.2. Topography

Between the sub-basin upstream and downstream ends, there is a significant height difference. Because of its unusual topographical steepness and importance as a supply of water for the Bale zone, other regions, and countries further downstream, the uppermost part of the sub-catchment needs to be safeguarded with great care. Bale has a wide range of physiographic features. It is made up of flat-topped plateaus, lowlands, mountainous terrain, deeply cut river valleys, and deep gorges. Southeast Rayitu, Guradamole, and Dawe Qachen are the surfaces that rise from below 300 meters above sea level to high ranges that culminate in Tulu Dimtu, the highest peak in the area at 4377 meters. The Sannate plateaus (Bale Mountain National Parks) and Mount Tulu Dimtu are incorporated into the high land plateaus. Flat plains, river basins, and gorges are all features of the lowlands, which are divided by hills and ridges.

2.3. Climate and Agro-ecologies

Bale Zone is separated into Dega (highlands), Waine Dega (midlands), and Kola (lowlands) according to topography. It also has a bimodal rainfall pattern. In accordance with this, the region has two cropping seasons: Ganna (March to June) and Bona (July to December). It displays extensive temporal and geographical climate variability, which is mostly influenced by variations in height. The large highland plateau and surrounding mountains are known for their cool climate and heavy rains, and high peaks like the Sanetti plateau and Tullu Dimtu may have winter snowfalls.

A tropical, hot, and dry climate predominates in the lowlands and farther south of the mountains. The region has a bimodal local climate with two wet seasons that feature both heavy and light precipitation. The bimodal rainfall pattern has light rains from March to June with a peak in April and strong rains from July to October with the highest peak in August. In the region with the monomodal pattern, there are typically four dry months (November–February) and eight rainy months (March – October). Annual rainfall in this lower-altitude area ranges from 600 to 1000 mm, while it ranges from 1000 to 140 mm in higher-altitude places. In the course of the dry season, there is a lot of variation in the daily temperatures. 18.4°C is the average annual high temperature, and 1.4°C is the average annual minimum.

2.4. Soil Types

Soils, the result of climate, topography, and geology, greatly control the rate of infiltration and infiltration into aquifers. Sub-basin soil type maps were clipped from digital soil maps [31] using ArcGIS 10.3 software (Figure 2 and Table 1).

Table 1. *Soil types and its area coverage of Bale Zone Genale Dawa sub-basin.*

Major soil types	Area (ha)	Area (%)
Calcic Cambisols	40384.50	2.67
Cambic Arenosols	19319.31	1.28
Chromic Cambisols	308859.70	20.45
Chromic Luvisols	247737.91	16.40
Chromic Vertisols	154710.08	10.24
Eutric Cambisols	32764.98	2.17
Eutric Nitosols	34432.52	2.28
Lithosols	146606.24	9.71
Pellic Vertisols	303248.92	20.08
Vertic Cambisols	222254.22	14.72

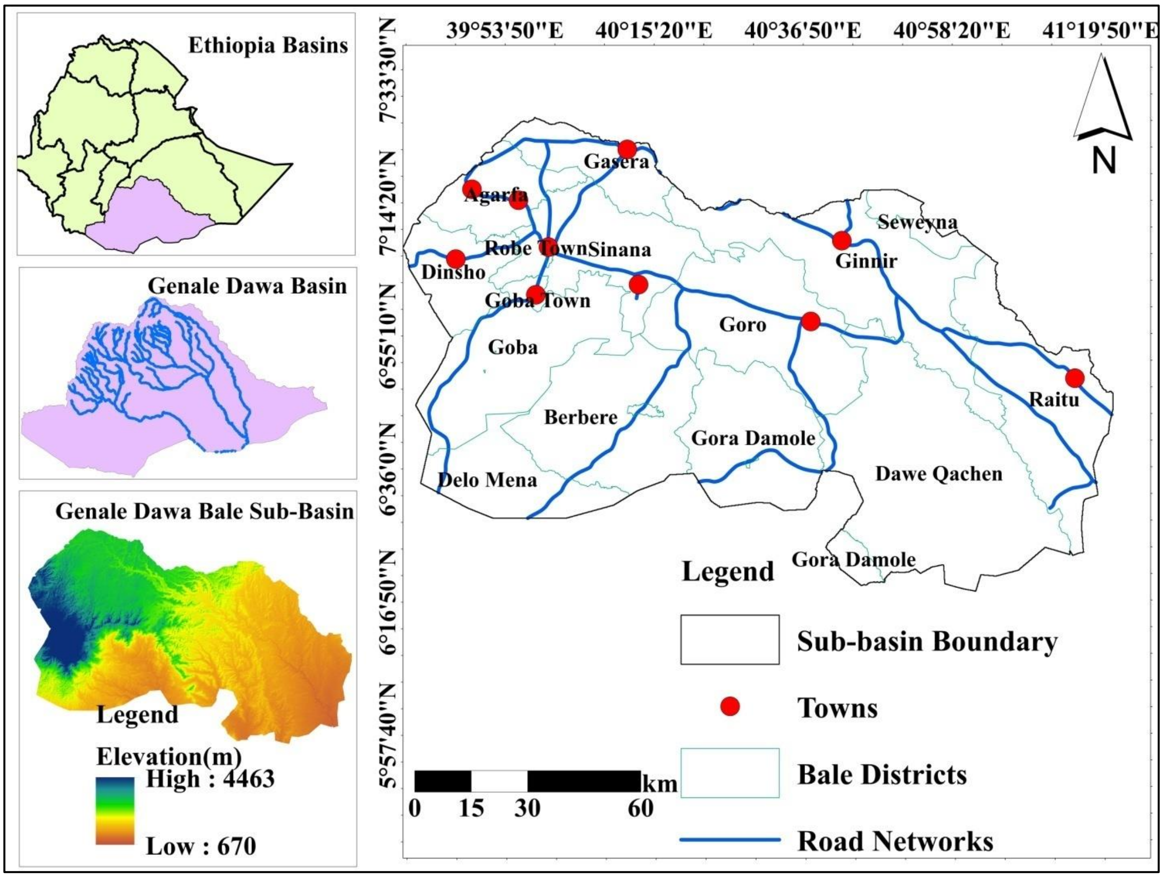

Figure 1. *Map of the study area Bale Zone Genale Dawa sub-basin.*

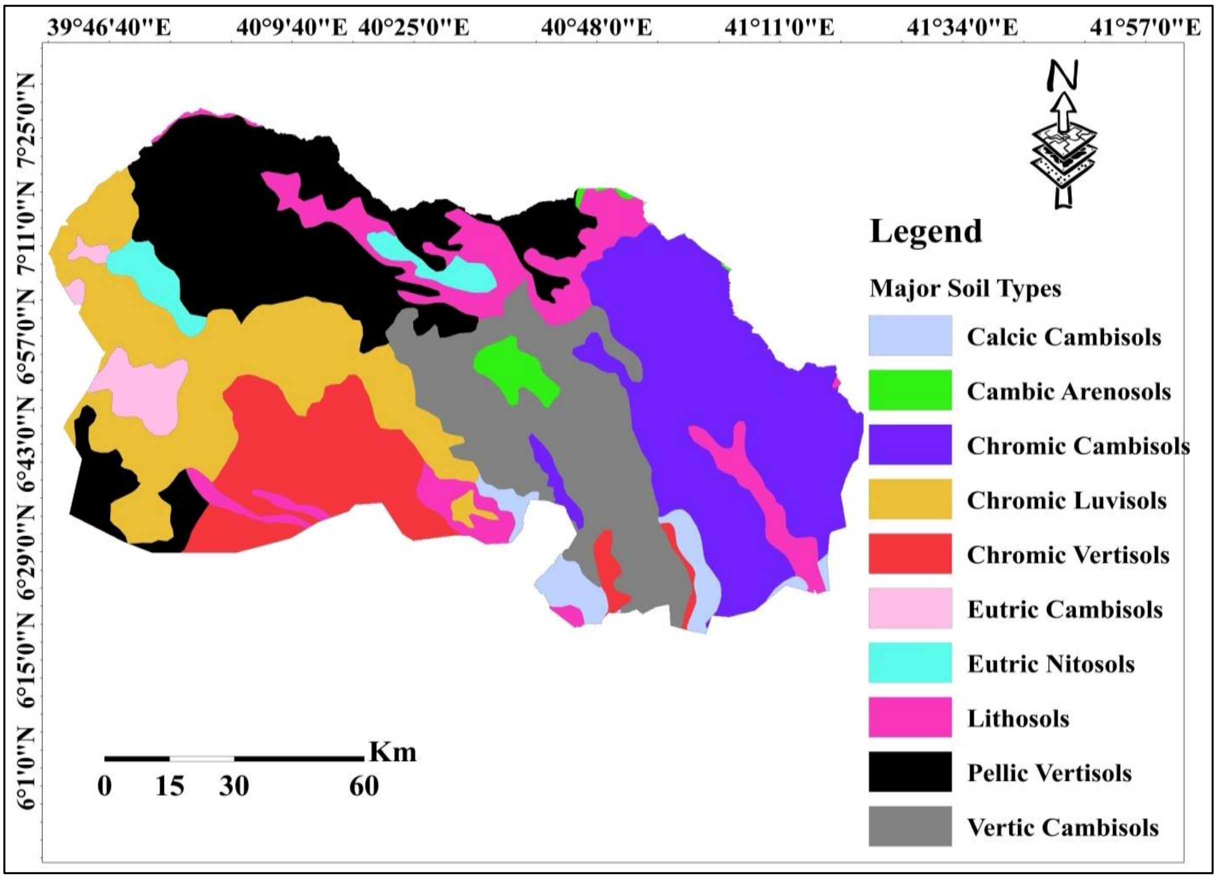

Figure 2. *Soil Type map of Bale Zone Genale Dawa sub-basin.*

2.5. Methods

Geospatial techniques and MCDA (AHP) were applied to create map of groundwater potential for the study area. This research work includes criteria identification, evaluation, preprocessing, reclassified, pairwise comparison of criteria, weight assigned, and ranking using the AHP process and ArcGIS 10.3 software were the main activities. Finally, groundwater potential zone maps for Bale Zone Genale-Dawa sub-basin were developed using weighted overlay Analysis in ArcGIS 10.3 software.

