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RESEARCH ARTICLE

GROUNDWATER POTENTIAL ZONE IDENTIFICATION USING REMOTE-SENSING-BASED/GIS BASED MACHINE AND ANALYTICAL HIERARCHY PROCESS (AHP) FOR ABBAY WATERSHED, EAST AFRICA

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ABSTRACT

This paper examines groundwater potential zones with the help of remote sensing and GIS methods for controlling and investigating the geospatial data of each parameter. Because of several conditions such as rapid population growth, urbanization, industrialization and agricultural development, groundwater sources are under severe threat. Climate change plays an important role in the quality and quantity of groundwater potential. Unreliable exploitation, poor quality of surface water resources tend to increase the decline in groundwater levels. This study was conducted in the Abbay River Basin, where groundwater serves as the main source for agricultural purposes rather than surface water. Seven selected parameters—lineament density, precipitation, geology, drainage density, land use, slope and soil data—were collected, processed, resampled, projected and reclassified for hydrological analysis. For generation of groundwater zones, weightage was calculated using an analytical hierarchy method. The consistency ratio estimated for this study was 0.089, which was acceptable for further analysis. Based on the integration of all thematic layers and the generated groundwater potential zones, the map was reclassified into five different classes, namely very good, good, moderate, poor and very poor. The results of this study reveal that 1295.33 km2 of the study area can be considered very poor, 58,913.1 km^2 is poor, 131,323 km^2 is moderate, 18,557 km^2 is good and 311.5 km2 is very good. Any groundwater management project performed in the better regions would offer the greatest value. A similar study would be valuable before planning any water resource development activity to save comprehensive field investigations.

KEYWORDS

Ground Water; Sensitivity Analysis; AHP; Thematic Layer; Watershed

1. INTRODUCTION

Groundwater comprises over 30% of the world's freshwater supply and is a critical natural resource (McStraw et al., 2021). Due to increasing agricultural, industrial, ecological and economic developments, the demand for groundwater has been increasing (Preeja et al., 2011; Hussein et al., 2016; Jasrotia et al., 2016). More than 80% of rural areas use groundwater for domestic purposes and 50% of urban areas use groundwater for domestic purposes. Due to being more dependent on groundwater usage for domestic purposes, agriculture and other sectors may cause the exploitation of groundwater resources (Shakak, 2015). Nearly two billion people use groundwater as their primary source of water (Alley et al., 2002). At least half of the world's food is grown using irrigation water extracted from groundwater, estimated to be a fundamental part of the global agricultural industry (Siebert et al., 2010). Using groundwater for water supply and irrigation agriculture is especially common in the dry, arid regions of the world that are most significantly affected by drought. Groundwater has been an essential source of water for areas located in arid and semi-arid regions. According to average global groundwater utilization increased by 3% per year between 1990 and 2010 (Wada et al., 2014). The quality and availability of surface water have also remarkably increased the demand for groundwater due to climate change and its extreme effects (Kirubakaran et al., 2016; Ibrahim and Ahmed, 2016).

Groundwater is an essential source of water for supporting human health and the environment (Serele et al., 2020). Safeguarding this natural resource from overexploitation serves as an essential part of water resource optimization and sustainability development. The recharge of aquifers in an area is affected by the capacity of the soil to conduct water and its ability to penetrate the aquifers. Groundwater is found mostly in the fractures and joints of geological conditions that were created due to lava flow. The formation of porosity is mostly influenced by geological formation and its weathering, which are noted essential factors that influence the downward movement of water to recharge an aquifer.

Groundwater is not only essential for domestic demands, but also important for different purposes, such as irrigation, agriculture and industrial demands. The spatial and temporal distribution of groundwater in the absence of depletion depends on aquifer recharge and groundwater conditions in the area of a groundwater potential zone (Manap et al., 2013). With regard to groundwater exploitation, most failures in drilling bore wells are due to improperly planned and randomly selected sites. So, decrease in the potential of aquifers to contribute to groundwater and reduced groundwater levels occur due to improper selection of sites in the region (Jha et al., 2007). Therefore, groundwater potential identification tries to solve the problem of appropriate site selection for groundwater

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exploitation for the purpose of groundwater management so as to maintain the sustainability of groundwater utilization.

Groundwater in many developing countries, including Ethiopia, is recognized as an important natural resource but remains unexploited for economic and social development (Fernandez et al., 2018; Gumma and Pavelic, 2013). In most African countries, the physical extent, accessibility and development potential of aquifer systems are not widely known (Hussein et al., 2016; Gumma and Pavelic, 2013). There is high water potential in Ethiopia and there is said to be a water tower in East Africa, but inefficient water resource management strategies lead to water shortages in the water supply and irrigation agriculture (Gebreyohannes et al., 2013).

