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Research Article

Assessment of Groundwater Potential Zones of Upper Blue Nile River Basin Using Multi-Influencing Factors under GIS and RS Environment: A Case Study on Guder Watersheds, Abay Basin, Oromia Region, Ethiopia

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Groundwater is the most crucial resource for human beings and plays an important role in combating climate change and is substantial to human existence on the globe. Overall increased demand for water in different sectors, population growth, and unreliable rainfall necessitates the planning and management of groundwater. In this study, groundwater potential zones are delineated by combining remote sensing and geographical information system techniques in the Guder watersheds of the Upper Blue Nile Basin. Groundwater potential zones are prepared by using various multi-influencing factors like geomorphology, land use/cover, lithology, soil type, soil texture, drainage density, slope, lineament, rainfall, and elevation. These influencing factors' features were given appropriate weightage according to Saaty's AHP method, expert judgment, and their relative significance for groundwater occurrence. The groundwater potential zone was classified into different categories as very poor, poor, moderate, good, and very good according to quantile classification. This study reveals that about 33.6% of the Guder River Basin represents a good andvery good GWPZ category with an equal value of 16.8%,; while values 23.3%, 20.2%, and 22.9% were denoted by very poor, poor, and moderate groundwater potential zone, respectively. GWPZ was validated by field-collected data such as well discharge and soil depth. An accepted similarity was observed between delineated GWPZ and the basin's soil depth graphically. The results of this study were also verified by correlation and kappa statistics values of 0.73and 77%, respectively. The study is certain with a sensible dimension of consistency in pairwise comparison between influencing and the overall weightage. The very high GWPZs are found in the northern part starting from the center longitude of the study area, more along with the northwestern, southern, and southwestern of the Guder subbasin. Low to very low groundwater potentiality has been seen at different distances from the center due to the presence of escapements, hills and steep side slopes, slopes, and rock surfaces. The study also revealed that the zone of high groundwater potential has high soil depth, and the zone of low groundwater showed low soil depth as the capacity of the aquifer to store water may depend on the depth of soil profile. This study attests to the GIS and remote sensing techniques as an effective model for delineation of GWPZs and can be applied at other basins of Ethiopia.

1. Introduction

Water is one of the most essential commodities for mankind [1–3] and the largest available source of freshwater lays underground [1]. And groundwater/subsurface water is a precious natural resource; its investigation, exploration, and proper management of this expensive resource play an essential role in determining suitable locations of groundwater recharge, water supply, groundwater quality, and monitoring wells [4–6]. GIS and remote sensing techniques enable cost-effective, time-saving, and quick assessment of groundwater resources, otherwise using traditional methods which is very costly, laborious, and time-wasting work [7–9]. Guder watersheds have been found under severe to very severe erosion [10], as a high runoff factor controls the ground water resources potentiality [11].

Many physical factors, climate factors, and hydrogeological factors alike geological/lithological structures, geomorphological landforms, slope angle or steepness, soil porosity, land use/land cover, drainage density/drainage pattern, rainfall (amount, intensity, spatial and temporal distribution), lineament density, soil physical property (type, texture, depth), elevation, and other physioclimatic conditions affect the occurrence of subsurface or groundwater which can support for proper location of groundwater potential zones (GWPZs) [4, 12, 13]. Improper use and ineffective water resources management cause adverse effects such as water pollution and land degradation, diminishing of water levels, saline water intrusion, and other hydrogeological and environmental difficulties [14–16].

Even though it is an important and dependable source of water supplies in all climatic regions including both urban and rural areas of the developed and developing countries [11], this valuable resource is largely unexploited for agricultural development in the study area. Instead of Guder subbasin receiving a medium annual rainfall (812 mm to 1699 mm), there has been limited agricultural production, and shortage of drinking water has been a common problem. There is a production and productive loss of crops in the area due to land degradation [17].

In Ethiopia, rainfall is erratic, its time is unpredictable, and about 95% of crop production is under smallholder rainfed practice which is put into effect during the long rainy season, i.e., (April-September) [18]. The livelihood of the population depends on agriculture. The spatial and temporal variations and distributions of climate and water and population growth dramatically in this country [19–21]; so, to be self-sufficient in food production and other water demands, sustainable use and management of groundwater resource is crucial to feed future generations [22–26]. Corresponding to the worldwide increased demand of freshwater in various sectors like industrial, domestic, and agriculture, calls for investigation of the groundwater potential zones (GWPZs) [4, 26–30].

In current period, remote sensing (RS) and geospatial techniques have been playing a vital role in the study of groundwater hydrology, although previously, with the aid of traditional methods like drilling, were used to identify groundwater potential. The application of geographical information systems in groundwater assessing, monitoring, and management such as delineation of groundwater potential zones has been reported by many scholars [3, 4, 11, 31–42]. Several researchers in current days perform several advanced methodological approaches for groundwater potential investigation, amongst which frequency ratio [43–61], logistic regression [50–56], fuzzy logic [22–24, 57–64], Dempster-Shafer model [22–24, 57–64], weights of evidence model [65–73], artificial neural network [74–81], maximum entropy model [82–85], and decision tree model [86–88] have been successfully implemented.

Guder River Basin, which is located in the western zone of the Oromia region, is found in the Upper Blue Nile Basin. It is one of the less-studied subbasins of the Abay Basin of Ethiopia [10, 89, 90], and groundwater potential zone investigation using GIS and remote sensing techniques is applied for the first time. The source area of the river is marked by an orographic rain landscape with high relief. Guder River is one of the main perennial tributaries of the Abay basin, Ethiopia.

The primary aim of this study is to apply GIS and RS techniques to prepare a groundwater zonation map of Guder subbasin of the Upper Blue Nile River Basin of Oromia Region Woredas (districts) found in this watershed using multi-influencing factors. Assessing and evaluating the groundwater potential zone must be crucial for the government, policymakers and decision-makers in identifying appropriate sites and positions for borehole construction for water use purposes and sustainable groundwater management. The delineated map may use to evaluate the geospatial factors governing the accumulation of groundwater, the relationship between Geomorphology, Geology/lithology, land use, drainage density, lineaments, soil, terrain, rainfall, and groundwater potentiality. Such kind of study has not been reported in this subbasin so far; so, this study should demonstrate a very appropriate technique for rapid assessment of groundwater potential zones. The accuracy assessment like correlation coefficient and kappa statistics gave outstanding results. The method is also an efficient and economical approach to groundwater potential zone investigation. Nevertheless, most of the scholars avoid the validation part, due to the absence of field data, and the study was established with more scientific meaning by validation. Therefore, regions of high, medium, low, etc. are marked on the map to give awareness for water users and policymakers for sustainable use and management of groundwater resources. The study would also provide information for the stakeholders and kebele administration office, Woreda, and the society to understand the areas with high and low groundwater for ease management of these precious resources. The outcome of the study would help management strategies to protect, exploit, and utilize available groundwater for water supply and agricultural production purposes.

2. Materials and Methods

2.1. Description of the Study Area. This watershed is geographically found in 8°40′00″ to 9°52′00″N latitude and 37°15′00″ to 38°10′00″E longitude (Figure 1) and has its outlet to the Abbay River [91]. The Guder Basin borders with the Muger Basin to the east, the Awash Basin to the south, and the Fincha River Basin to the west. Tributaries of the Guder include Dabis and Tarantar. The Guder has a drainage area of about 6725 square kilometers in size [17, 92, 93]. The climate of the study area is classified as unimodal characteristics with one rainy and one dry season. The rainy season extends from May to October and the dry season from November to April. The high concentration of rainfall occurs in July and August [93, 94]. The mean annual

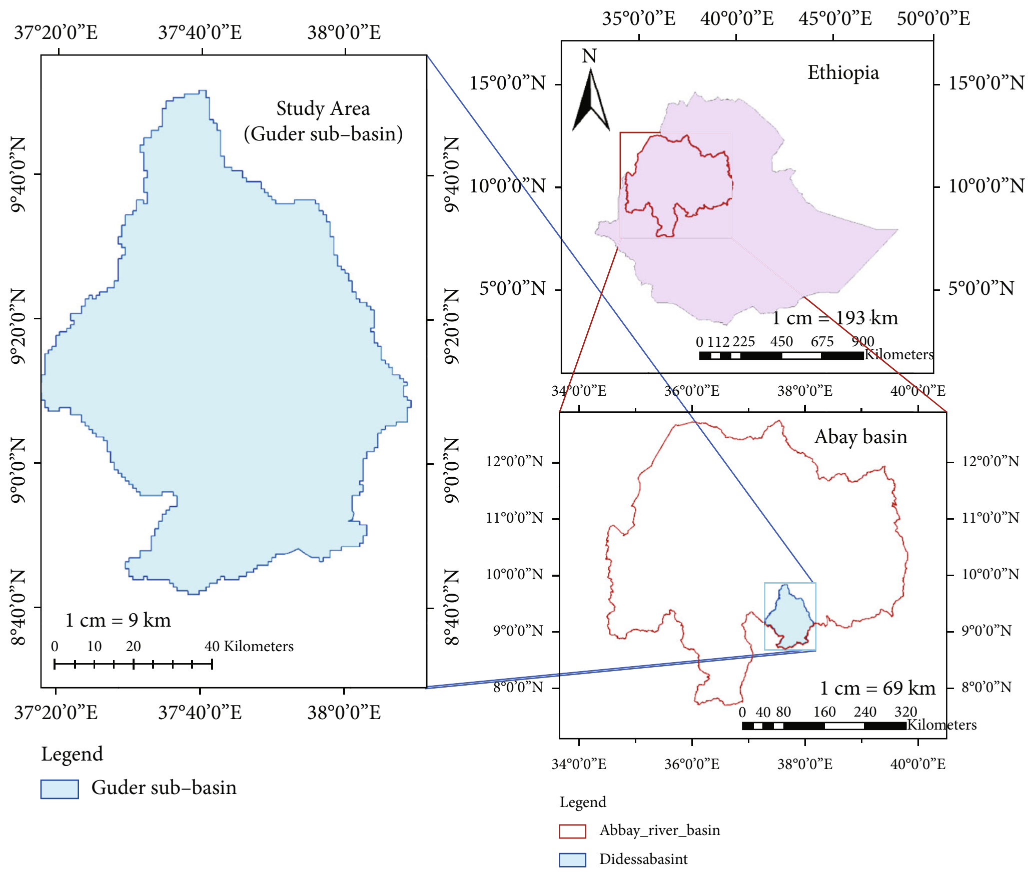


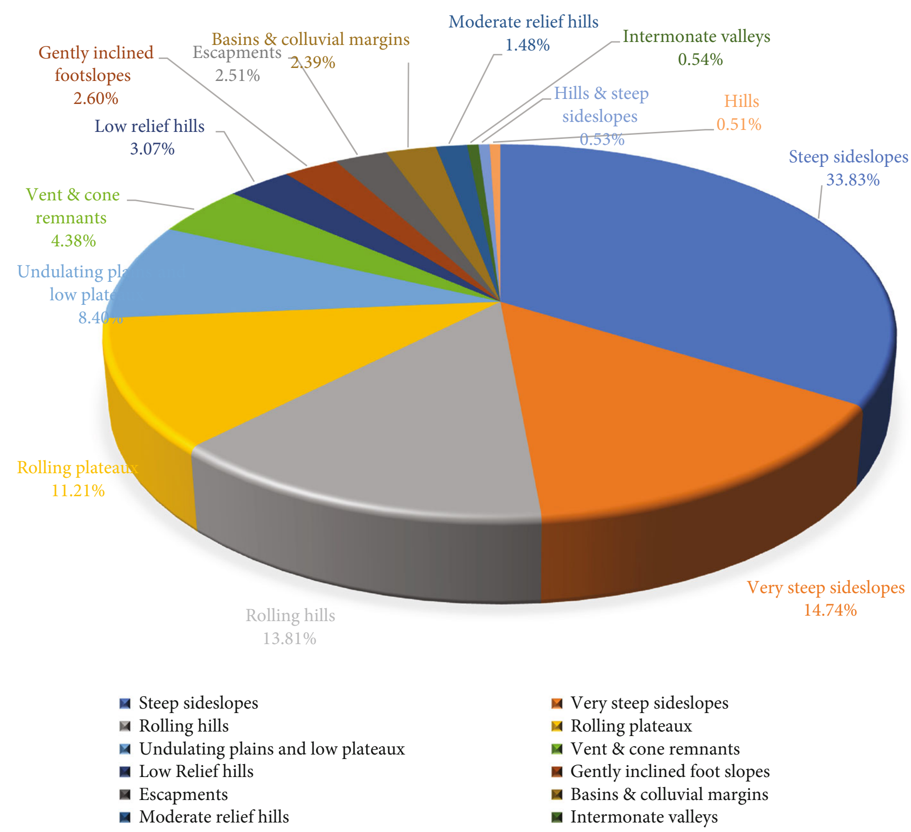
Figure 1: Geographical location of the study area.

temperature of the Guder watershed ranges between 6.5°C and 30°C. Some of the major tributaries of the Guder catchment include the upper side of the watershed which collects surface runoff from Huluka, Bello, Fetto, Melke, and Indies in the middle part of the watershed which collects surface runoff from Dabis and in the dawn stream part Gudar xiqqaa (smaller Guder) and Gudar Guddaa (the bigger Guder) that contributes the main Guder River [92–94].