2.6. Data Collection and Description

This section describes the data sources, purpose, description, and data processing techniques used to establish the study area's groundwater potential zones. The required data were collected from various government agencies, field surveys, and satellite imagery published on the United States Geological Survey (USGS) Earth Explorer website. All data were resampled after acquisition and processing to a spatial resolution, row, and column sampled suitable for overlay analysis of groundwater potential maps and descriptions (Table 2).

Table 2. *Summary of data collected descriptions.*

Data collected	Sources	Resolution	Output layer
Rainfall	Metrological Agency of Ethiopia,	30 m	Rainfall Map
Soil data	FAO and laboratory analysis	30 m	Soil texture
Geological Map	Geological survey of Ethiopia	30 m	Geology map
DEM	http://igskmncngs506.cr.usgs.gov/gmtd	30 m	Drainage, slope
Landsat8	USGS	30 m	Lineament
Water inventory data	Regional and Zonal MoWIE	30 m	validation map

Data collected	Sources	Resolution	Output layer
Landsat8	USGS with path 166 having row 055, and 056, path 167 with row 055 and 056 and path 168 with row 055	30 m	LULC Map

2.7. Types of Software

Different software was used for data preprocessing, preparation, data analysis, editing, and final output of the zone where groundwater is possible. Generally, detailed descriptions of the software used and their purpose in the groundwater potential zones map were described (Table 3).

Table 3. Types and Purposes of software.

No.	Software used	Version	Description
1	ArcGIS	10.3	image preprocessing and thematic map generated
2	ERDAS	15	Image preprocessing, classification
3	IDRISI	17.02	weights Calculation
4	Google Earth		accuracy of the classification
5	PCI Geomatica	17	lineament generated
6	GPS		Ground data collection

2.8. Factorsidentification and Preparations for Groundwater Potential Map

2.8.1. Rainfall

The rainfall map was created using an annual average of 40 years (1981-2021) of historical rainfall data collected from 11 nearby weather stations, and the Ethiopia National Meteorological Agency (Figure 3). Precipitation data were spatially interpolated using the IDW interpolation method using ArcGIS 10.3 software to obtain rainfall distribution maps. Similarly, the IDW interpolation method has been adopted by several authors due to the uneven distribution of stations [69, 40, 93, 99, 77, 47]. Finally, the interpolated rainfall data were classified using this IDW interpolation technique and then divided into five classes, and weightings were assigned based on intensity and groundwater potential as the standard suggested by [47] (Table 4).

2.8.2. Geomorphology

The Bale Zone's Genale-dawa sub-basin geomorphological features was clipped from the geomorphology map of a geological survey of Ethiopia. Based on the views of groundwater potential, geomorphological classification, weight, and ratings were made according to the standard rate suggested by [52] (Table 4).

2.8.3. Land Use Land Cover

Landsat 8 downloaded from the United States Geological Survey (USGS) for the study area to create a LULC map, added to ERDAS 2015 software, processed for image preprocessing, and ArcGIS 10.3 software integration. According to [56], standard LULC was classified into five classes based on groundwater potential (Table 4).

2.8.4. Lithology

The lithology map was developed from a 1:2,000,000 geologic map published by an Ethiopian geologic survey. These maps were geo-referenced and clipped to the study area's shapefile. The shapefile for the lithological units inside the study area was sketched to create a vector layer, and the vector layer was converted to a raster layer of the same in ArcMap 10.3. According to the possibility for groundwater potential points of view lithological classication, weight assigned, and ranking were conducted as standard rate suggested by [86, 33, 1].

2.8.5. Soil Texture

Soil samples from 0 to 20 cm depth were collected using a stratified random sampling technique using Auger sampling points (Figure 4). Soil samples, were air-dried, grind using a mortar and pestle, and passed through a 2 mm mesh sieve. Soil texture analysis was performed at the Sinana Agricultural Research Center Soil Laboratory using the Bouyoucos hydrometer method [17]. Finally, soil texture classes were assigned using his USDA classification system of texture triangles [94]. The laboratory analysis results were further encoded, and IDW spatially interpolated using ArcGIS 10.3 software to obtain the soil texture map was conducted. Finally, the soil texture was reclassified into five classes [91, 52, 99] (Table 4).

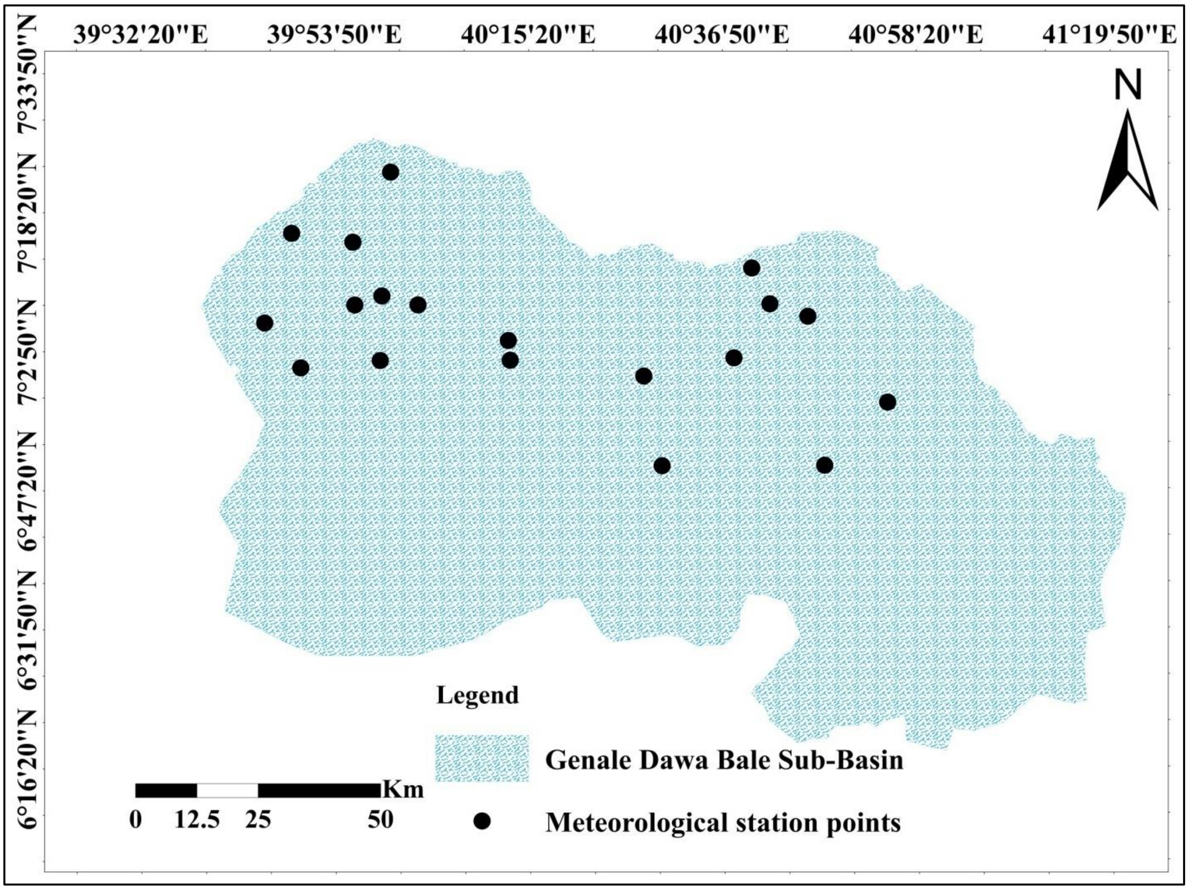

Figure 3. *Meterological sations points.*

2.8.6. Slope

Slope maps were developed from Shuttle Radar Topography Missions (SRTM) DEM 30m resolution downloaded from USGS using ArcGIS 10.3 software. As a result, the slope maps were rearranged into five classes according to his ranking of groundwater potential suitability. Then classified the slopes by degrees according to the standard set by [47] (Table 4). Therefore, the lower the slope, the higher the potential of groundwater and the lower the runoff, hence the higher rank.

2.8.7. Topographic Wetness Index

TWI (Topographic Wetness Index) was calculated from SRTM DEM 30 m spatial resolution using ArcGIS 10.3 software. Finally, classification, weight, and ratings were made according to the standard rate [1] as per suitability groundwater potential (Table 4). The lowest rank was assigned to low TWI values, and the highest rank to high TWI values, indicating a trend of soil moisture accumulation.

2.8.8. Elevation

Elevation was classified from Shuttle Radar Terrain Mission (SRTM) with a spatial resolution of 30 m using ArcGIS 10.3 software. Next, classification was conducted into five categories based on groundwater potential standards as stated rate by [60] (Table 4).

2.8.9. Drainage Density

The DEM was used to extract the study area's drainage density map at 30 m spatial resolution using a boundary shapefile after filling with ArcGIS 10.3 software. The resulting maps of drainage density were classified into five categories as suitable for groundwater potential according to standard rates given by [1] (Table 4). Drainage density (Dd), was calculated according to the following equation (1):

$$Dd = \frac{\sum_{i=1}^{n} Si}{A} \quad (1)$$

Where, $\sum_{i=1}^{n} Si$ represents the length of drainage and A represents the area of catchment

2.8.10. Lineament Density

Lineament densities were calculated using Landsat-8 using the Geomatica (Principal Component Imaging) (PCI) 17 software supporting ArcGIS 10.3 software. Similarly, the method and procedure for extracting lineaments from Landsat 8 OLI using ArcGIS software and PCI Geomatica 17 version integration have been adopted by several authors in previous studies [44, 8, 2, 81, 93, 40, 65, 39, 33, 47]. Finally, the lineament density maps were categorized into five categories as a basis for the groundwater potential given by [61] (Table 4). Therefore, low weights to low linear densities and high weights to high linear densities. Lineament density (LD), was calculated as follows (equation 2):

$$LD = \frac{\sum_{i=1}^{i=n} Li}{A} \quad (2)$$

Where, $\sum_{i=1}^{i=n} Li$ represents the length of lineament lines, and A represents the area of catchment.