Groundwater potential identification has been carried out using different methods, including geological models and drilling tests (Balbarini et al., 2017; Chen et al., 2011). These techniques are important for identifying the hydrological conditions of groundwater but have high cost in terms of time and money (Nampak et al., 2014; Helaly 2017). Identification of the groundwater potential zone via GIS and computers has been a key issue in recent years (Ghorbani et al., 2017; Sameen et al., 2019). Spatial distributions of groundwater for quantitative analysis have been found using GIS methods in environmental, geological and hydrological studies (Fernandez et al., 2018; Srinivasa and Jugran, 2003; Elmahdy et al., 2015). The great problem of groundwater analysis is the limitation of available data for analysis (Lee, 2017).

Due to recharge sources and hydrological conditions, the yield of groundwater varies, as only a limited number of groundwater wells have been measured (Hadžić et al., 2015). So, to plan groundwater projects accurately for sustainable development, estimation of the potential zone is essential for water resource optimization and management. Because of this reason, groundwater potential mapping using different data models has commonly been increasing (Golkarian et al., 2018; Kim et al., 2018; Rahmati et al., 2018). Different models and methodologies such as computers, statistics, probability and data mining models and factors such as location of well yield and springs were used to develop groundwater potential identification. GIS and remote sensing are essential for groundwater sustainability development due to the direct relationship of groundwater with GIS and remote sensing characteristics (Lee et al., 2019; Kim et al., 2019; Lee et al., 2019).

Groundwater potential estimation using GIS based/remote sensing and AHP utilizes land use, land cover, geology, geomorphology, precipitation, digital elevation models, slope, lineament density lithology, water depth characteristics and surface water bodies. Groundwater potential index values have been produced by combining all of the thematic weights with AHP techniques (Gdoura et al., 2015; Javed and Wani, 2009; Kaur et al., 2020; Gupta et al., 2010). These groundwater potential index values were then categorized, and groundwater potential maps for various geographical areas were produced (Rahmati et al., 2015; Shankar and Mohan, 2006; Murthy, 2000). However, the thematic layers used to estimate groundwater potential zones are different between studies and from region to region and the qualitative layers used were arbitrary.

Most of these studies rely heavily on drainage density, geomorphology, soil, land use, land cover and slope characteristics. Geology was included by (Sikdar et al., 2004; Madruci et al., 2008; Prasad et al., 2007; Chowdhury et al., 2009; Senanayake et al., 2016; Zaidi et al., 2015). Precipitation was included in for semiarid Andhar Pradesh; utilized water bodies; focused on water table depth, recharge rate and water bodies; included digital elevation models; and lineament density and precipitation were also utilized as a thematic layer for groundwater potential identification (Murthy, 2000; Jha et al., 2010; Senanayake et al., 2016; Agarwal and Garg 2016; Ibrahim and Ahmed, 2016; Machiwal et al., 2011). In this study, seven variables were selected to estimate the groundwater potential zone map of the study area.

Groundwater assessment in Ethiopia has been mostly conducted via field survey, which is either tedious to handle in terms of time and resources or conducted locally with limited data (Hussein et al., 2016). In the present study area, due to varied topography, groundwater exploration is a challenging task and there is little explicit information about the benefits of groundwater utilization for water supply and agriculture (Worqlul et al., 2017). The absence of reliable hydrological data, insufficient knowledge of aquifer structure and properties, and limited technology are among the major problems (Worqlul et al., 2017; Hagos and Mamo, 2014). So, it is important to understand the nature of aquifers and look into cost-effective and user-friendly tools and methods for the proper delineation, utilization and management of groundwater resources. Very limited studies are available in the Ethiopian context in general and the Blue Nile watershed in particular related to groundwater potential mapping.

Hence, to fill the gap, we used an ArcGIS/remote sensing-based and analytical hierarchy method to generate groundwater potential zones of the Abbay River Basin using hydro-metrological and geospatial features. To identify groundwater potential zones, a weighted overlay algorithm of a spatial analysis tool of ArcGIS 10.4 was utilized. An AHP technique was used in the GIS environment to estimate the relative weights of each thematic layer. As a result, groundwater potential zones for the study area were created. An estimated groundwater potential zone accurately indicates key sources, aiding groundwater potential optimization and the development of proper management plans for sustainable groundwater monitoring and exploitation. In general, the main objective of this study was to identify groundwater potential zones in the Abbay watershed by using remote sensing and analytical hierarchical process techniques by integrating the thematic maps and various spatial domains of ArcGIS to make guidelines for decision makers to identify suitable groundwater potential for optimization and planning policies within an area.