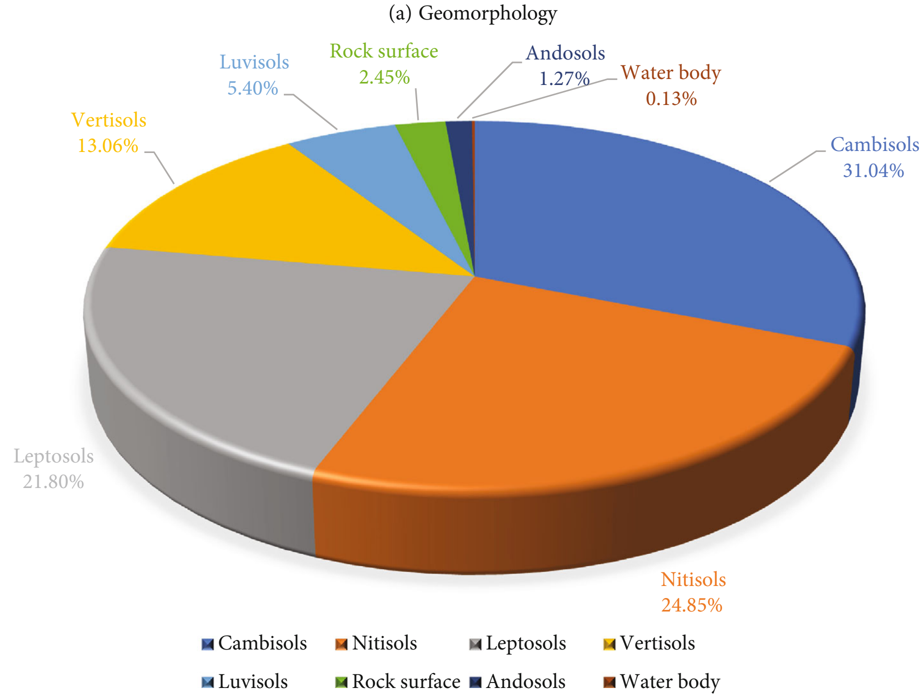
The catchment, which comprises the Guder watershed, drains to the Blue Nile where the Blue Nile is the major and most important river in Ethiopia by the volume of water and size of the river [94]. The main soil types of Guder catchment which is one part of the Guder subbasin include soil Cambisols, Nitisols, Leptosols, Vertisols, Luvisols, and Andosols (Figure 2(b)) in decreasing percent of area coverage according to the land survey conducted by OWWDSE, Ethiopia in the year 2016. The first three soil types constitute about 75% of the soil type of the study area. Soil acidity, depth, and permeability are some of the limiting factors which reduce agricultural productivity [17].

The total population of the watershed is about 130,500 of which 64,881 are male and 65,619 are female [17, 94]. The dominant economic activity is agriculture involving crop and livestock production which is mainly subsistent, but here are some off-farm activities that include petty trade and forest product collection and sale. According to the study, the major land use/cover of the Guder subbasin is dominated by cultivated land (30.3%); while moderately cultivated land, dense bush land, open grass land, plantation forest, and open shrub land covers 17.78%, 15.78%, 15.47%, 8.73%, and 7.05% portion of the area, respectively (Figure 2(d)). The altitude of the area ranges from 1144 to 3288 meters above sea level as delineated by a 30 m spatial resolution ASTER DEM. It receives an annual mean rainfall of 812 mm to 1699 mm, and the average temperature ranges between 10°C and 25°C. Sheep, goat, cows, horses, donkeys, and mule are very common live stocks in the study area. Guder watershed has been highly promoted in the irrigation activities in the study area [17].

2.2. Collection and Preparation of Input Data for GWP Zone. The method adopted for the current study is explained in Figure 3. Input data for groundwater potential mapping of the study area were collected as secondary data by reviewing the literature, online available resources, and the research office of Ethiopia. Remote-sensing data of various spatial and temporal resolutions were collected as it can afford accurate, cost-effective, automated, near-real-time information, even in areas on the Earth that are difficult to access [95]. Technological advances in image processing and analysis have allowed for the extraction and combination of information in a fast manner that can help improve decision-making [95–97]. It is a very significant approach to reveal the geologic, structural, and hydrologic conditions for better assessment, planning, and observation of water resources under any conditions [95, 96].

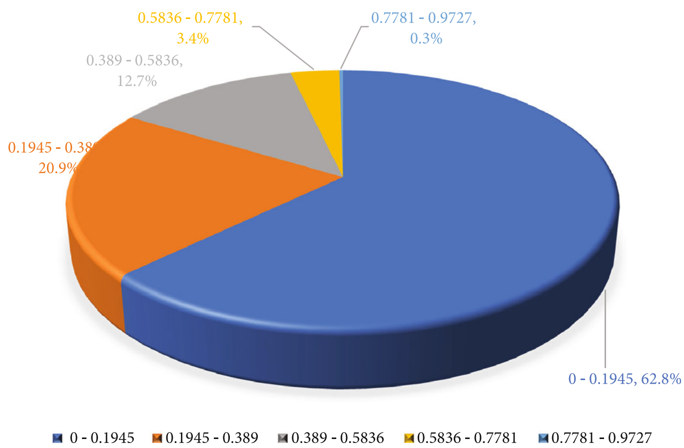


(a) Geomorphology

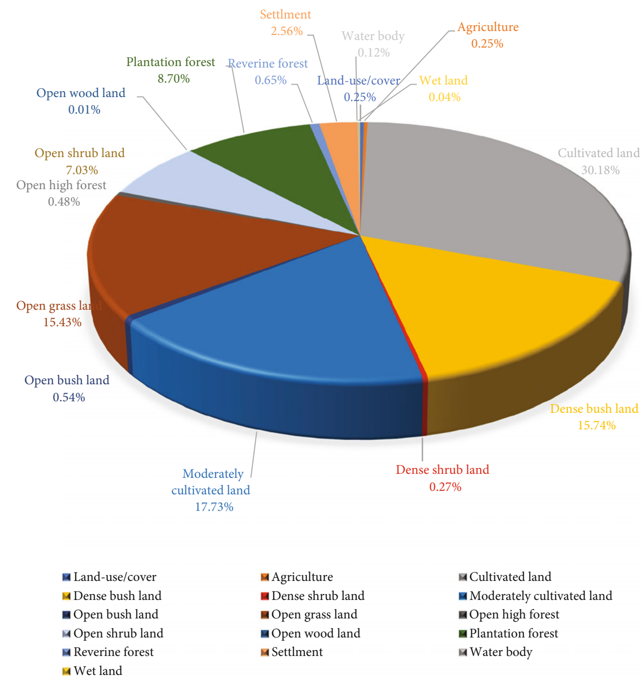


(b) Soil type

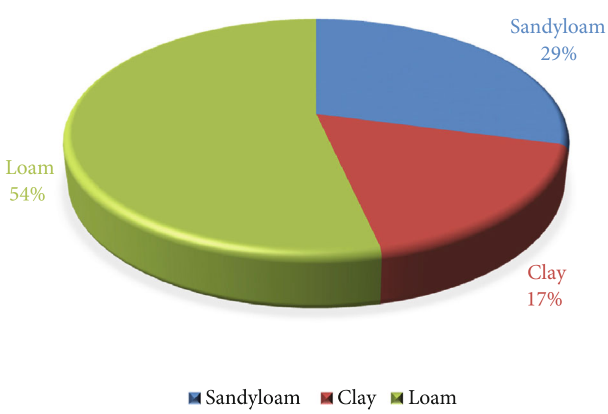
Figure 2: Continued.



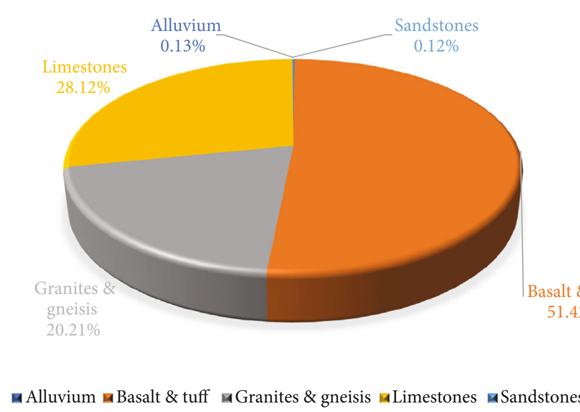
(c) Lineament



(d) Land use/land cover

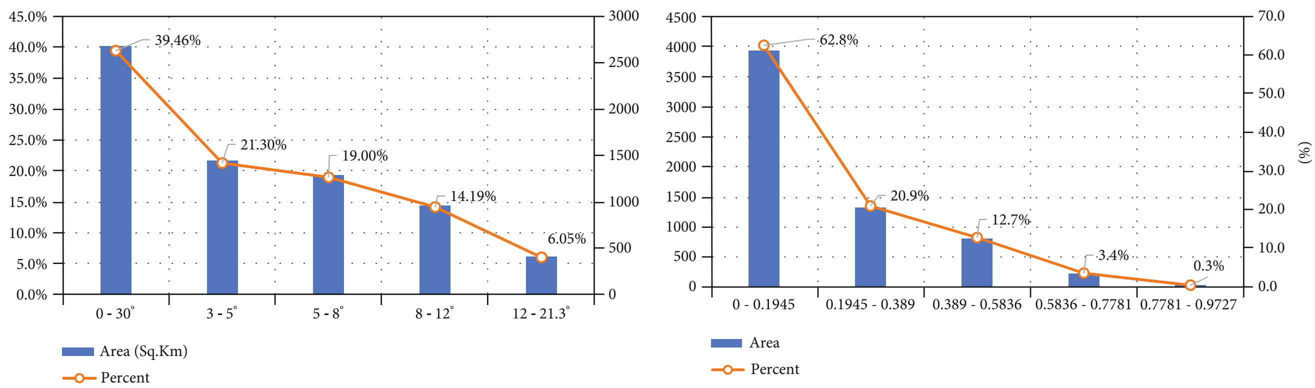


(e) Soil texture



(f) Geology

Figure 2: Continued.