Table 4. *A standard classification rate and ranks of factors determines groundwater potential.*

Factors	Class	Rate	Rank	Factors	Class	Rate	Rank
Rainfall (mm)	374.6 - 940.7	Very low	1	TWI	2.08 -7.47	Very low	1
	940.7–1090.8	low	2		7.47 – 9.36	low	2
	1090.8–1281	Moderate	3		9.36 – 11.82	Moderate	3
	281–1561.3	High	4		11.82 – 15.51	High	4
	1561.3 –2236	Very high	5		15.52 – 26.27	Very high	5
Geomorphology	Volcanic landform	Very low	1	Elevations (m)	670 - 1400	Very high	5
	Structural landform	Low	2		1400 - 1900	High	4
	Residual landform	Moderate	3		1900 - 2500	Moderate	3
	Alluvial landform	High	4		2500 - 3000	low	2
	Flat or flood plain	Very high	5		3000 - 4461	Very low	1
LULC	Others	Very low	1	Drainage density (km/km^2)	0 - 21	Very high	5
	Built up	Low	2		21 - 33	High	4
	Water body	Moderate	3		33 - 45	Moderate	3
	Agricultural area	High	4		45 - 58	low	2
	Forest	Very High	5		58 – 68.95	Very low	1
Lithology	Jurassic	Low	2	Lineament (km/km^2)	0 – 0.15	Very low	1
	Cretaceous	High	3		0.15 – 0.35	Low	2
	Tartary	Moderate	4		0.35 – 0.65	Moderate	3
	Quaternary	Very high	5		0.65 – 0.95	High	4
					0.95 – 1.81	Very high	5
Soil texture	Clay	Very low	1	Slope (degree)	0- 4.5	Very high	5
	Clay loam	Low	2		4.5 - 10.4	High	4
	Sandy clay loam	Moderate	3		10.4 – 17.9	Moderate	3
	Sandy loam	High	4		17.9 – 27.7	Low	2
	Sandy	Very High	5		27.7 – 79.21	Very low	1

2.9. Analytical Hierarchy Process

They were based on multi-criteria decision analysis (MCDA) using the Analysis Hierarchy Process (AHP), and the thematic layer maps were weighted. The GIS software for the groundwater potential zones map was integrated with an analytical hierarchical process (AHP). The various thematic layers selected include rainfall, geomorphology, LULC, lithology, soil texture, slope, elevation, topographic wetness index, drainage, and lineament density. The study used large-scale thematic layers that have a significant influence on the groundwater potential zones. The weighting of these factors were based on the literature review, expert opinion, and multi-discipline field survey local condition experience on groundwater resources. Comparisons was made utilizing the 1–9 scale, indicating how often one shift is more important than another. [80] Shows the scaling used in AHP (Table 5).

If the matrix formed is equal to bij, then aij = wi/wj, where w is the weight of each parameter, the element of all elements of each positive number i, j=1…. n and the reciprocal property bnij = i /bij, what is called the matrix inverse.

Table 5. *Saatty's, scale of intensity relative importance.*

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

The consistency index (CI), which defines the consistency coefficient of the pairwise comparison matrix, was estimated using (Equation 3).

$$CI = \frac{\lambda\max - n}{n-1} \quad (3)$$

Calculation of the consistency index relies on the λmax value using [80]. The weights of each factor were calculated by the pairwise comparison matrix and the maximum eigenvalue (λmax) of the normalized matrix was calculated (Equation 4).

$$\lambda\max = \frac{1}{n}\sum_{i}^{n} = 1 \left[\frac{\sum_{j=1}^{n} aijwj}{wi}\right] \quad (4)$$

A random consistency index (RI) served as a means of determining the degree of consistency, or a consistency ratio (CR) was calculated using (equation 5 and Table 6).

$$CR = \left(\frac{CI}{RI}\right) \quad (5)$$

Table 6. *Random consistency index.*

Matrix size	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.51

2.9.1. Weight Assigning and Normalization

Apply the AHP technique to normalize the weights assigned to different thematic layers. As shown in (Table 7), a value of 1 indicates equal importance for the two factors, and a value of 9 indicates that one factor is very important compared to the other. According to [80], the tolerance/value of CR should be less than 0.1.

2.9.2. Overlay Weighted Analysis

Map of the study area's groundwater potential zones were mapped using the weighted index overlay method in ArcGIS 10.3. Weight assignment was done by assigning new weight values to map sub-units (sub-criteria) calculated from the AHP. The reclassified tools in ArcGIS 10.3 Spatial Analyst tools were used for this task. Finally, a map of groundwater potential zones was created by overlaying all thematic layers using the weighted overlay analysis tool.

2.10. Validation of Groundwater Potential Map

To confirm probable groundwater zones, groundwater inventory data from the regional, district, and Bale zone water and energy sectors were also gathered in addition to field survey data. As a result, the groundwater potential zones of the Bale Zone Genale-Dawa sub-basin were validated in the current study using a total of 100 well yield data points (Table 7). The observed groundwater data were mapped using ArcGIS 10.3 software, and the analysis was overlaid on the map of the groundwater potential zone. In this case, a higher overlay analysis indicates that the produced map is considered more dependable. Model reliability and well-yield data are also true indicators of potential zone availability. Similarly, several authors [9, 15, 53, 63, 27, 82-84] used groundwater inventory data such as borehole data, wells, and hand digging yield to validate the developed groundwater potential zone.

Table 7. Groundwater (spring and well) yield classification by different authors.

References	Spring and well yield in (l/s) and its standard classifications				
	Very low	Low	Moderate	High	Very high
Tuinhof *et al*. (2011)	< 0.1l/s	0.1-0.5l/s	2-5 l/s	5-20l/s	>20l/s
[15]	-	0- 1 l/s	1-5 l/s	>5 l/s	-
[63]	-	<0.28 l/s	0.28 – 5.8 l/s	13.3 – 22.5 l/s	-
Sapkota *et al* (20201)	-	0.017 l/s	0.017 – 0.17 l/s	>0.17 l/s	-
Enideg (2012)	-	0.05-0.5l/s	2-5l/s	5-20l/s	-
Sogrea (2013).	-	0-3l/s	3-6l/s	6-20l/s	>20l/s

3. Result and Discussion

3.1. Groundwater Potential Mapping Criteria and Determining Factors

3.1.1. Rainfall

The mean rainfall map of the Bale zone of the Genale-Dawa sub-basin varies from 374.6 mm to 2236 mm and was classified into five classes based on the groundwater perspective: very low, low, moderate, high, and very high (Table 8) and Figure 4). Similarly, those with the highest rainfall were assigned the highest weights and had the highest groundwater potential, and vice versa. In this study, the highest area of about 501738.16 ha (33.22%) received rainfall varied from 1561.3 to 2236 mm, followed by an area of 289588.83 ha (19.17%) rainfall ranged from 1090.8 - 1281 mm, considered very high, and moderate from groundwater potential perspective views (Table 8). On the other hand, 233064.85 ha (15.43%) with rainfall range from 374.6 to 940.7 mm and 217454.12 ha (14.50%) with rainfall varies from 940.7 to 1090.8 mm were considered as very low and low, respectively, from groundwater potential the point of view (Table 8). Several studies confirmed that higher rainfall leads the higher groundwater potential and vice versa [52, 9, 24, 69, 5, 65, 99, 1].

Table 8. Rainfall class and its rank as per suitable for groundwater potential.

RF Class (mm)	Rates	Rank	Area (ha)	Area (%)
374.6 - 940.7	Very low	1	233064.85	15.43
940.7–1090.8	Low	2	217454.12	14.50
1090.8–1281	Moderate	3	289588.83	19.17
281–1561.3	High	4	268512.45	17.78
1561.3 –2236	Very high	5	501738.16	33.22

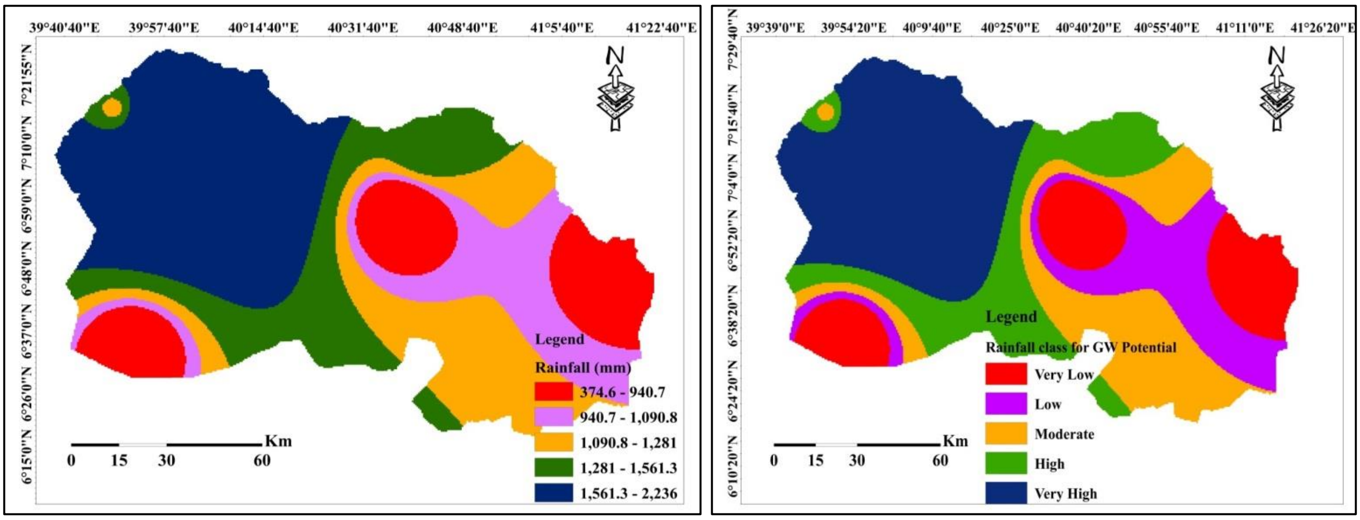

Figure 4. Rainfall map of Bale Zone Genale-Dawa sub-basin.

3.1.2. Geomorphology

The geomorphology map of the studied Bale Zone Genale-Dawa sub-basin consist of five classes (Table 9 and Figure 5). Accordingly, volcanic landform, structural landform, residual landform, alluvial landform, and flat/flood plain, and 509125.22 ha (33.71%), 20862.12 ha (1.38%), 523800.97 ha (34.68%), 3769.21 ha (0.25%), and 452666.57 ha (29.97%) area coverage, respectively (Table 9). Therefore, in terms of groundwater potential, alluvial landforms and flat/flood plain lands have high and very high, respectively, while volcanic landform and structural landform have very low and low, respectively (Table 9). Likewise [52] reported similar potential groundwater conditions in the geomorphological categories of volcanic landform, structural landform, residual landform, alluvial landform, and flat/flood plain. This means that geomorphology is an important part of the groundwater potential as it describes zones of porosity and permeability. Several studies have also included geomorphological features that reflect different landforms and structural features as important factors in determining groundwater potential [96, 52, 36, 11, 50, 44, 7, 8].