The specific objectives of the study can be organized as follows:

To identify factors that affect groundwater potential zone and prepare thematic maps;

To identify and delineate groundwater potential zones through integration of various thematic layers with ArcGIS and remote sensing techniques;

To assess the sensitivity of each thematic layer and identify its effect on the identification of groundwater potential zone

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The Abbay watershed (Figure 1) is located in the northwestern part of Ethiopia at 7°40′N and 12°51′N latitude and 34°25′E and 39°49′E longitude with an area of approximately 176,200 km^2 and an elevation difference from 483 to 4266 m AMSL. The Abbay River is an essential river for Ethiopia, and the Grand Renaissance Dam of Ethiopia was constructed on it. The river starts in the high mountainous part of Ethiopia and serves as a contributor to the Nile River. It is located in an area where water is a critical resource for domestic use and irrigation agriculture. The upstream part of the river basin is dominated by mountainous landscapes and most of the downstream areas are relatively flat or gently undulating. There are varying climatic zones in the river basin due to environmental conditions. The maximum temperature of the river basin ranges from 28 °C to 38 °C and the minimum temperature is 15 °C to 20 °C downstream. Generally, rainfall in the study area ranges between 787 mm and 2200 mm per year and the lowest rainfall recorded was less than 100 mm per year.

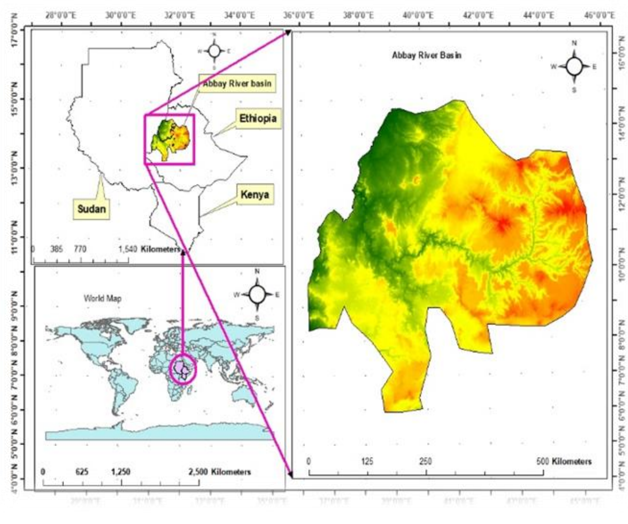


Figure 1: Location of study area.

2.2 Data Description, Software and Methods

The input data used in this study to identify groundwater potential zones of the watershed included spatial data, involving a digital elevation model of the study area for the delineation and definition of streams, to generate drainage density, lineage density and slope. Secondary data, which were modified and used, were precipitation, geology, land use, land cover and soil map of the area. Individual features of each thematic layer were classified into very poor, poor, moderate, good and very good based on their suitability for groundwater occurrence.

2.2.1 Method

1. Estimation of the groundwater potential map by using GIS and remote sensing has become a commonly utilized method in recent years (Gumma and Pavelic 2013; Sikdar et al., 2004; Madrucci et al., 2008; Machiwal et al., 2011; Jha et al., 2009; Mehrahi et al., 2013; Nithya et al., 2019; Patra et al., 2018; Saidi et al., 2017; Chi et al., 1994; Krishanmurthy and Srinivas, 1995; Kamaraju et al., 1995; Kamaraju et al., 1995; Krishnamurthy et al., 1996; Sander et al., 1996; Edet et al., 1998; Saraf and Choudhury, 1998; Shahid et al., 2000; Rao and Jugran, 2003; Sener et al., 2005; Solomon and Ouiel, 2006; Sahu and Sikdar, 2011; Kaur et al., 2020; Pandey et al., 2013; Manap et al., 2012; Jaiswal et al., 2003; Khodei and Nassery, 2011; Ganapuram et al., 2009; Bera and Bandyopadhyay, 2012; Ravi and Mohan, 2006; Dar et al., 2010).

2. Groundwater potential represents the amount of groundwater available in an area and it is a function of several hydrologic and hydrogeological factors (Jha et al., 2010). From a hydrogeological point of view, this term indicates the possibility of groundwater occurrence in the area. In this study, seven variables were selected to estimate the groundwater potential zone map of the study area. First, feature maps of all variables were prepared. Second, all thematic layers were converted to a raster format, resampled and reclassified based on its effect on the groundwater recharge. Finally, the groundwater potential zone map was generated by overlaying all the thematic layers using an ArcGIS weighted overlay. The generalized methodology for assessing groundwater potential zones is presented in Figure 2 below.