(g) Slope (h) Lineament

Figure 2: Area percentage (%) covered by the attributes of the study area.

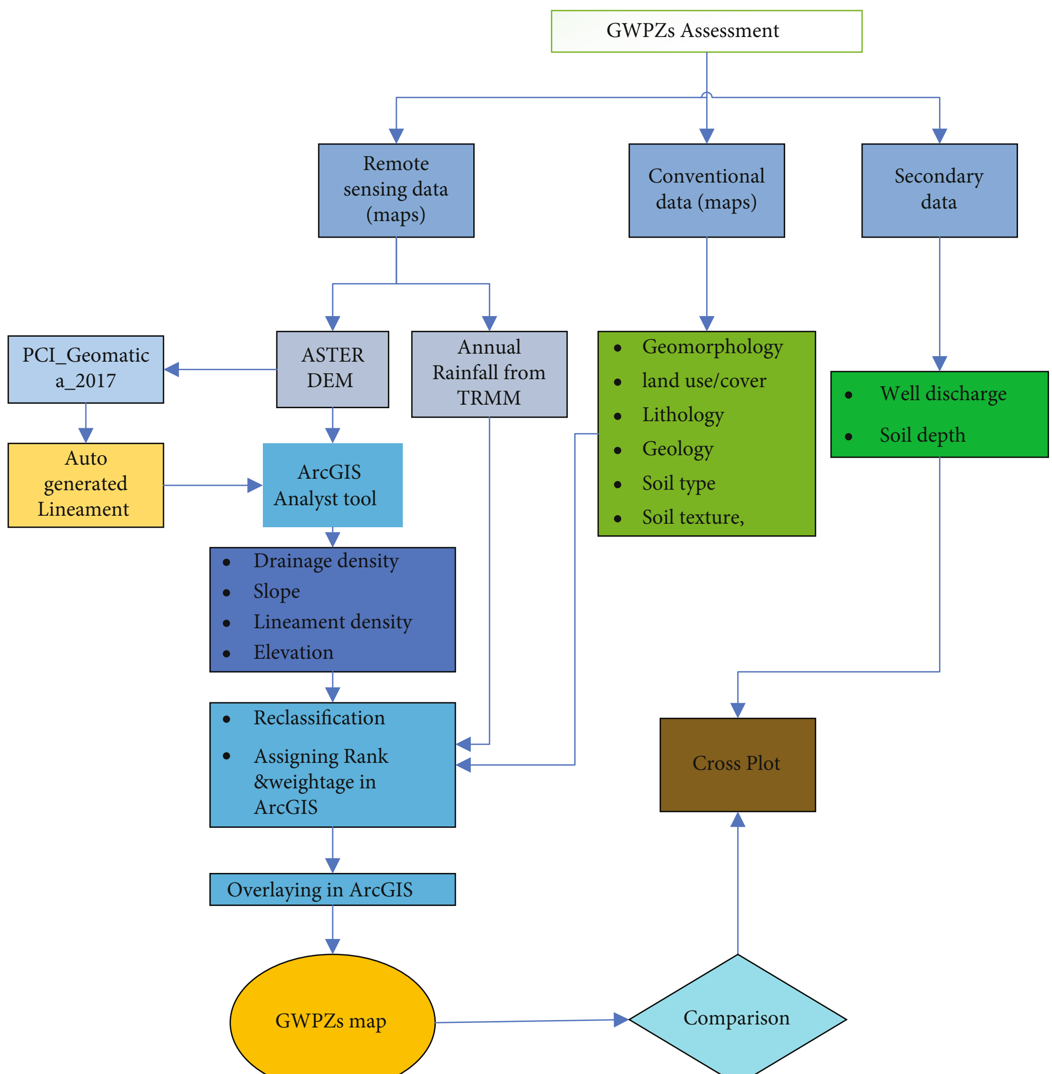


Figure 3: Flowchart indicating assessment of GWPZs.

Based on the available data/online resources, about ten (10) groundwater modeling factors were collected. These were geomorphology, lithology/geology, land use/cover, soil type and soil texture, soil depth, digital elevation model (for preparation of slope, drainage density, lineament), and rainfall were also collected from different and reliable sources. The collected data sources of data are presented in (Table 1).

Table 1: The data type, source and importance of thematic factors.

SN	Thematic layers	Data collection site and preparation year	Importance of the data
1	Geomorphology	OWWDSE, in 2016	For the preparation of the geomorphology map
2	Lithology	OWWDSE, in 2016	Geological material of the study area
3	Land use/cover	OWWDSE, in 2016	To know the dominant land use/cover of the study area
4	Soil type	OWWDSE, in 2016	To know the soil property of the study area
5	Sol-AWC and soil texture	Addis Ababa University (B. [98])	To know the soil property of the study area and for validation
6	Soil depth	OWWDSE, in 2016	For validation
7	ASTER DEM	Acquired on march 08, 2016 from: http://www.gdem.aster.ersdac.or.jp/search.jsp	For the preparation of slope, drainage density, lineament
8	Rainfall	Acquired on 18 July 16, 2021, from https://people.geog.ucsb.edu/~bodo/TRMM/	To identify spatial magnitude precipitation of the area
9	Well discharge	Ethiopian MoWIE, in November 2021	For validation purpose

ASTER: Advanced Spaceborne Thermal Emission and Reflection Radiometer; DEM: digital elevation model; OWWDSE: Oromia Water Works Design and Supervision Enterprise, Sol-AWC: Soil Available Moisture capacity; TRMM: Tropical Rainfall Measurement Mission; MoWIE: Ministry of Water, Irrigation, and Energy.

The collected thematic layers were projected to similar projections, and those of the raster file were converted to a polygon. The shapefiles like drainage density and slope were prepared in ArcGIS from DEM. Lineament density was extracted by an automated processing LINE tool in PCI_Geomatica_2017 software from the digital elevation model of the study area. After the lineaments were extracted, further processes of editing the watershed reclassification task were done in ArcGIS to make sure regarding the quality of the extracted lineaments.

Geomorphology, land use, lithology, slope and soil type are the crucial factors to control the availability of groundwater in an area. All the thematic layers and their subclass were reclassified and given weightage depending on their influence on groundwater occurrence.

Each thematic layer and subclass were given a weightage depending on the analytic hierarchy process (AHP) technique, the expert decision, and their impact on groundwater potential occurrence. These thematic layers were overlaid in the analyst tool of the ArcGIS analysis tool environment (Figure 3). The delineated map was again reclassified into the different zone from good to very good groundwater potential. The map was overlaid with administrative woreda of the Guder watershed to identify the groundwater potentiality of the woredas found in the study area. The delineated groundwater potential zones were validated with field collected borehole/well data.

3. Preparation of Factors Influencing Groundwater Recharge Potential (Geospatial Database)

The occurrence and movement of groundwater are influenced by geology, structure, geomorphology, and drainage while replenishment is further affected by land use, rainfall, and infiltration rate [99–106]. The number of thematic layers employed was different for different researchers as it may depend on the availability of data. In this particular study, about ten thematic layers like geomorphology, lithology/geology, land use/cover and soil type and soil texture, soil depth, digital elevation model, slope, drainage density, lineament), and rainfall have been applied for investigation and assessment Guder subbasin groundwater potential zone analysis. The relationships of these influencing factors are weighted according to previous studies conducted in the different watersheds of the world, their influence on GWPZ, and skilled judgment. The representative weight of a factor of the potential zone is the sum of all weights of each factor. A factor with a higher weight shows a larger impact and a factor with a lower weight value shows a smaller impact on groundwater potential interrelationship. Integration of these factors with their potential weights is computed through weighted overlay analysis in the ArcGIS environment.

3.1. Geomorphology. Geomorphology of an area gives information about the description and genesis of its landforms, which depends upon the structural evolution of geological formation [3, 107]. In another way, geomorphologically, the area depicts both its erosional and depositional landforms. Among the ten different thematic layers, geomorphology was assigned the highest weight, because it plays a dominant role in the movement and storage of groundwater at any place [3, 107]. The geomorphology GIS data collected from OWWDSE was given total and individual weightage according to its influence on groundwater occurrence.The task of arranging the values was done in ArcGIS 10.1 attribute table. The study area is covered by several kinds of geomorphological features like steep side slopes, very steep side slopes, rolling hills, rolling plateau, undulating plains and low plateau, vent and cone remnants, low relief hills, gently inclined foot slopes, escapements, basins, and colluvial margin (Figure 4). The steep side slope covers about (33%) which is about one-third of the study area. Landforms like very steep sides, lopes, rolling hills, and rolling plateau covers the area in percent of 14%, 13%, and 11%, respectively. Those covers with more than 0.5% were shown by the pie chart (Figure 2(a)). Most areas of Aanaa Guduruu (Guduru district), the eastern part of Jeldu and Ginde Beret, are dominated by undulating plains and low plateau. Very steep side slopes are found in all woredas except the southern and northern part of Ambo woreda, northern midakegni, the eastern part of Ginde Beret and Elifata, southwestern of Guduru, Jima Rare, Cheliya, and southwestern part of Midakegn. Rolling hills at the middle periphery of the subbasin and rolling plateaux dominate the southern and southeastern part of the subbasin like Jima Rare, Cheliya, Toke Kutaye, Dandi, and southern part of Ambo District.

3.2. Geology/Lithology. Geology/lithology is the greatest important factor for the groundwater potential occurrence as the penetration mostly depends on the permeability or conductivity level of different rock types [4, 30, 108, 109]. Conferring to the GIS data collected from OWWDSE, the major rock type in the study area is basalt, but some small alluvium and sandstones are found in the southern and eastern parts of the Guder subbasin, respectively (Figure 5). Geologically, the major covers in the subbasin were basalt and tuff with a total area of 3435.51 square kilometers (51.42%), which is about one-half of the study area. This lithological type mostly covers the southern, middle, and upper part of the study area as shown in (Figure 2(f)). Limestones, Granites, and Gneiss cover about 1878.69 (28.12%) and 1350.42 (20.21%) square kilometers, respectively. It highly covers the middle periphery of the area under study (Figure 5). The geological material collected from OWWDSE was prepared by given weightage in ArcGIS 10.1 attribute table and made ready for GWPZs delineation.

3.3. Digital Elevation Model. As Ethiopia receives the orographic type of rainfall [110, 111], altitude/elevation can have a significant effect on the groundwater potential of the study area. Elevation may have a direct relationship to precipitation, areal precipitation magnitude and occurrence, and thus the groundwater recharge [2]. Hence, high elevations are certain with more groundwater recharge and ensure the availability of groundwater in low-lying areas of the watershed. Therefore, it is often assumed that high elevation areas favor recharge in deep settled confined aquifers situated at low elevation or low land areas [2, 43, 112]. In other ways, highland areas can also contribute some recharge through springs and play an important role in the occurrences of groundwater. Water tends to store at lower topography than at the higher topography; so, the low elevation of the Guder River Basin favors more groundwater potential. Therefore, the more in the elevation above sea level, the smaller the groundwater potential and vice versa. More conveniently, the subbasin has a higher altitude at the southern part and the boundary and lower elevation at the middle and northern part where the river joins Abay river (Figure 6). Accordingly, the maximum and minimum elevations of the Guder River Basin were found to 3288 m and 1144 m above sea level, respectively.

The ASTER DEM retrieved from (http://www.gdem.aster.ersdac.or.jp/search.jsp) was clipped and projected, and appropriate weightage was given depending on its influence on groundwater potentiality. All these activities were done in ArcGIS 10.1, and the shapefile was ready for groundwater potential delineation.