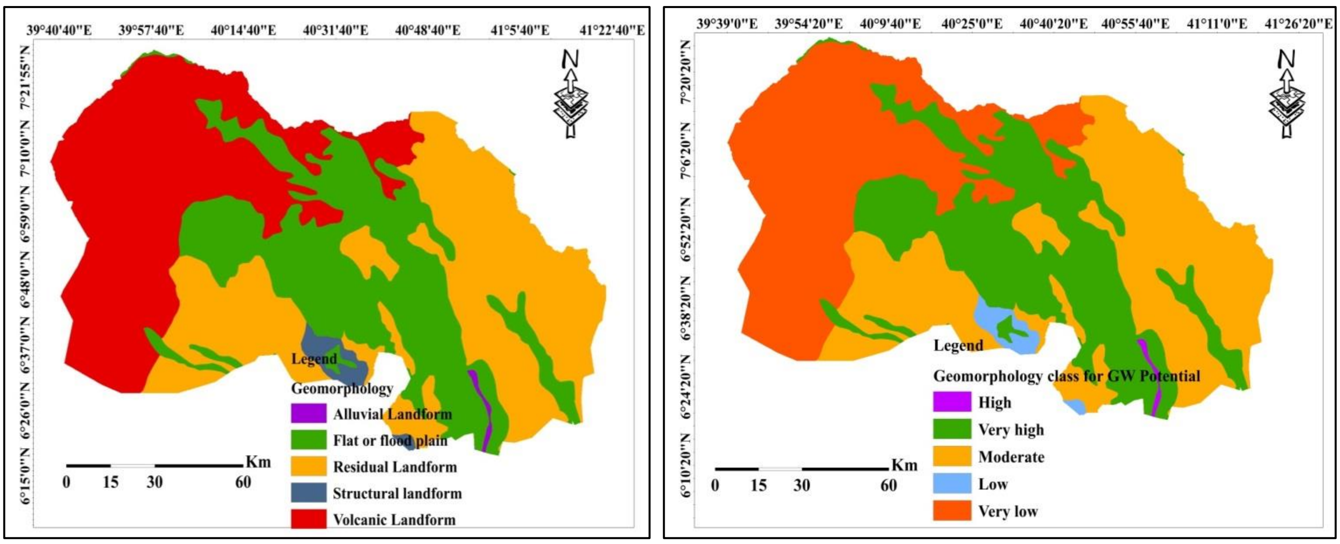

Figure 5. Geomorphology Typemap of Bale Zone Genale-Dawa sub-basin.

Table 9. Geomorphology Type and its rank as per suitable for groundwater potential.

Geomorphology Types	Rates	Rank	Area (ha)	Area (%)
Volcanic landform	Very low	1	509125.22	33.71
Structural landform	low	2	20862.12	1.38
Residual landform	Moderate	3	523800.97	34.68
Alluvial landform	High	4	3769.21	0.25
Flat or flood plain	Very high	5	452666.57	29.97

3.1.3. Land Use and Land Cover Classification

The results of the land use land cover (LULC) map shows that forest land 190081.42 ha (10.02%) is very high in groundwater potential, cultivated land 772202.57ha (40.72%) high whereas other land 860770.74ha (45.39%) low, and urban land 36090.42 ha (1.90%) very low in groundwater potential (Table 10 and Figure 6). In line with this finding [56] reported similar status groundwater potential under specific LULC categories. This implies that LULC significantly, controls many hydrogeological processes in the water cycle viz., infiltration, evapotranspiration, surface runoff, discharge, and recharge. LULC plays a significant role in influencing groundwater potential [44].

The highest weightage was given to forest land followed by cultivated land whereas the lowest was given to other land use types (Table 10). The land covered with forest land creates low surface runoff and, evapotranspiration, therefore considered as having very high groundwater potential and hence highest ranked. Several studies also used LULCfeatures as a significant factor to identify and delineate groundwater potential as it provides essential information on infiltration, soil moisture, and evapotranspiration [3, 19, 23, 73, 16, 40, 95, 81, 93]. In contrast, other land viz., built-up and bare land percolates less water, hence considered as very low and given the lowest rank (Table 10 and Figure 6). The LULC subjected to other lands like settlements, bare land, and build-up area increase surface runoff [78, 71, 39]. Thus LULC is the most crucial human stimulated influencing parameter that is responsible for the groundwater potential and recharge via runoff and infiltration [69, 20, 65, 99, 1].

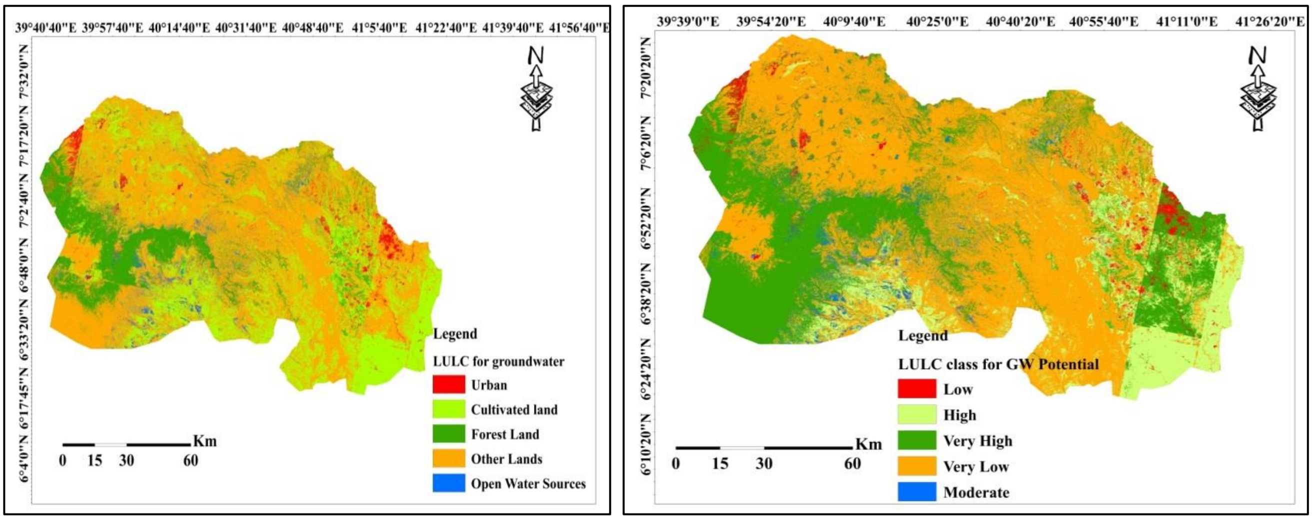

Figure 6. Land use land covermap of Bale Zone Genale-Dawa sub-basin.

Table 10. Land use land cover type and its rank as per suitable for groundwater potential.

LULC Types	Rates	Rank	Area (ha)	Area (%)
Urban	Very low	1	36090.42	1.90

LULC Types	Rates	Rank	Area (ha)	Area (%)
Others land	Low	2	860770.74	45.39
Open water sources	Moderate	3	37392.54	1.97
Cultivated land	High	4	772202.57	40.72
Forest Land	Very high	5	190081.42	10.02

3.1.4. Lithology

The results of the lithological map show that in this study, the Bale Zone Genale-Dawa sub-basin consists of four (4) lithological classes namely: Jurassic, Tartary, Cretaceous, and Quaternary were classified as low, moderate, high, and very high groundwater potential, respectively (Table 11 and Figure 7). In terms of area coverage, the Jurassic has the highest (37.15%), followed by the Quaternary (32.56%), but the Cretaceous has the lowest (2.25%) (Table 11). Similarly, with this study, [33] found that the Cretaceous consists of sandstone and often exhibits high infiltration and subsurface layers. Quaternary has a very high groundwater potential due to its high permeability, consisting of silt, sand, and gravel. Similarly, [86, 33, 1] reported that Quaternary lithology has a very high groundwater potential due to the contribution of highly permeable alluvium.

Jurassic consists of dolomites, limestones, sandstone, and multicolored clays lowest rank assigned due to their low groundwater potential [1]. Likewise, [86, 1] reported moderate groundwater potential for the Tartary lithology class. Several studies have confirmed that groundwater potential has been significantly affected due to local lithological characteristics [73, 16, 89, 95, 93, 99].

Table 11. *Lithological units and their ranks for suitability to groundwater potential.*

Lithological Codes	Age	Rates	Ranks	Area (ha)	Area (%)
Jg1	Jurassic	Low	2	102656.76	6.80
Jg2				315761.80	20.91
Jh				19555.05	1.29
Ju				123083.80	8.15
				458400.65	37.15
Ncb	Tartary	Moderate	4	83443.03	5.52
P2a				100233.97	6.64
PNab				135692.51	8.98
PNmb				104229.46	6.90
				423598.97	28.04
Kg1	Cretaceous	High	3	34005.71	2.25
Qb	Quaternary	Very high	5	89825.93	5.95
Qb1				135723.90	8.99
Qg				266214.39	17.63
				491764.22	32.56

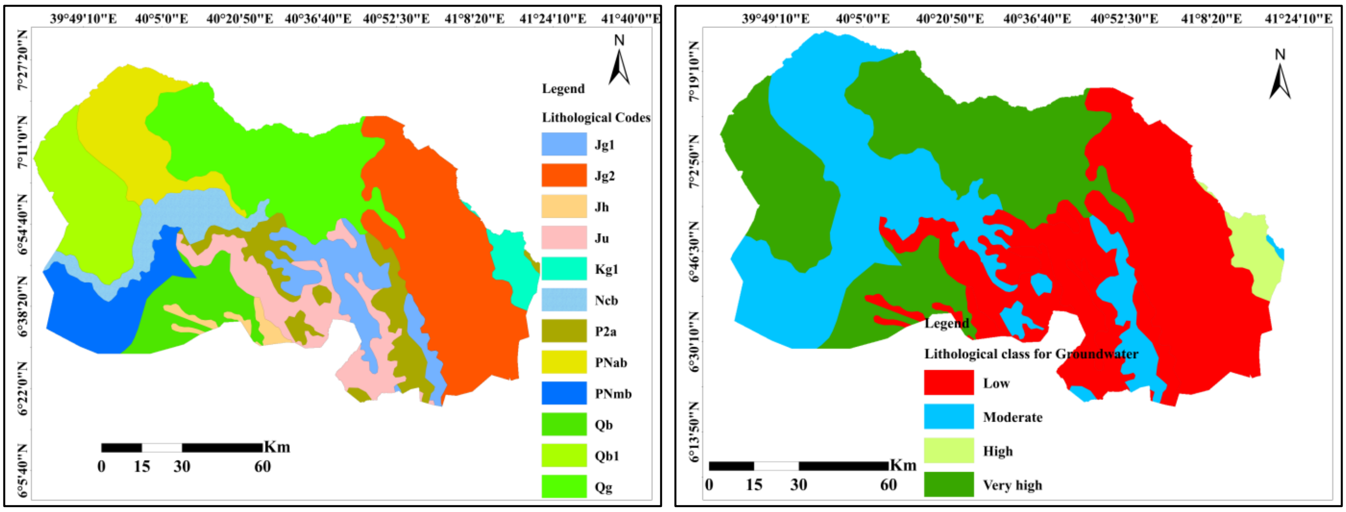

Figure 7. Lithological types map of Bale Zone Genale-Dawa sub-basin.

3.1.5. Soil Texture

Laboratory analysis and interpolation map results indicated that the soil texture of the Genale-Dawa Sub-Basin in the Bale Zone consisted of five classes. The area coverage of clay, clay loam, loam, sandy clay, and sandy clay loam is 199130.94 ha (13.18%), 331948.27 ha (21.98%), 509785.98 ha (33.75%), 430029.71 ha (28.47%), and 39627.90 ha (2.62%) (Table 12 and Figure 8). Overall, the main soil texture class in the stud area was loam followed by sandy clay loam, with the lowest sandy clay loam class shown in area coverage (Table 12 and Figure 8).

In terms of groundwater potential, clay and clay loam were classified as very low and low, while loam soils were moderate groundwater potential. The sand clay and sandy clay loam have very high and high groundwater potential, respectively (Table 12). This means clay contains fine-grained soils with small pore sizes, while coarse-grained soils such as sandy soil contain large pores with high permeability. Soils with smaller pore sizes have lower infiltration rates therefore, low groundwater potential. Similarly, the soil textures classification, assigned weights and ratings, and its suitability for groundwater potential have been given by [31, 91, 52, 99, 8].

Therefore, relatively sandy soils have high groundwater potential, while loam-textured soils with moderate porosity are categorized as moderate. On the other hand, soils belonging to the clay structure layer has relatively low groundwater potential due to low infiltration and high surface runoff. Soil texture determines groundwater potential to a large extent, as soil particle size distribution greatly affects groundwater potential of soil [18, 39, 8, 93]. Groundwater potential depends on soil properties such as structure and texture type, which can result in zones of higher groundwater potential in areas of sandy soil [79, 24].

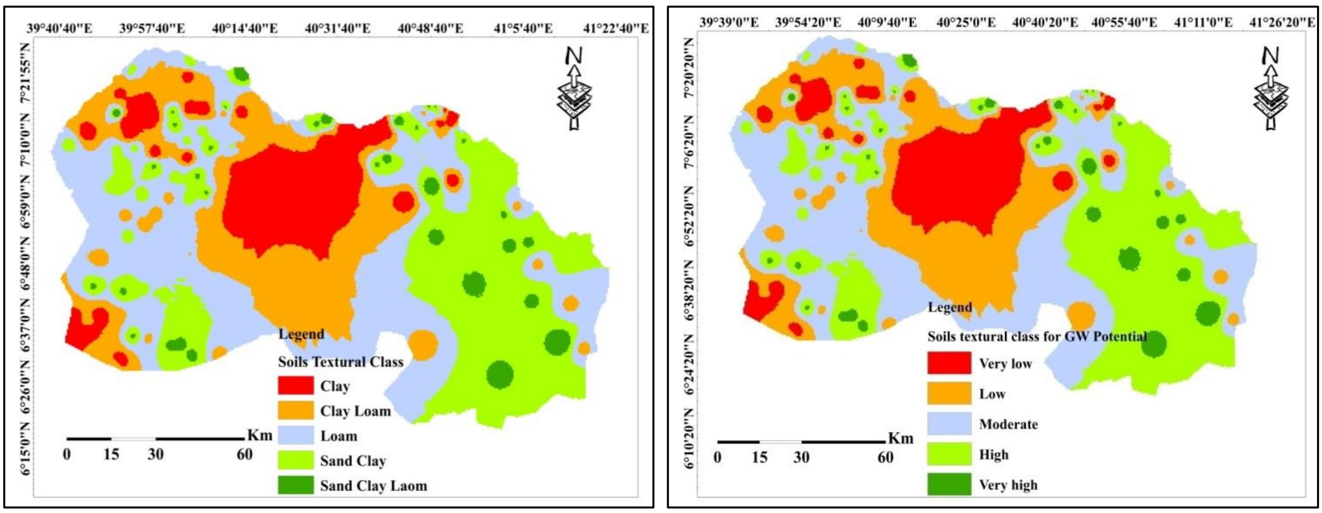

Figure 8. Soil Textural map of Bale Zone Genale-Dawa sub-basin.

Table 12. *Soil textural class and its rank as per suitable for groundwater potential.*

Textural Class	Rates	Rank	Area (ha)	Area (%)
Clay	Very low	1	199130.94	13.18
Clay loam	Low	2	331948.27	21.98
Loam	Moderate	3	509785.98	33.75
Sand clay	High	4	430029.71	28.47
Sand clay loam	Very high	5	39627.90	2.62

3.1.6. Slope

The slope of the Bale Zone Genale-Dawa sub-basin ranges from 0 to 79.21 degrees. According to the slope classification, slope class 0 - 4.50 covers an area of 841640.30 ha (55.74%), slope ranges from 4.5 - 10.40 covers an area of 360055.89 ha (23.84%), slope varies from 10.4-17.90 with an area of 175206.88 ha (11.60%), slope category was varied from 17.9 to 27.70, an area with area 92649.50 ha (6.14%), slope ranges from 27.7 to 79.210 degrees, covered area 40502.30 ha (2.68%) groundwater potential zones categorized as very high, high, moderate, low and very low (Table 13 and Figure 9). Similarly, [47] suggested that slope areas with gentle slopes (0 – 4.5°) were classified as zones with very high groundwater potential, while steep slopes (> 27.7°) zones with low groundwater potential. Thus, implies that gentle slopes have high infiltration so that high groundwater potential while low surface runoff and vice versa.

Slpoe was inversely correlated with infiltration, as much water was exposed to runoff [72, 7, 40]. The slope is directly proportional to the runoff rate [69]. Previous studies have shown that areas with high slopes have relatively low groundwater potential due to high runoff, while areas with gentle slopes have low water flow, which stimulates the recharge rate and increases groundwater potential [15, 8, 93, 46, 65, 48, 51]. It was shown that steep slopes have low groundwater potential zones, while gentle slopes are advantageous by retaining rainwater, so it is considered to be a zone with high groundwater potential.

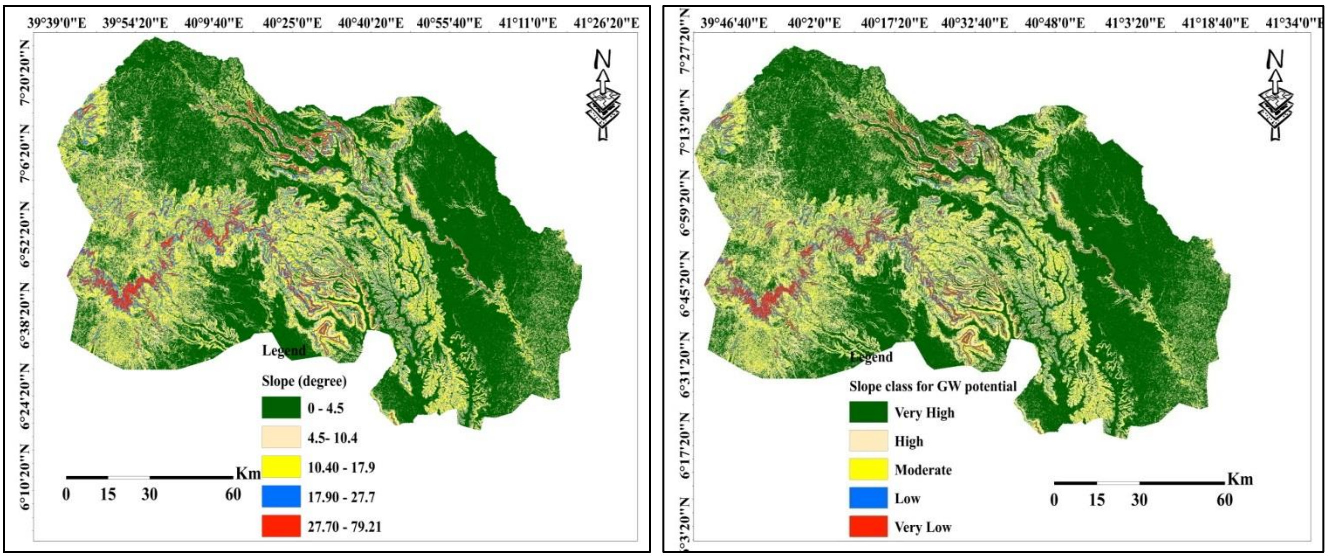

Figure 9. *Slope Class map of Bale Zone Genale-Dawa sub-basin.*

Table 13. *Slope classes and their ranks according to groundwater potential suitability.*

Slope Class	Rates	Rank	Area (ha)	Area (%)
0 - 4.5	Very high	5	841640.30	55.74

Slope Class	Rates	Rank	Area (ha)	Area (%)
4.5 - 10.4	High	4	360055.89	23.84
10.4 - 17.9	Moderate	3	175206.88	11.60
17.9 - 27.7	Low	2	92649.50	6.14
27.7 – 79.21	Very low	1	40502.30	2.68

3.1.7. Topographic Wetness Index

Topographic wetness index is also an important indicator of groundwater potential. Based on the topographic wetness index (TWI) calculated in the study, values varied between 2.08 and 26.27 (Table 14 and Figure 10). According to the TWI values, the Bale Zone Genale-Dawa sub-basin was classified into five classes; very low (2.08 – 7.47), low (7.47 – 9.36), and TWI class values (9, 36 – 11.82) was moderate class. In contrast, the TWI values varied between 11.82 to 15.51, and 15.1 to 26.37, classified into zones of high and very high potential for groundwater, respectively. This implies high and low values of TWI indicate that the lowest and the highest altitude zone, respectively due to strongly correlate with soil moisture and surface runoff.