3.4. Land Use/Land Cover. Land use/land cover has a significant role in the runoff, infiltration, and groundwater recharge capacity of any watershed or subbasin [46], and it also provides soil information such as soil moisture content, groundwater and surface water, and an indicator regarding groundwater potential prospectus [57]. Land use/cover GIS data was collected from OWWDSE of Ethiopia. The data shows that the land use/cover of the study area has been dominated by five land-use categories (Figures 2(d) and 7). These are cultivated land with an aerial extent of 2037.0 km^2 (30.26%) dominated the land cover of Guder Basin followed by moderately cultivated land 1196.8km^2 (17.78%), dense bush land 1062.0 km^2 (15.78%), open grass land 1041.0 km^2(15.47%), plantation forest 587.3 km^2 (8.73%), open shrub land 474.3 km^2 (7.05%), and settlement 172.8 km^2(2.57%) according to the data collected (Figure 2(d)). Landcover classes like riverine forest, water body, wetland, agriculture, and cultivated land are considered the top subclass for the occurrence of groundwater, and urban land use or settlement and bushland is expected to be less for groundwater occurrence (Table 2). The land-use/cover was clipped, projected, and given weightage in the attribute table of ArcGIS 10.1 and prepared for groundwater potential delineation.

3.5. Soil Texture. Soil texture generally influences the moisture content in the soil, infiltration rate, hydraulic conductivity, and soil permeability, the grain size of the soil, and the specific composition of the soils, which in turn plays an important role in recharge potentiality. Loam and sandy loam and have better infiltration capacity than clay. Therefore, the soil texture of sandy loam and loam has good groundwater potential as compared with clayey texture. According to the study conducted by Addis Ababa University, the soil in the study area shows three main soil categories, namely, loam, clay loam, and sandy loam ([98]) (Figure 8). More than one-half of the basin is covered by loam 3600.10 km^2 (53%) which is found along the middle and margin of the study area, followed by sandy loam 1963.83 km^2 (29%) that covers the middle edge of the watershed (Figure 2(e)). And the minor portions of the area are covered by clay 1168.61 km^2 (17%) in southern parts at the middle of Ambo district and the middle northern part of Tikur Enchini, middle of Midakegn, Elifata, and middle and northern parts of Jeldu district. Sandy loam soils are a high infiltration rate and have good groundwater potential zones, whereas clay soils are a small infiltration rate with less groundwater potentiality. Like other thematic layers, the soil texture GIS data was projected to similar projection, clipped to the study area, and required weightage and became ready for delineating GWPZs. These mentioned activities were done in ArcGIS 10.1 version.

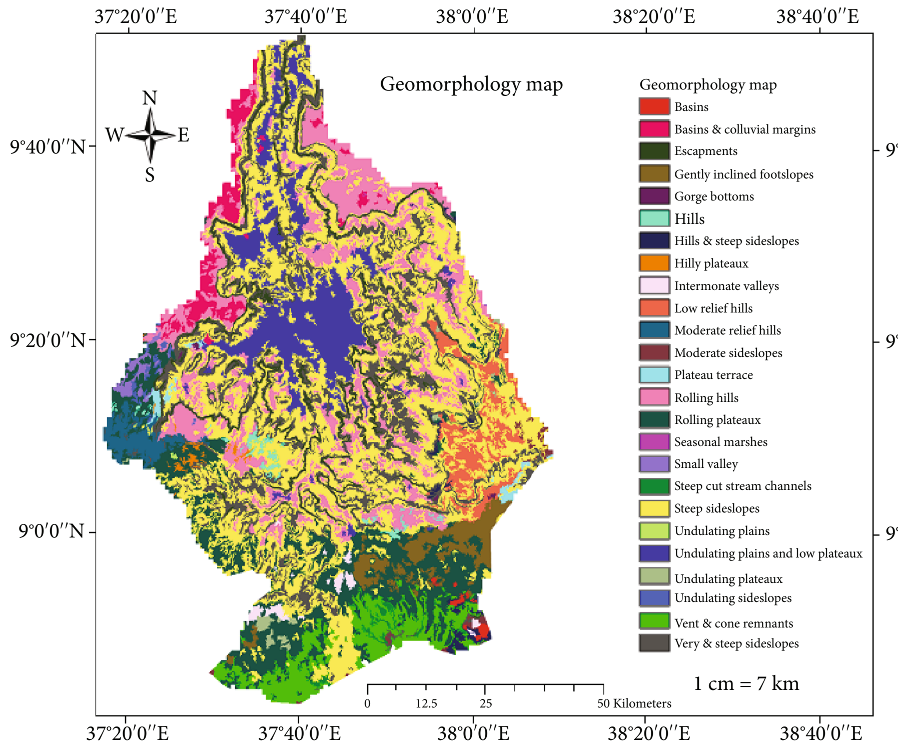


Figure 4: Geomorphology map.

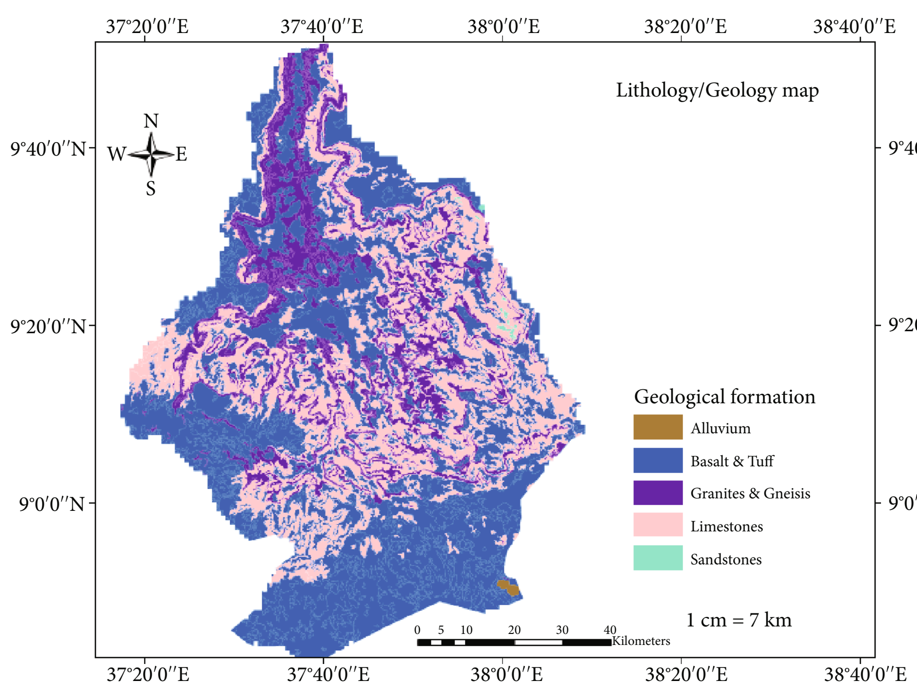


Figure 5: Geological map of the study area.

3.6. Soil Type. The moisture capacity of the soil is affected by soil type and its conductivity/permeability [3]. The soil type of the study was gathered from OWWDSE was also projected to similar projections and clipped to the study area extent in ArcGIS 10.1 version. This thematic layer was also given individual weightage and became ready for GWPZs delineation. According to the collected data about one-third of the study area is covered by cambisols 2073.9 km^2 (31.04%), followed by nitisols 1660.3 km^2 (24.85%), leptosols 1456.6 km$^{2(}$21.80%), vertisols 872.8 km^2 (13.06%), luvisols 360.9 km^2 (5.40%), rock surface 163.5 km^2 (2.45%), and andosols 85.1 km^2

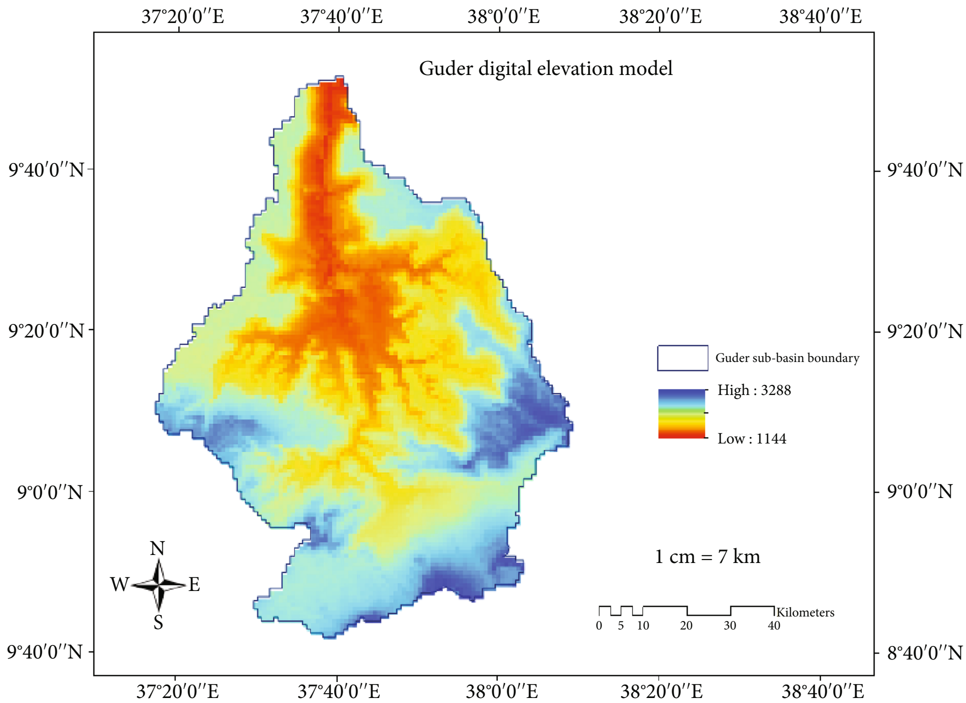


Figure 6: Elevation map of the study area.

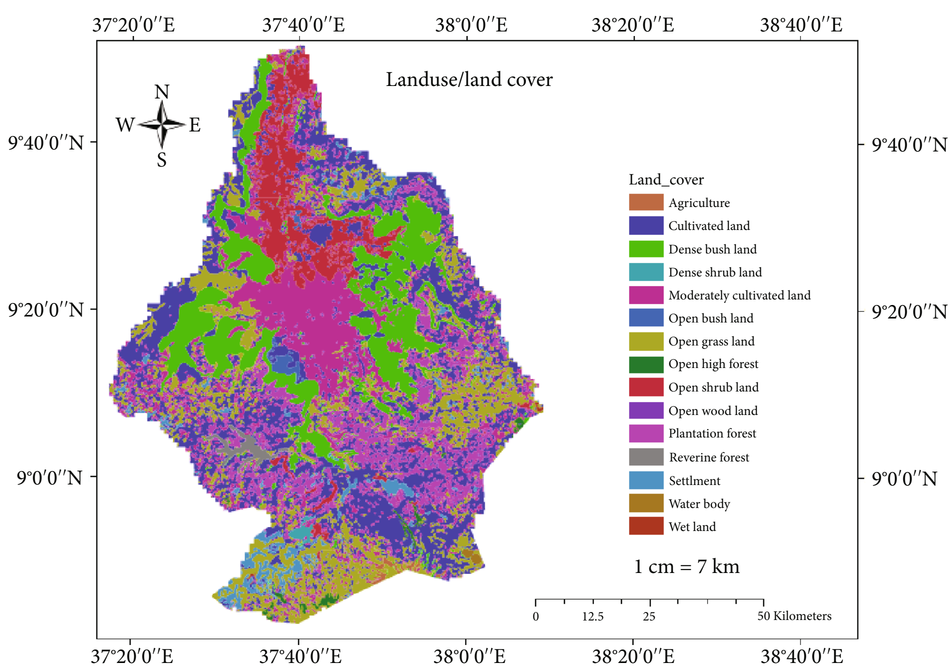


Figure 7: Land use/land cover of the study area.

(1.27%) as indicated by the data collected for the study (Figures 2(b) and 9).

3.7. Slope. The slope describes the variation of altitude/elevation in a certain area under consideration which influences the runoff as well [61, 63, 64, 107]. The slope is an essential parameter in groundwater investigation as infiltration is inversely proportional to land steepness. Usually, the gentle steepness slopes, the less speediness of surface water flow, and the more groundwater percolation are into the ground. On the contrary to this, the more steepness of the slope, the more surface runoff and which lessens the groundwater percolation. The ASTER DEM satellite (digital elevation model) of spatial resolution $30\,m \times 30\,m$ was applied for making a slope map of the area under investigation. The slope was prepared and reclassified into five classes under

Table 2: Classification of weighted factors influencing the potential zones in the study area.

SN.	Thematic layers	Subclass and potentiality	Total weightage	Individual weightage
		Basins		18
		Basins and colluvial margins		19
		Escapements		1
		Gently inclined foot-slopes		15
		Gorge bottoms		25
		Hills		3
		Hills and steep side slopes		2
		Hilly plateau		7
		Intermediate valleys		14
		Low relief hills		6
		Moderate relief hills		5
1	Geomorphology	Moderate side slopes	25	10
		Plateau terrace		9
		Rolling Hills		4
		Rolling plateau		8
		Seasonal marshes		21
		Small valley		12
		Steep cut stream channels		25
		Steep side slopes		9
		Undulating Plains		24
		Undulating plains and low plateau		25
		Undulating plateau		20
		Undulating side slopes		11
		Vent and cone remnants		2
		Very steep side slopes		8
		Agriculture		12
		Cultivated land		11
		Dense bushland		5
		Dense shrubland		10
		Moderately cultivated land		13
		Open grassland		8
2	Land-use	Open high forest	15	9
		Open shrubland		9
		Open woodland		7
		Plantation forest		8
		Riverine forest		14
		Settlement		2
		Waterbody		15
		Wetland		15
		Alluvium		10
		Basalt and tuff		7
3	Lithology/geology	Granites and gneiss	10	3
		Limestone		4
		Sandstone		8
		Andosols		6
		Cambisols		4
		Leptosols		1
4	Soil type	Luvisols	7	7

Table 2: Continued.

SN.	Thematic layers	Subclass and potentiality	Total weightage	Individual weightage
		Nitosols		7
		Rock surface		0
		Vertisols		6
		Water body		7
		Loam (very good)		6
5	Soil texture	Clay (poor)	6	2
		Sandy loam (good)		4
		0-0.35 (very good)		7
		0.35-0.72 (good)		6
6	Drainage density	0.72-1.07(intermediate)	7	5
		1.07-1.43 (poor)		4
		1.43-1.80 (very poor)		3
		0-3° (very good)		12
		3-5° (good)		10
7	Slope	5-8° (intermediate)	12	8
		8-12° (poor)		5
		12-21.3° (very poor)		2
		912–1252 (very poor)		4
		1253–1592 (poor)		5
8	Rainfall (mm)	1593–1932 (intermediate)	8	6
		1933–2272 (good)		7
		2273–2612 (very good)		8
		0-0.1945 (very poor)		1
		0.1945-0.389 (poor)		2
9	Lineament density (km/km^2)	0.389-0.5836 (intermediate)	5	3
		0.5836-0.7781 (good)		4
		0.7781-0.9727 (very good)		5
		1144-1572.8 (very good)		5
		1572.8-2001.6 (good)		4
10	Elevation (m)	2001.6-2430.4 (intermediate)	5	3
		2430.4-2859.2 (poor)		2
		2859.2–3288 (very poor)		1
	Total		100%	

ArcGIS spatial analyst tools. The weightage was given in the attribute table depending on its effect on groundwater potential occurrence. The slope of the study area ranges from 0 to 21.3%, and gentle slopes are found in the northern and southern part of the Guder watershed (Figure 10). The slopes are classified into five classes according to natural breaks in ArcGIS spatial analyst tool. About 40% of the study area is covered with gentle slope of 0-3° area 2679.2 km^2 (39.5%), slope of 3-5° area 1445.9 km^2 (21.3%), slope of 5-8° area 1289.6 km^2 (19.0%), slope of 8-12° area 963.6 km^2 (14.2%), and slope of 12 -21.3° area 410.8 km^2 (6.1%) shown in (Figure 2(g)).

3.8. Lineament Density. Lineaments are linear, rectilinear, and curvilinear features of tectonic origin, which can easily observe in the satellite imagery [113], and it may characterize master joints, fractures, faults, topographic linearity and formation, vegetation cover, infrastructures like road and bridges, valleys and straight course of streams, and boundaries between the different lithological units [2]. In this particular study, lineaments were extracted by an automated processing LINE tool in PCI_Geomatica_2017 software, and further processes of editing and watershed classification job were done in ArcGIS spatial analyst tool environment. High lineament densities favor groundwater potential than fewer lineament densities. Hence, big value weights are given for high-density lineaments and less value for low-density lineaments. After lineament density, map was completed, and it was reclassified into five as very low (0-0.1945 km/km$^{2)}$ "very poor groundwater potential," low (0.1945-

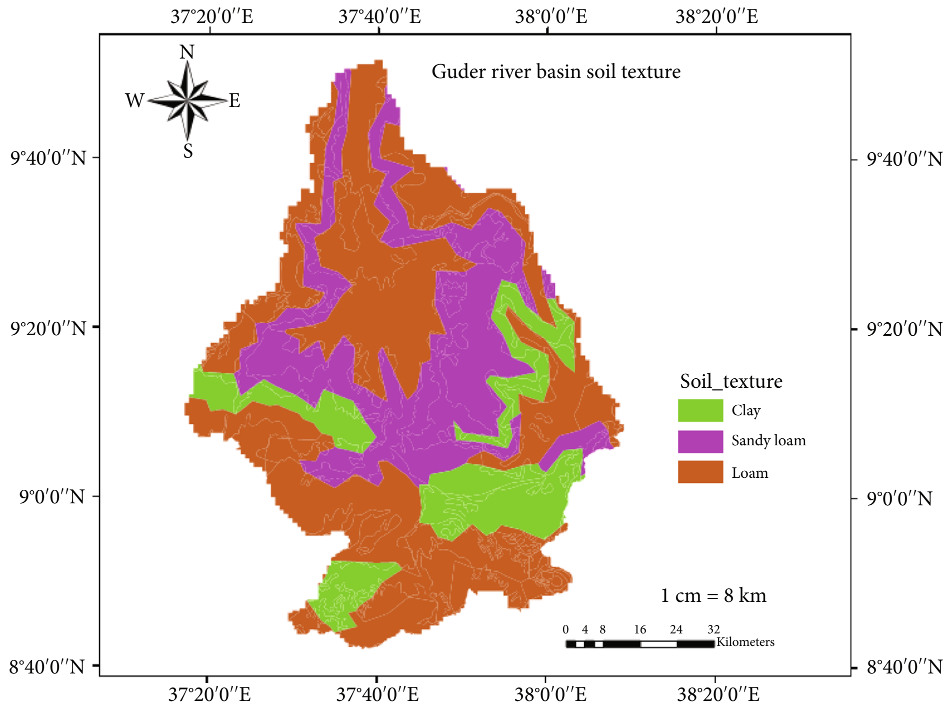


Figure 8: Soil texture of the study area.

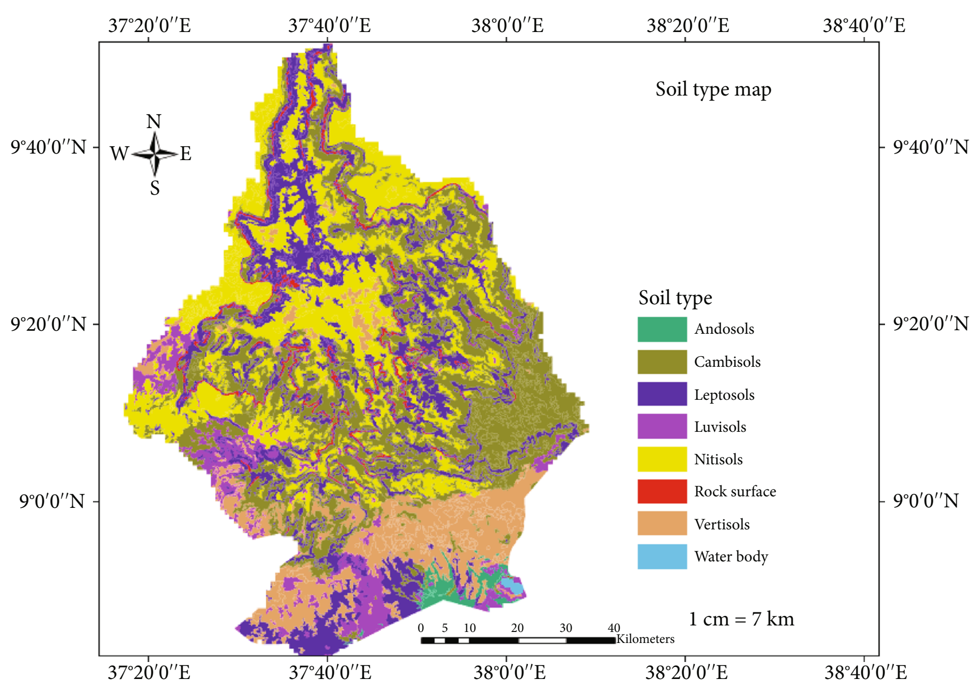


Figure 9: Soil types of the study area.

0.389 km/km$^{2)}$ "poor groundwater potential," medium (0.389-0.5836 km/km^2) "intermediate groundwater potential," high (0.5836-0.7781 km/km$^{2)}$ "good groundwater potential," very high (0.7781-0.9727 km/km^2), and "very good groundwater potential" in terms of increasing groundwater potentiality see (Figures 2(h) and 11 and Table 2.

3.9. Drainage Density. Drainage density is defined as the total length of all streams/rivers in a drainage basin divided by the total area of the drainage basin [114, 115]. Drainage density is an inverse function of permeability and therefore an essential parameter in assessing the groundwater potential zone. High drainage density values are favorable for runoff

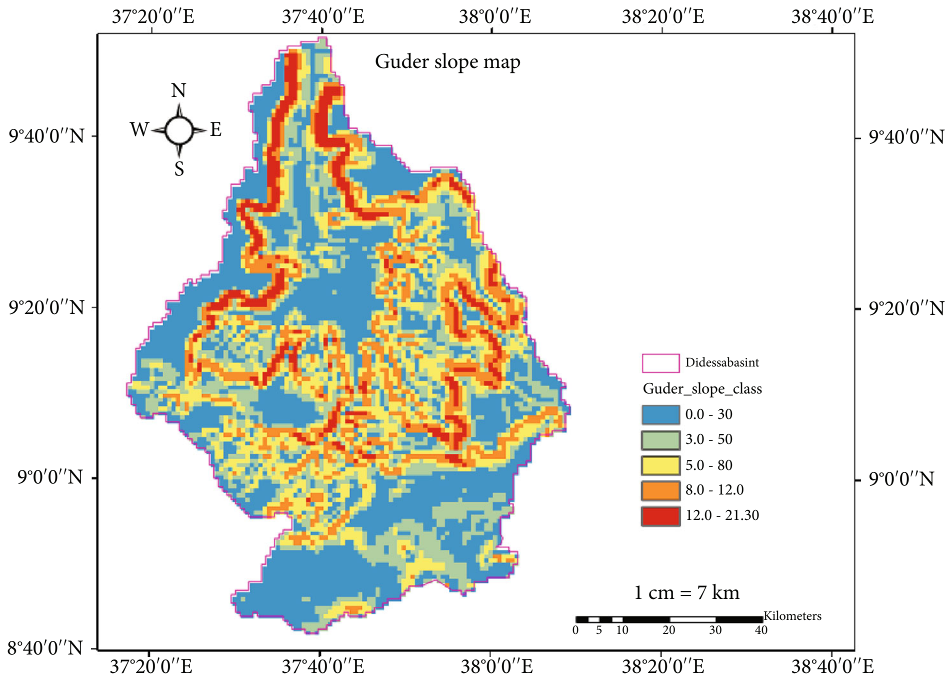


Figure 10: Slope map of the study area.

and hence indicate a low groundwater potential zone [114, 115]. The drainage density was done under the spatial analyst tool of ArcGIS 10.1. The DEM was delineated under hydrology of spatial analyst tool followed by density preparation reclassification. The drainage density thematic layer shows that the drainage density value was ranged from 0 to 1.80 km/km^2 (Figure 12). These are reclassified into five classes, i.e., 0-0.35 very low (very good), 0.35-0.72, low (good), 0.72-1.07 medium (intermediate), 1.07-1.43 high (poor), and 1.43-1.80 very high (very poor) depending on their effect on groundwater occurrence for analysis (Table 2).