In this study, a large area of 874482.26 ha (57.91%) was classified as very low class (2.08 - 7.47), and a small area of 21433.35 ha (1.42) was classified into the very high rate (15.1 – 26.37) (Table 14). Therefore, the lowest weight to low TWI values while the highest weight to high TWI values indicating a tendency to form zones of soil moisture accumulation (Table 14). Likewise, [1] adopted a similar approach to TWI classification to map groundwater potential zones. Several authors who have investigated relevant groundwater potential zone maps have confirmed that the higher the TWI value, the higher the groundwater potential [26, 64, 11, 58, 14, 71, 93, 81]. This confirmed that TWI values depended on soil depth, soil quality and groundwater depth.

Table 14. Topographic witness index and its rank according to groundwater potential suitability.

TWI Class	Rates	Rank	Area (ha)	Area (%)
2.08 - 7.47	Very low	1	874482.26	57.91
7.47 - 9.36	Low	2	352792.44	23.36
9.36 - 11.82	Moderate	3	153641.43	10.17
11.82 - 15.51	High	4	107710.71	7.13
15.1 - 26.37	Very high	5	21433.35	1.42

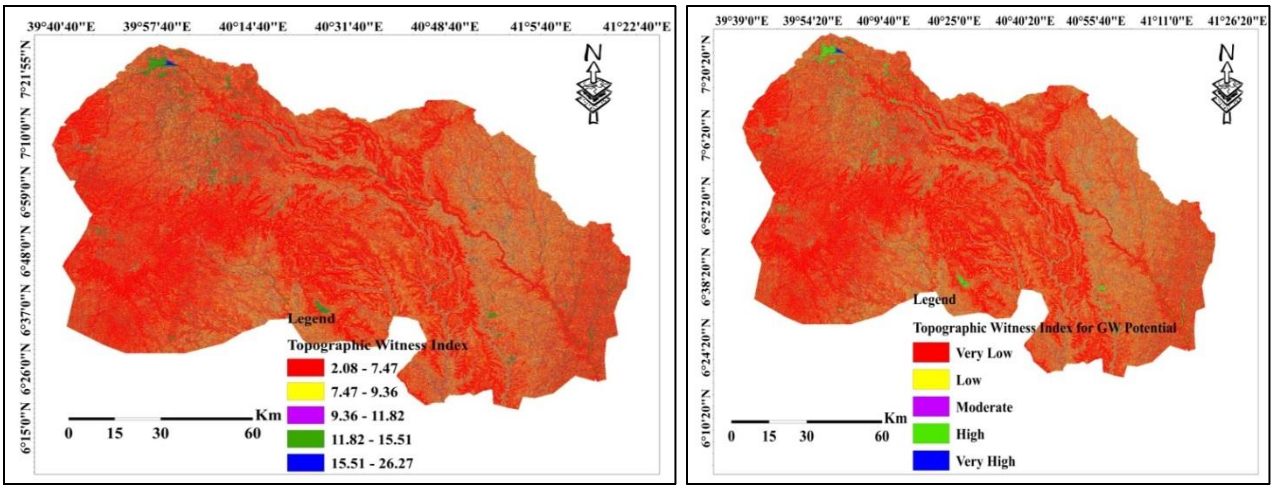

Figure 10. Topographic Witness index map of Bale Zone Genale-Dawa sub-basin.

3.1.8. Elevation

The elevation of the Bale Zone Genale-Dawa sub-basin ranges from 670 m to 4463 m, and according to the elevation classification, 670-1400, 1400-1900, 1900-2500, 2500-3000, and 3000-4463 classified as very high, high, moderate, low, and very low, respectively with an area 561682.90 ha (37.20%), 344831.94 ha (22.84), 332258.60 ha (22.00%), 134750.30 ha (8.92%), and 136529.59 ha (9.04%), respectively (Table 15 and Figure 11). Similarly, Mojtaba *et al* (2019) also used elevation as a determinant and adopted a similar range of classification for groundwater potential zone maps. In the lower Bale Zone Genale-Dawa sub-basin, the large area covered by the elevation class 561,682.90 ha (37.20%), ideally indicating a very high groundwater potential, but the minimum area 134750.30 ha (8.92%), and 136529.59 ha (9.04%) ideal low and very low groundwater potential, respectively (Table 15).

The high-elevation areas have relatively low groundwater potential and vice versa. This might be due to the gradual decrease in runoff at low elevations, more recharge time for rainwater, results in high groundwater potential, and vice versa. Previously studied by [56, 88, 39, 40, 1] confirmed that groundwater tends to high in a lower elevation than high altitude.

Table 15. *Elevation class and its rank as per suitable for groundwater potential.*

Elevation Class	Rates	Rank	Area (ha)	Area (%)
670 - 1400	Very high	5	561682.90	37.20
1400 - 1900	High	4	344831.94	22.84
1900- 2500	Moderate	3	332258.60	22.00
2500 - 3000	Low	2	134750.30	8.92
3000 - 4463	Very low	1	136529.59	9.04

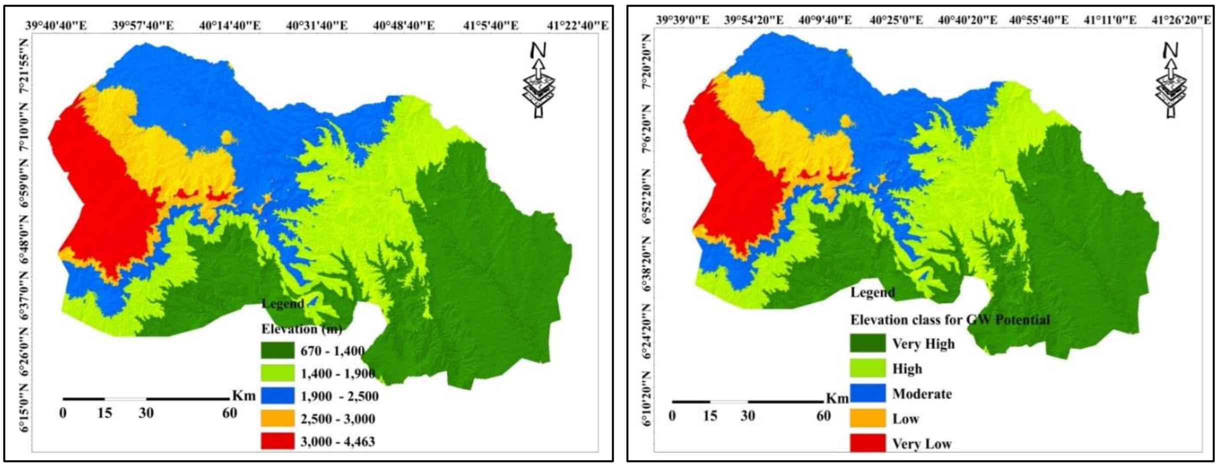

Figure 11. *Elevation class map of Bale Zone Genale-Dawa sub-basin.*

3.1.9. Drainage Density

Drainage densities (DD) varied between 14 and 68.85 km/km^2. Consequency, DD was classified into five categories based on their contribution to groundwater potential: very high (14 –21 km/km^2), high (21 - 33 km/km^2), moderate (33 – 45 km/km^2), and low (45 – 58 km /km^2), and very low (58 – 68.85 km/km^2) (Table 16 and Figure 12). Similarly, [1] stated high weights to an area of low drainage and low weight to the high drainage area. This is because of the higher drainage densities that favor runoff and lower groundwater potential, and vice versa. Likewise, other scholars [72-74, 43, 74, 89] reported that high drainage densities lead to relatively low groundwater potentials and vice versa.

Furthermore, this indicates that drainage density is a function of topography, precipitation, slope, LULC, geology, climatic conditions, and anthropogenic factors in the study area. Similarly, [55, 74, 99, 2, 44, 30, 47] reported that drainage density is a good indicator of groundwater potential zone.

Table 16. Drainage density class and its ranking according to groundwater potential suitability.

Drainage Density Class (km/km^2)	Rates	Rank	Area (ha)	Area (%)
0- 21	Very high	5	1561.05	0.10
21 – 33	High	4	42347.7	2.80
33 -45	Moderate	3	83267.55	5.51
45- 58	Low	2	1071437.85	70.96
58 -68.85	Very low	1	311249.07	20.61

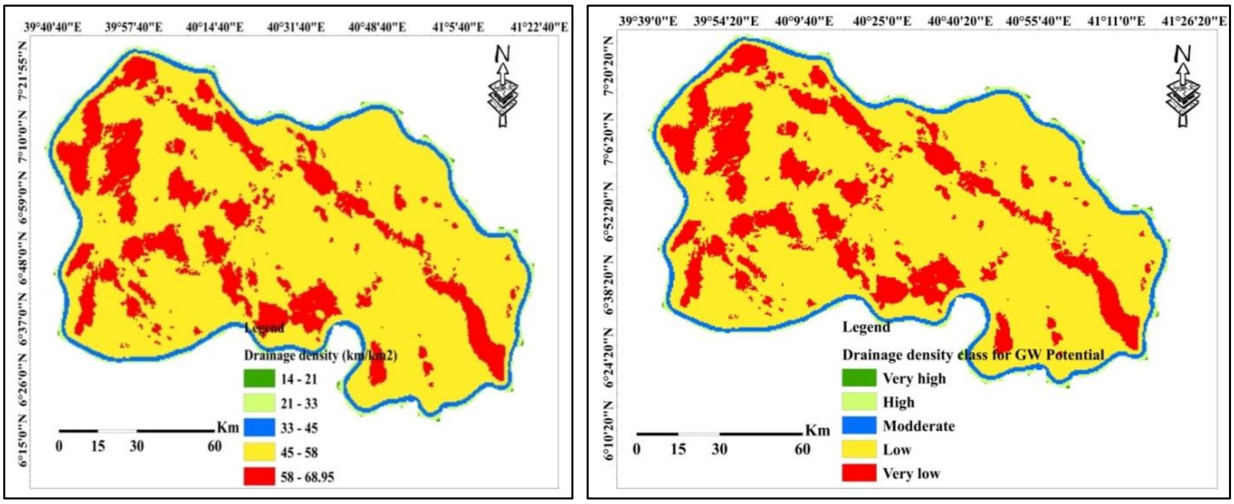

Figure 12. Drainage density class map of Bale Zone Genale-Dawa sub-basin.