3.10. Annual Rainfall. Rainfall plays an important role in the hydrologic cycle and controls groundwater potential. Rainfall is the major source of surface and groundwater in this area, and therefore, the intensity of rainfall and its spatial distribution strongly control the recharge volume of the basin as established by many scholars like [1, 2, 57, 63, 93, 113, 116]. The possibility of groundwater recharge would be high at the place where the rainfall is high and is low where rainfall is low [2, 113]. Annual rainfall is collected from Tropical Rainfall Measurement Mission (TRMM) and reclassified in ArcGIS spatial analyst tool. The high resolution downloaded from The Tropical Rainfall Measuring Mission (TRMM) was clipped to the study area extent, projected, converted from raster to point under conversion tool, and interpolated under spatial analyst tool. The annual rainfall was collected in millimeters and reclassified into five classes as 912–1252 mm (very poor), 1253–1592 (poor), 1593–1932 (intermediate), 1933–2272 (good), and 2273–2612 (very good) for simplifying the analysis of groundwater potential (Figure 13 and Table 2).

3.10.1. Normalized Weights for Thematic Layers. Analytic hierarchy process (AHP) technique was carefully chosen for the decision guidelines to evaluate the input layers for delineating the groundwater zone through ArcGIS. The weights assigned to different thematic maps and their features were decided based on field experience and expert judgment that was normalized using Saaty's AHP method [117, 118]. In the analytic hierarchy process, each pair of factors in a particular cluster is evaluated at a time, regarding their relative importance (Table 3).

A pairwise comparison matrix is formed in which $a_{ii} = 1$ and $a_{ij} = 1/a_i$. The weightage factor of the ranking criteria and the resulting subcriteria are calculated using the right eigenvector, which is calculated from the maximum absolute eigenvalue ($\lambda_{\max}$, 1, 2). The principal eigenvalue (λ) was calculated by the eigenvector technique [117].

$$\lambda_{\max} = \sum_{\mathrm{wi}}^{n} \frac{1}{n} \frac{(\mathrm{AW})_i}{\mathrm{wi}},$$
$$\mathrm{AW} = \begin{pmatrix} a11 & a12 \cdots\cdots & a1n \\ a21 & a22 \cdots\cdots & a2n \\ \cdots & \cdots\ \cdots\cdots & \cdots \\ \cdots & \cdots\cdots\cdots & \cdots \\ an1 & \mathrm{an}2 \cdots\cdots & ann \end{pmatrix} \begin{pmatrix} w1 \\ w2 \\ \cdots \\ \cdots \\ wj \end{pmatrix}, \quad (1)$$

where W is the corresponding eigenvector of λmax, and wi $(i = 1, 2, \cdots, n)$ is the weight value for ranking. In this

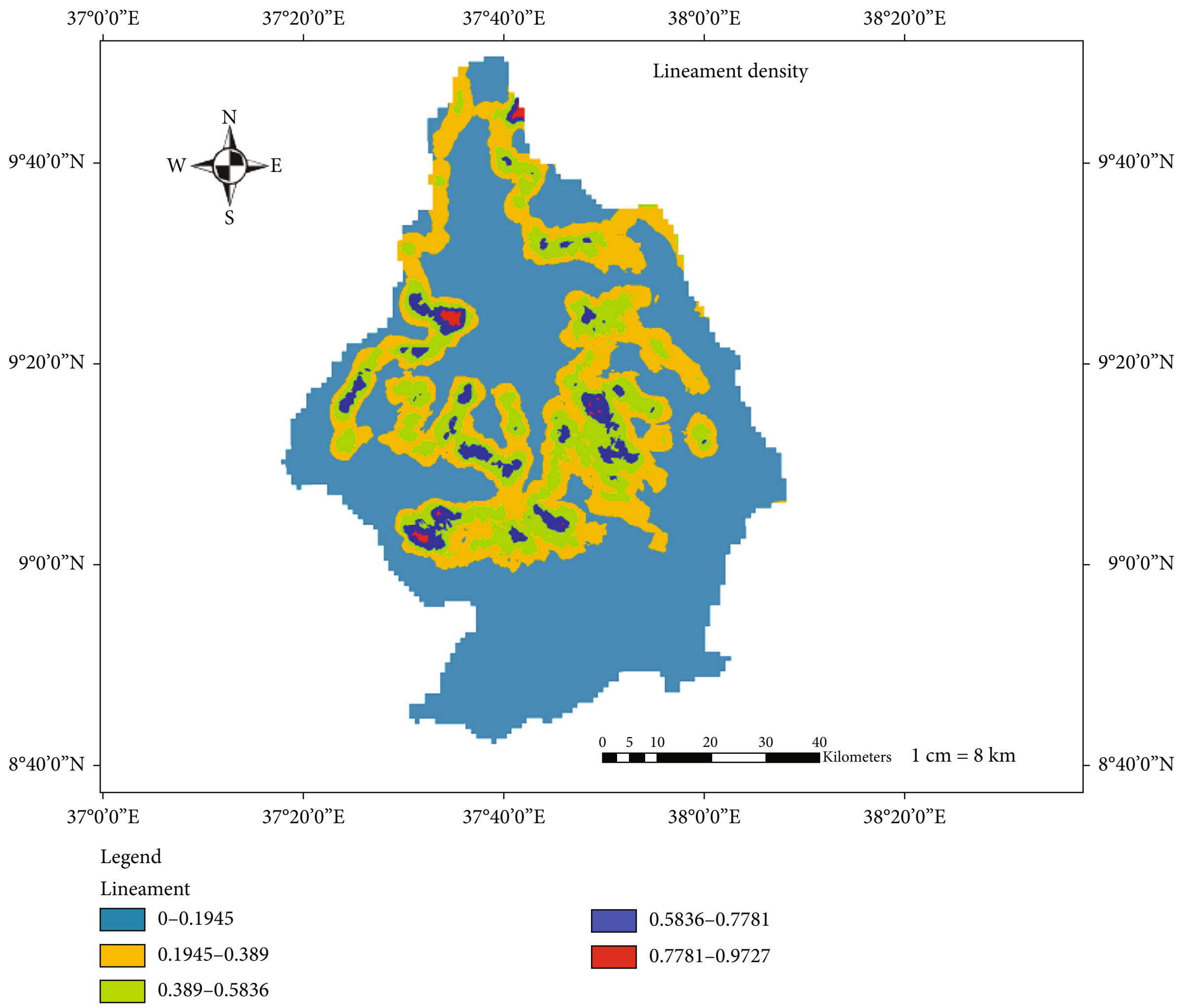


Figure 11: Lineament density map of the study area.

research, $\lambda_{max} = 10.236$. The consistency of the judgment matrix should be evaluated with the calculation of the consistency index (CI) which is defined as [118, 119]

$$CI = \frac{\lambda_{max} - n}{n - 1}, \quad (2)$$

where CI is the consistency index, λmax is the maximum or principal eigenvalue of the judgment matrix and could be easily calculated from the matrix, and n is the order of the matrix [117, 119]. The consistency ratio (CR) coefficients are calculated using equation (3).

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RCI}}, \quad (3)$$

where RCI is the random consistency index. The value of RCI was obtained from the Saaty's 1–9 scale. The consistency ratio value (CR) should be less than 0.1, indicating the overall cohesiveness of the pairwise comparison matrix [117, 119] for consistent weights; if not, the corresponding weightage must be reexamined to avoid inconsistency.

Next, delineation of groundwater potential zones was applied. The groundwater potential index (GWPI) is a dimensionless quantity that can be used in the estimation of GWPZs in the study area. The weighted linear combination technique that was applied to govern the GWPI is as follows [117–119].

$$\mathrm{GWPI} = \sum_{t=1}^{m} \sum_{f=1}^{n} \left(W_t X_f \right), \quad (4)$$

where W_t represents the normalized weight of the t thematic layer, X_f represents the rank value of each class with respect to the f layer, m represents the total number of thematic layers, and n represents the total number of classes in the thematic layer.

3.11. Validation of the GWP Zone Map. It has been common that the groundwater potential map is validated with well discharge or well yield data [117–119], but in the case, the well yield data is not available, and GWPZs were delineated without validation [3, 102–105]. In this study, discharge data were found along the main road passing through Ginchi and

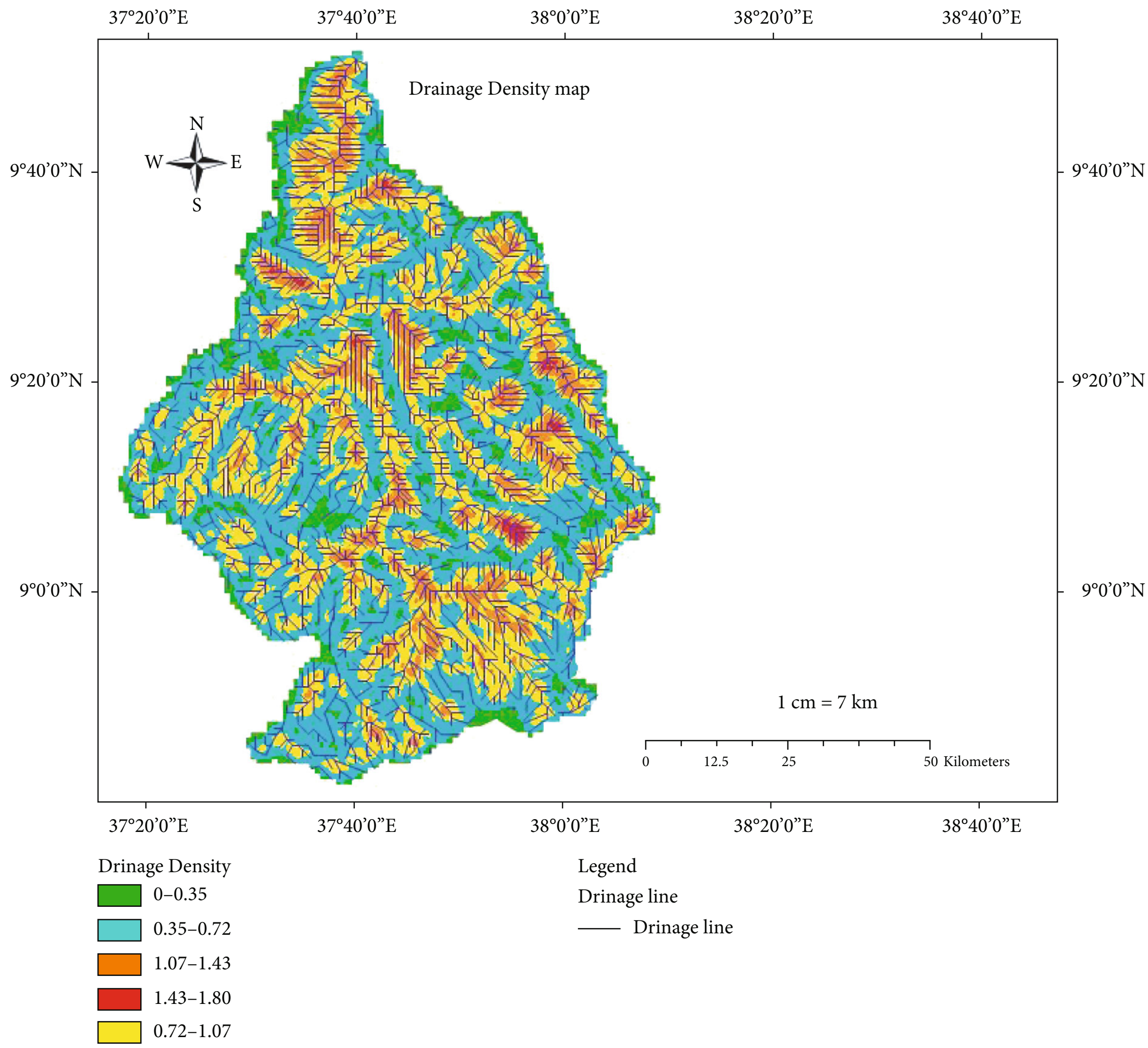


Figure 12: Drainage density map of the study area.

Ambo, and the delineated GWPZs were compared with the available data. In this particular study, the output GWPZs were also compared with soil depth.

4. Results and Discussion

The weightage assigned to the various groundwater influencing factors or thematic layers and estimated values of the normalized weightage using AHP and eigenvector techniques are shown in Table 4. In this study, the consistency index (CI) and consistency ratio (CR) coefficient values were 0.06 and 0.017, respectively. In this research, $RCI_{10} = 1.49$ because of using the ten criteria.

The lithology/geology, geomorphology, land use/land cover, slope, drainage density, lineament density, soil type, soil texture, rainfall distribution, and elevation shapefile of the study area have been overlaid in ArcGIS software to determine the groundwater potential zones of the area under study. Analytic hierarchy procedure (AHP) was put into effect to provide weightage ranking and to reclassify these maps in the ArcGIS of version 10.1 environment, and the final groundwater thematic map had been prepared by overlaying of all maps. Rating task for each class in a thematic layer was created on their relative importance for groundwater potential (Table 4). Each thematic layer assigned weightage along with its subclass, i.e., geomorphology (25%), land-use (15%), slope (12%), lithology/geology (10%), soil type (7%), soil texture (6%), drainage density (7%), slope, rainfall (8%), lineament density (5%), and elevation (5%) (Table 2).

The delineated groundwater potential zones (GWPZs) were reclassified into five classes based on the overall weightage in percentage; these are very good, good, moderate, poor, and very poor groundwater potential zone areas (Table 5 and Figure 14).

Figure 15 shows the groundwater potentiality map of the study area. The very high GWPZs are found in the northern part starting from the center longitude of the study area, more along the northwestern, southern and southwestern of the Guder subbasin. Low to very low groundwater

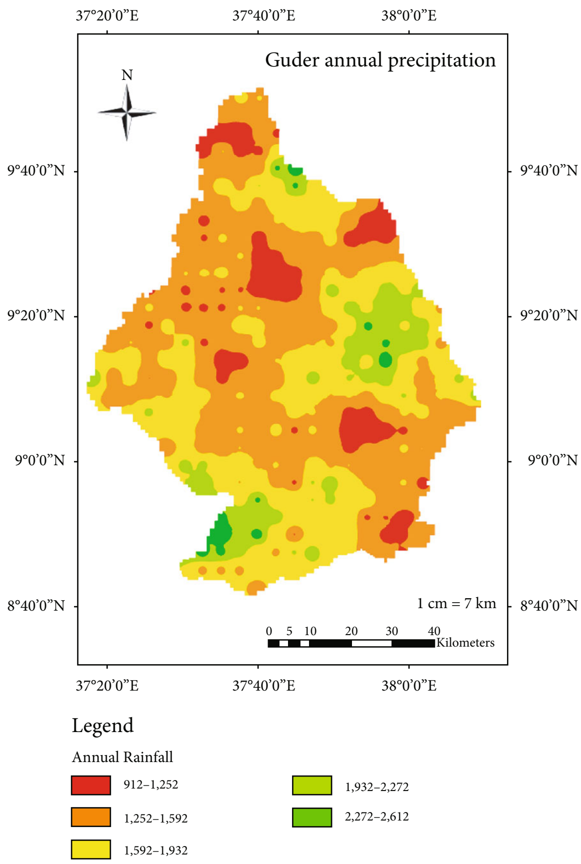


FIGURE 13: Annual rainfall distribution map of the study area.

potentiality has been seen at different distances from the center due to the presence of escapements, hills and steep side slopes, slopes, and rock surfaces. Therefore, the study observed that geomorphology has a critical influence on groundwater potential in comparison to other factors. Moreover, slope steepness, type of formation (geology), high steepness areas, and limestone type of lithological formation have been certain in areas of very poor groundwater potential.

Aanaa/Warada/District wise, northern Ambo boundary between Cheliya and Jeldu and southern Ambo, eastern and western part of Tikur Enchini, southern Dendi, southern and western part of Cheliya, eastern of Jeldu, northern and western part of Jima Rare, the eastern and western part of Guduru part found in Guder subbasin, south and eastern Ginde Beret, and the eastern part of Abuna Ginde Beret may have very good to good groundwater potentiality, whereas middle mountainous areas of Ambo, Cheliya, Guduru, and Ginde Beret, northwestern part of Jeldu and Dendi, northeastern of Jima Rare, and Nono district parts found in Guder subbasin were found to be districts those have poor to very poor possibility of groundwater potential Figure 15.

Moreover, after the GWPZs were prepared, ten (10) influential factor or thematic layer values correlated with the overall weightage in SPSS 20 software based on the Pearson correlation coefficient, and the value calculated was found in (Table 6).

The negative values indicate that there is an inverse relationship between thematic layers and that of overall weightage, and the positive values show the presence of a positive relationship among thematic layers. Pearson correlation coefficient shows that there is a sensible dimension of consistency in pairwise comparison between influencing factors (geomorphology, geology, slope, soil, rainfall, drainage density, land use/land cover, and geomorphology) and the overall weightage (Table 6).

4.1. Validation. The available well discharge data were collected from the Ethiopian Ministry of Water, Irrigation, and Energy. About thirteen (13) were found to validate the delineated GWPZs. The studies observed were located along the main road passing through Asgori, Ambo, Guder, and Babich.

The observed well data were highlighted with pink color as found in Figure 16. The study was certain with correlation coefficient (R^2) [120–122] and kappa statistics [123–126] value. The correlation coefficient was found to be 0.73 (Figure 17), and the average kappa statistics value was 77% (Table 7). Thus, the study was accepted a high correlation value, and there was substantial agreement between observed and field data according to the kappa statistics value range.

The delineated GWPZS was also validated using soil depth which may influence the presence of groundwater. If the soil has been under severe erosion and covered by hard surfaces, it minimizes the soil layer and the potential capability of the soil to store water.

Shallow soil depth indicates a small layer of the unconfined aquifer and low groundwater potentiality to be stored. The study further compared the developed GWPZ with the soil depth data collected in 2016 by Oromia Water Works Design and Supervision Enterprise. Accordingly, the study showed a direct relationship between soil depth and groundwater potential zone in Guder subbasin. The deeper the soil profile, the higher the water can be stored in an unconfined aquifer, and the higher the groundwater potentiality and vice versa. The relationship between the two parameters was shown by the following map (Figure 18). The study also revealed that there is an exact relationship between soil depth and groundwater potential zones in Guder watersheds. The zone of high groundwater potential has high soil depth, and the zone of low groundwater showed low soil depth as the capacity of the aquifer to store water may depend on the depth of soil profile.

4.2. Conclusion. This particular study deals with the assessment of groundwater potential zones (GWPZs) using geographical information systems and remote sensing techniques in the Upper Blue Nile basin of Ethiopia, Western Oromia region, the case study of the Guder subbasin. The thematic layers influencing GWPZs such as geomorphology, lithology/geology, land use/cover, slope, lineament density, drainage density, soil properties (soil texture, soil type), rainfall, and elevation maps were getting prepared with the available data, i.e., conventional data, satellite image, and assigned individual weights along with their subclass divisions depending on literature and expertise decision. The study assessment revealed that about 33.6% (2315 km^2) of the study area have "good" and "very good" groundwater potentiality in

Table 3: The comparison scale in AHP intensity [117, 119].

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another, and its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation

Table 4: Comparison matrix and significance weightage value of the influential factors.

Matrix		Geomorphology	Land-use	Lithology	Soil type	Soil texture	Drainage density	Slope	Lineament	Rainfall	Elevation	**Weights**
		1	2	3	4	5	6	7	8	9	10	
Geomorphology	1	1	2	3	4	4	4	3	5	3	5	25%
Land-use	2	1/2	1	2	3	3	3	1	3	3	4	15%
Lithology	3	1/3	1/2	1	2	2	2	1/2	3	2	3	10%
Soil type	4	1/4	1/3	1/2	1	1	1	1/2	2	1	2	7%
Soil texture	5	1/4	1/3	1/2	1	1	1	2/5	2	1	2	6%
Drainage density	6	1/4	1/3	1/2	1	1	1	1/2	1	1	2	7%
Slope	7	1/3	1	2	2	2	2	1	4	2	3	12%
Lineament	8	1/5	1/3	1/3	1/2	1/2	1	1/4	1	1/3	1	5%
Rainfall	9	1/3	1/3	1/2	1	1	1	1/2	3	1	3	8%
Elevation	10	1/5	1/4	1/3	1/2	1/2	1/2	1/3	1	1/3	1	5%

$\lambda_{max} = 10.224$, $CI = 0.06$, $RCI = 0.37$, and $CR = 0.017 \leq 0.1$.

Table 5: Groundwater potential classes and their quantitative values.

Estimated GWPZs in (%)	GWPZ classification	Occupying study area (km^2)	Area in percent (%)
<49%	Very poor	1601.0	23.3%
50–54%	Poor	1388.7	20.2%
55–59%	Moderate	1578.8	22.9%
60–64%	Good	1158.5	16.8%
65–90%	Very good	1156.5	16.8%

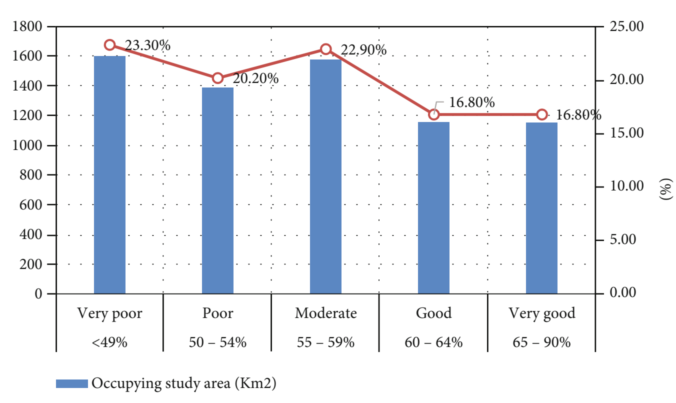


Figure 14: Groundwater potential classes.