3.1.10. Lineament Density

The lineament density of the Bale Zone Genale-Dawa sub-basin varied between 0 and 1.81 km/km^2 and was classified into five categories based on their contribution to groundwater potential namely, very low (0 - 0.15), low (0.15 - 0.35), moderate (0.35 - 0.65), high (0.65 - 0.95), and very high (0.95 - 1.81) with an area range of 385,452.07 ha (25.52%), 408,769.84 ha (27.06%), 375,241.06 ha (24.84%), 247,493.88 ha (16.39%), and 93474.93 ha (6.19%), respectively (Table 17 and Figure 13). The high lineament density indicates excessive secondary porosity, thus indicating an area of high groundwater potential. The areas with high lineament density facilitate infiltration and recharge consequently high groundwater potential zones. In turn, those with low lineament density have low groundwater potential. The higher lineament densities lead to higher recharges and higher groundwater potentials and vice versa. Lineament density is directly proportional to groundwater potential [64, 74, 69, 9, 89, 33, 1, 47]. Different studies confirmed that areas with high lineament density have ideally better groundwater potential zones due to their high permeability [52, 86, 76, 89, 8, 2, 93].

Table 17. Lineament Density class and its ranking according to groundwater potential suitability.

Lineament Density Class (km/km^2)	Rates	Rank	Area (ha)	Area (%)
0 - 0.15	Very low	1	385452.07	25.52
0.15 - 0.35	Low	2	408769.84	27.06
0.35 - 0.65	Moderate	3	375241.06	24.84
0.65 - 0.95	High	4	247493.88	16.39
0.95 - 1.81	Very high	5	93474.93	6.19

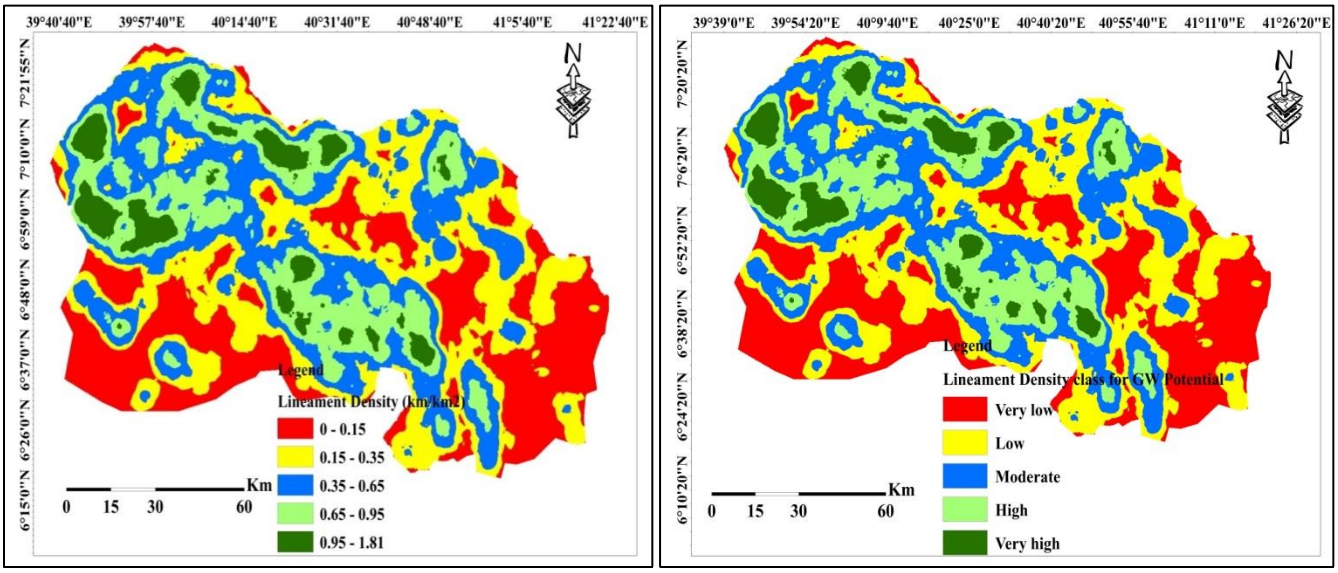

Figure 13. Lineament Density class map of Bale Zone Genale-Dawa sub-basin.

3.2. Analytic Hierarchical Process Assigned Weights for Thematic Maps

The map of groundwater potential for the Bale Zone Genale-Daw sub-basin was produced using Analytical Hierarchy Process (AHP). Similar to the present study, the AHP analysis integrated with GIS spatial techniques was adopted for the problem-solving framework, criteria weight, and groundwater potential map [75, 85].

3.2.1. Weight Assessment

In this study, ten (10) factors affecting groundwater potential namely, rainfall, geomorphology, land cover and use, geology, soil texture, slope, topographic wetness index, elevation, drainage and lineaments of density were identified, classified, and weight was assigned based on the knowledge of experts, field experiences and review of a previous study from literature review (Table 18).

Table 18. Relative weight assigned for selected ten groundwater thematic layers for AHP.

Parameters	RF	Gm	LULC	Glg	ST	SL	TWI	El	DD	LD
RF	1	2	4	3	4	4	3	4	4	3
Gm	1/2	1	4	2	2	4	4	5	3	3
LULC	1/4	¼	1	1	1	2	4	3	3	3
Glg	1/3	½	1	1	2	3	3	5	3	3
ST	1/4	½	1	1/2	1	2	2	2	1	2
SL	1/4	¼	½	1/3	1/2	1	2	2	1	2
TWI	1/3	¼	¼	1/3	1/2	1/2	1	1/2	3	2
EL	1/4	1/5	1/3	1/5	1/2	1/2	2	1	1/3	1/2
DD	1/4	1/3	1/3	1/3	1	1/3	1	3	1	1
LD	1/3	1/3	1/3	1/3	1/2	1/2	3	2	1	1
Total	3.75	5.62	12.75	9.03	13.00	17.83	25.00	27.50	20.33	18.83

Where, RF = Rainfall, Gm = Geomorphology, LULC = land cover and use, Glg = Geology ST= soil texture, SL= slope, TWI = topographic witness index, EL = elevation, DD = drainage density, LD= Lineament density

3.2.2. A Pairwise Comparison Matrix and Normalized Weights

The AHP model has been used to compute a pairwise comparison matrix of normalized weights for the groundwater potential's thematic layer. The normalized weight findings for every parameter have been reported in Table 19. The parameter with the highest weight represents the parameter with the most influence, and the parameter with the lowest weight represents the parameter with the least influenced over the others.

The results show that the highest rainfall value (24.2%), TWI, and elevation are equally weighted, with the lowest value (3.8%). The results show that the factors affecting groundwater potential follow the order rainfall (24%) > geomorphology (18.7%) > lithology (13) > LULC (10.7%) > soil texture (7.9%) > slope (6.9%) > Lineament density (5.7%) > drainage density (5.4%) > topographic witness, and elevation (3.8%), both of which are equally important (Table 19). Normalized principal eigenvector values (λmax) were calculated to check the weight assigned to each parameter. As the computation shows that 10.898, 0.0998, and 0.066 for the normalized principal eigenvectors (λmax), consistency Index (CI), and consistency ratio (CR) (Table 19).

In this study, the calculated CR was 0.066 < 0.1 therefore, the pairwise comparison matrix of the models is considered consistent, reasonable, and acceptable for further analysis and the estimated weights given in Table 19. This result is consistent with the finding by [80, 57] that the consistency ratio (CR) is < 0.1. In line with this study, valid CR was 0.06 and 0.0617 in the geospatial analysis of the identification and mapping of groundwater potential zones considering the matrix is consistent and acceptable was calculated and reported by [90, 21]; respectively. Similarly, several studies by [70, 14, 29, 92] calculated and obtained CR values of 0.07, 0.09, 0.069, and 0.076, respectively, reported as the reasonable, acceptable and valid level of consistency in the pairwise comparison matrix for mapping groundwater potential.

Table 19. *Pairwise comparison matrix and normalized weights.*

Factors	RF	Gm	LULC	lith	ST	SL	TWI	EL	DD	LD	Eigen-values (weights)	Weight (%)	Consistancy
RF	0.267	0.356	0.314	0.332	0.308	0.224	0.120	0.145	0.197	0.159	0.242	24.2	0.908
Gm	0.133	0.178	0.314	0.221	0.154	0.224	0.160	0.182	0.148	0.159	0.187	18.7	1.052
LULC	0.067	0.045	0.078	0.111	0.077	0.112	0.160	0.109	0.148	0.159	0.107	10.7	1.358
Lith	0.089	0.089	0.078	0.111	0.154	0.168	0.120	0.182	0.148	0.159	0.13	13	1.172
ST	0.067	0.089	0.078	0.055	0.077	0.112	0.080	0.073	0.049	0.106	0.079	7.9	1.023
SL	0.067	0.045	0.039	0.037	0.038	0.056	0.080	0.073	0.148	0.106	0.069	6.9	1.227
TWI	0.089	0.045	0.020	0.037	0.038	0.028	0.040	0.018	0.049	0.018	0.038	3.8	0.954
EL	0.067	0.036	0.026	0.022	0.038	0.028	0.080	0.036	0.016	0.027	0.038	3.8	1.035
DD	0.067	0.059	0.026	0.037	0.077	0.019	0.040	0.109	0.049	0.053	0.054	5.4	1.090
LD	0.089	0.059	0.026	0.037	0.038	0.028	0.120	0.073	0.049	0.053	0.057	5.7	1.079
Total	1	1	1	1	1	1	1	1	1	1	1	100	

Where, RF = Rainfall, Gm = Geomorphology, LULC = land use land cover, lith = lithology ST= soil texture, SL= slope, TWI = topographic witness index, EL = elevation, DD = drainage density, LD= Lineament density
Principal Eigen vector (λmax) = 10.898
Consistency index (CI) = 0.0998
Consistency ratio (CR) = 0.066
Random consistency index (RI) = 1.51

3.3. Groundwater Potential Zones Map

The Bale Zone Genale-Dawa sub-basin groundwater potential zones map has developed through a weighted overlay process of ten (10) different thematic layers: rainfall, geomorphology, LULC, lithology, soil texture, slope, topographic wetness index, drainage density, elevation, and lineaments density. Consequently, the study area was classified into five categories based on the mapped groundwater potential: very low, low, moderate, high, and very high, with area coverage of 249151.07 ha (16.58%), 366001.80 ha (24.36%), 271817.69 ha (18.09%), 278347.13 ha (18.53%), and 337194.06 ha (22.44 ha), respectively (Table 20 and Figure 14). Zones of very low (16.58%), and low (24.36%) groundwater potential zone are mainly located in the middle, lower, and partially at the upper part with impermeable lithology, steep slope, low rainfall, low TWI value, low lineament density, fine-grained soil texture, bare land, undifferentiated aquifer material, volcanic, and structural geomorphology (Table 20 and Figure 14).