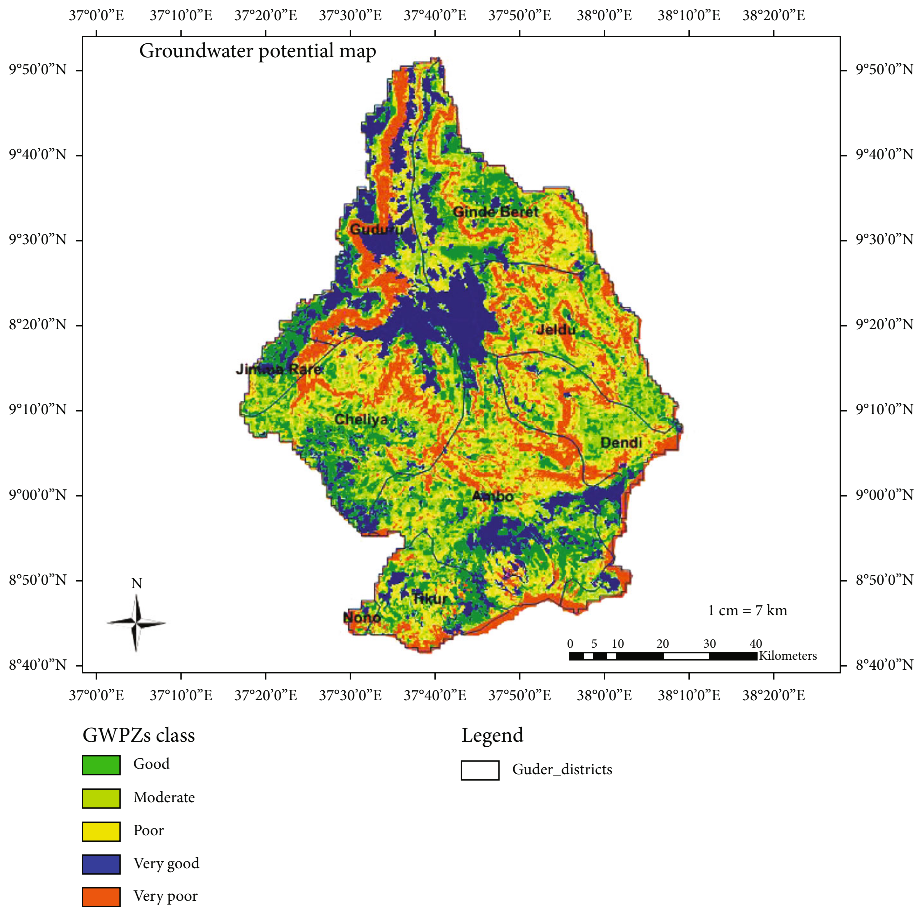


Figure 15: Map showing groundwater potential zones over the study area (districts).

Table 6: Pearson pairwise correlation of influencing factors.

	Soil type	Soil texture	Slope	Land use	Lineament	Geomorphology	Geology	Elevation	Drainage	Rainfall	Overall weightage
Overall weightage	.527**	.382**	.479**	.507**	.005*	.635**	.510**	.252**	.201**	.309**	1

**Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).

equal magnitude, whereas 22.9% (1578.8 km^2), 20.2% (1388.7 km^2), and 23.3% (1601.0 km^2) falls under "good," moderate, and "poor," respectively, of the delineated total area of Guder subbasin 100% (6883.5 km^2).

The high to very high groundwater potential zones are generally located in the middle, northeastern, and southern part, whereas low potential zones are in the western part of the study area, whereas low to very low GWPZs were found in the middle periphery mountainous area of the watershed. A very good zone indicates the most appropriate region of groundwater, but a low zone designates the least favorable for groundwater occurrence. The areas with escapements, hills and steep side slopes, slopy, and rock surfaces have shown poor GWPZs. Therefore, geomorphology has a critical influence on groundwater potential in comparison to other factors. Besides, slope steepness and type of formation (geology) play an essential role, as the areas with a steep slope and "lime stones" type of lithological formation have been certain with areas of very poor groundwater occurrence.

The study extends to validate GWPZs map with the observed well discharge data and conventional soil depth map graphically. The study is certain with high correlation coefficient value of 0.73 and kappa statistics value of 77%, respectively. According to the study, zones with high GWPZs revealed high soil depth and vice versa as compared to the soil map collected from OWWDSE.

This particular study also provides cost-effective, time-saving, and quick assessment of groundwater resources evidence for the stakeholders and kebele administration office, Woreda, and the society to understand the areas with high and low groundwater for ease management of these precious resources. It can also help policymakers' strategies to protect, exploit, and utilize available groundwater for different purposes.

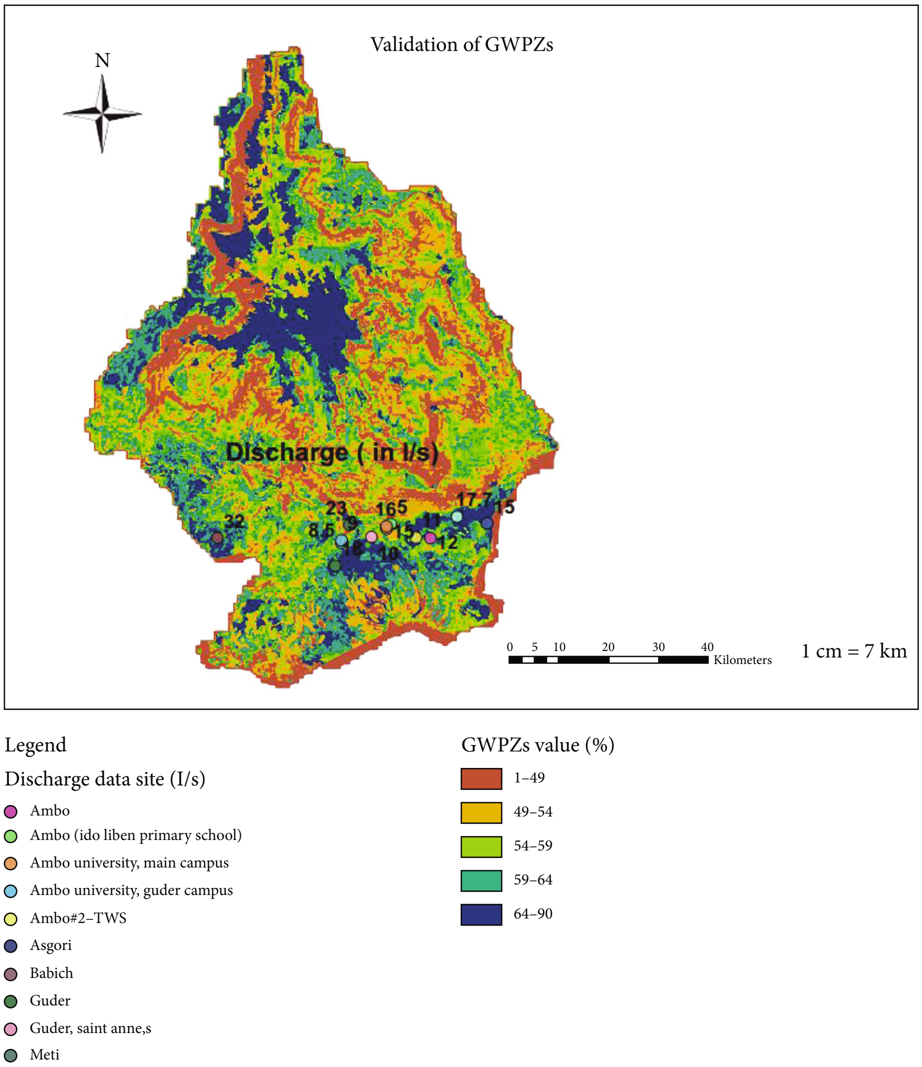


Figure 16: Validation map of GWPZs using well discharge data.

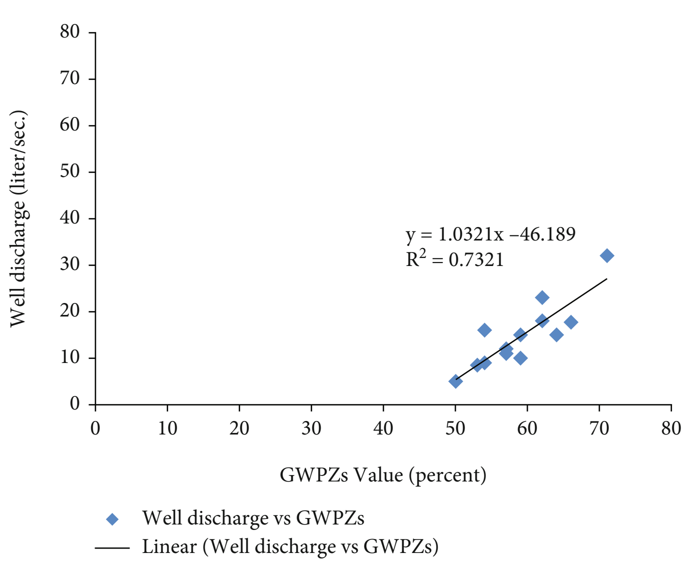


Figure 17: Correlation between GWPZs and well discharge.

Table 7: Kappa statistics value.

Observed Q (l/s)	Simulated	Difference (col1-col2)	1-col2	col3/col4
17.7	66	-48.3	-65	0.74
23	62	-39	-61	0.64
12	57	-45	-56	0.80
5	50	-45	-49	0.92
15	64	-49	-63	0.78
32	71	-39	-70	0.56
18	62	-44	-61	0.72
11	57	-46	-56	0.82
10	59	-49	-58	0.84
8.5	53	-44.5	-52	0.86
9	54	-45	-53	0.85
15	59	-44	-58	0.76
16	54	-38	-53	0.72
Average				77%

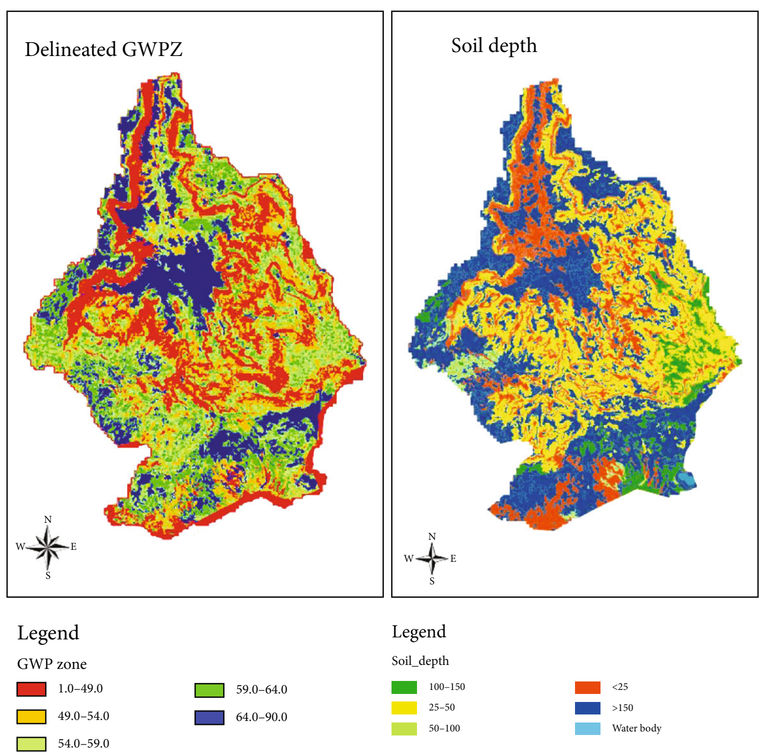


Figure 18: Map showing validation of GWPZs with soil depth.

Data Availability

The data used to support the findings of this study are included within the article. And the GIS and RS data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Both authors contributed to the whole study like study conception and design, material preparation, data collection, and analysis. The draft of the manuscript was written and submitted by the same authors.

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