The moderate (18.09%) groundwater potential zone extends from the upper to lower of Bale Zone Genale-Dawa sub-basin in areas where groundwater potential influencing factors are intermediate class or optimal coverage (Table 20 and Figure 14). On the other hand, the high (18.53%) and very high (22.44 ha) groundwater potential zones in Bale Zone Genale-Dawa sub-basin might be due to the area's high rainfall, high TWI value, high lineament density, gentle slope, coarse-grained soil texture, good forest coverage, most permeable lithology, Alluvial and flat/flood plain geomorphology (Table 20 and Figure 14). There are several studies along this line [9, 58, 15, 27, 53, 63, 5, 82] who confirmed the significant impact of parameters such as rainfall, soil texture, slope, LULC, geology, drainage, and lineament density on groundwater potential zones.

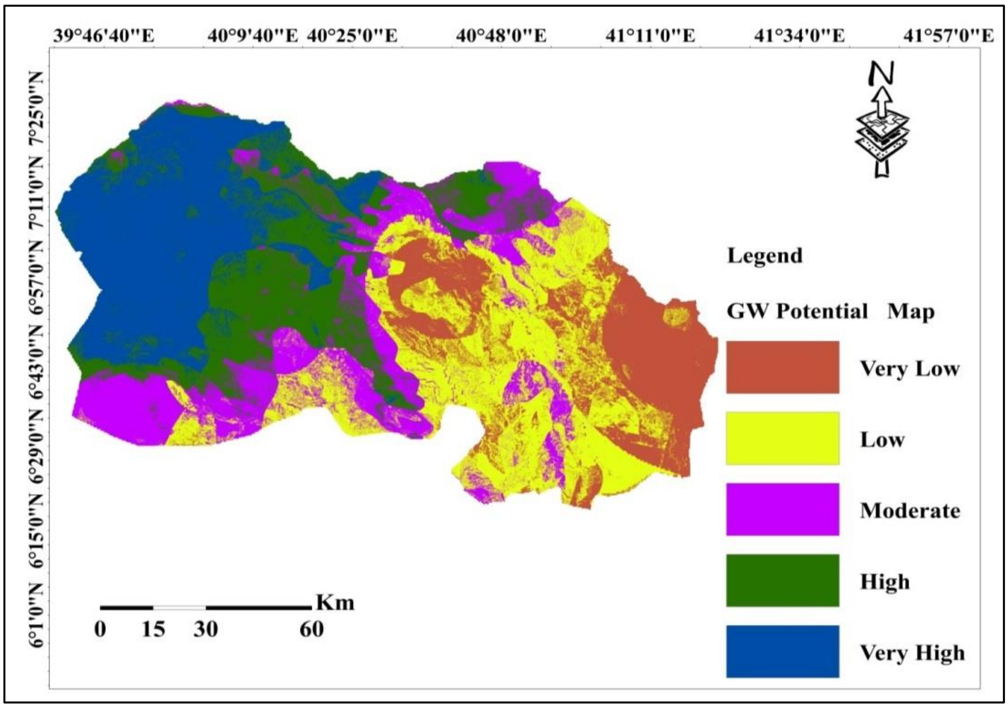

Figure 14. *The Bale Zone Genale-Dawa sub-basin groundwater potential Map.*

Table 20. *Groundwater class and area coverage.*

Groundwater Potential Class	Area (ha)	Area (%)
Very low	249151.07	16.58
Low	366001.80	24.36
Moderate	271817.69	18.09
High	278347.13	18.53
Very High	337194.06	22.44

3.4. Groundwater Potential Zone Validation

A total of 100 groundwater inventory data from five groundwater potential zones each: very low, low, moderate, high, and very high groundwater potentials were used to confirm the validation. Overall, according to the groundwater potential map by overlaying the well yield data and the final groundwater potential zone map, 18 (90%), 19 (95%), 17 (85%), 18 (90%), and 19 (95%) were very low, low, moderate, high, and very high in groundwater potential zones, respectively (Table 21 and Figure 15).

The prediction accuracy achieved showed that the mapped groundwater potential zones matched 91% of the groundwater inventory data (spring and well yield) data, which was a reliable and accurate result (Table 21). This implies that the developed groundwater potential zones map using integrated geospatial techniques (GIS and RS) and an analytical hierarchical process for the Bale Zone Genale-Dawa sub-basin more consistent and acceptable for multi-purpose uses. Likewise, several authors [58, 9, 7, 15, 53, 63, 27, 82-84, 89, 10, 38] used groundwater inventory data to validate, confirm their correlation and reliability for groundwater potential map developed using integrated geospatial techniques, and the analytical hierarchy process.

Furthermore, the results validated with groundwater inventory data revealed that the mapped groundwater potential zones are accurate and acceptable to serve as a credible source of information that supports decision-makers, planning, and formulating sustainable management.

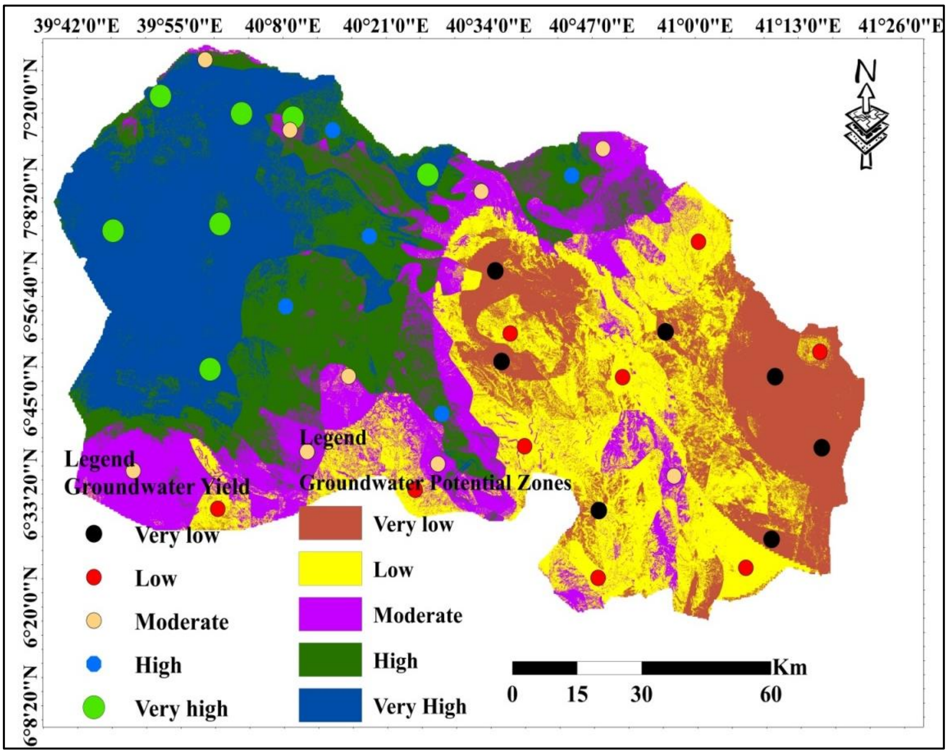

Figure 15. *Groundwater potential zones validation map of Bale Zone Genale-Dawa sub-basin.*

Table 21. *Validation of Bale Zone Genale-Dawa Sub-Basin map of groundwater potential zones.*

GWPZ rate	Well yield (l/s)	No. Well yield	No. Well yield	Validated (%)
Very low	< 0.1	20	18	90.00
Low	0.1 – 0.5	20	19	95.00
Moderate	2 - 5	20	17	85.00
High	5 - 20	20	18	90.00
Very High	>20	20	19	95.00
Total/Overall percentage		100	91	91.00

Where, GWPZ = groundwater potential zones.

4. Conclusion and Recommendation

The map of groundwater potential zones was developed using ten (10) various multi-influencing factors like rainfall, geomorphology, land use land cover, lithology, soil texture, slope, elevation, topographic wetness index, drainage, and lineament density. Since not all of these factors have the same influence on the groundwater potential the criteria weighted and ranking was applied. Consequently, rainfall

(24.2%), geomorphology (18.7%), land use land cover (10.7%), lithology (13%), soil texture (7.9%), slope (6.9%), topographic wetness index (3.8%), elevation (3.8%), drainage density (5.4%), and lineament density (5.7%). The groundwater potential in the study area was categorized into five zones: very low, low, moderate, high, and very high groundwater potential, 249,151.07 ha (16.58%), 366,001.80 ha (24.36%), 271,817 ha (18.09%), 278,343.13 ha (18.53%), and 337,194.06 ha (22.44%) of the research area, respectively. The acceptable results (91%) were obtained by correlating groundwater inventory data with the study area's developed groundwater potential zones map.

The obtained groundwater potential map with other thematic factor maps results can serve as a preliminary reference for the development of sustainable management, effective groundwater use planning to ensure long-term sustainability, decision-makers, further research study, and appropriate site selection to drill new holes. In this study, integrated geospatial techniques supported with multi-criteria decision analysis (MCDA - AHP) are powerful tools, efficient, time-saving, and cost-effective tools for mapping groundwater potential zones. The artificial groundwater recharge systems and in-situ soil and water conservation measures should be needed to enhance areas of zones with a low for groundwater. The groundwater potential zones and other determinant factors maps serve as a baseline information database that is updated over time by adding new information. Further studies on detailed hydrogeochemistry, geophysical investigation studies, and potential well drilling sites should be recommended.

Abbreviations

AHP	Analyitical Heriarical Process
GIS	Geogrphical Information System
MCDA	Multi Cerateria Decision Analysis

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Availability of Data and Material

The datasets generated and used to support the findings of this study are available from the corresponding author upon reasonable request.

Ethics Approval

The authors of this research followed the appropriate scientific research ethics and declared to follow the publishing ethic.

Informed Consent

Consent to participate: Not applicable in this research. Consent for publication: Not applicable in this research.

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Conflicts of Interest

The authors declare no conflicts of interest.

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