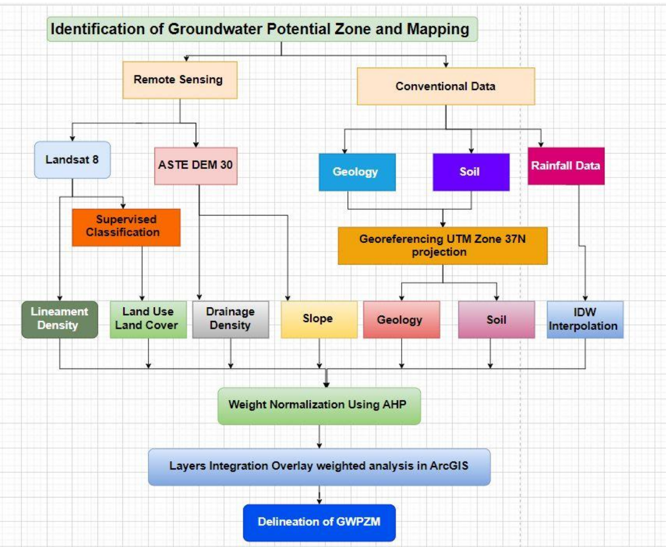


Figure 2: Flow chart for method of groundwater potential mapping.

2.2.2 Digital Elevation Model (DEM) Data

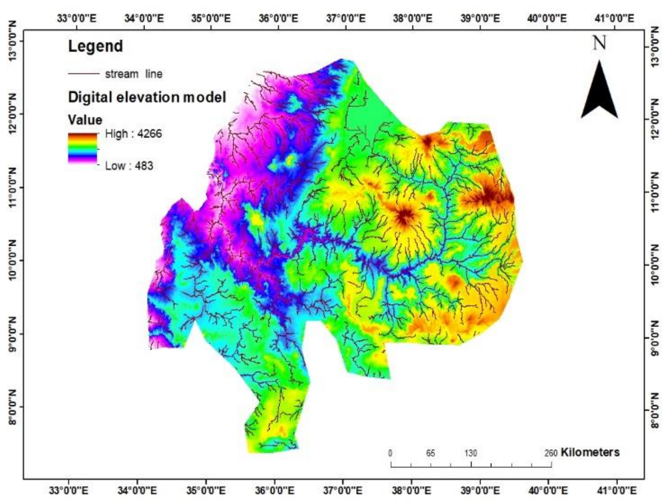


Figure 3: Digital elevation model.

Figure 3 is a DEM of the Blue Nile watershed at the high resolution of (30 m × 30 m) arc second from the United States Geological Survey (USGS) website (https://earthexplorer.usgs.gov/2022/09/28/2:15). A digital elevation model is a geographic information system that describes the topography of an area. To prepare the drainage density, slope, lineament density and elevation map, either SRTM or ASTER DEM 30 m data are important. In this study, SRTM DEM 30 m data were selected since they are more accurate both in their vertical and horizontal accuracy than ASTERM DEM.

2.2.3 Land Use Land Cover Data

For developing countries, understanding land use types has been essential for making decision systems in order to maintain sustainable natural resources. For the identification of groundwater potential zones, land use type is affected by decreasing runoff and increasing the infiltration of water to recharge the aquifer (Ibrahim and Ahmed, 2016). Areas covered by agricultural vegetation have opportunities to recharge ground water, but settlement areas poorly recharge aquifers (Shifaji and Nitin, 2014). The land use type of the study area was classified into seven classes such as built area, bare land, rangeland, trees, cropped area, flooded vegetation and water body. Land cover is the most important factor for groundwater potential mapping. To produce the land use land cover map (Figure 4) of the study area, sentinel-2 10-meter land use/land cover data were used; they were downloaded from (https://livingatlas.arcgis.com/landcover /2022/09/26/4:30) and clipped with the study area.

For the produced land use, land cover supervised image classification was used and the accuracy of image calcification was analyzed by using the confusion matrix of the spatial analysis tool of ArcGIS. Kappa value (k) is a statistical coefficient that is used to calculate classification accuracy. It is generated using a probability matrix. According to some researchers when the kappa value is 75% or more, the classification accuracy is considered to be very excellent, when it is between 40% and 75%, it is considered to be medium-good, and when it is below 40%, it is considered to be weak (Demir and Keshin, 2020; Ayhan et al., 2007). The estimated kappa value for this study area was 84%, which is very good and was acceptable for further hydrological analysis. The scoring of land use land cover classes was decided based on the character of each land cover feature in terms of contributing to runoff.

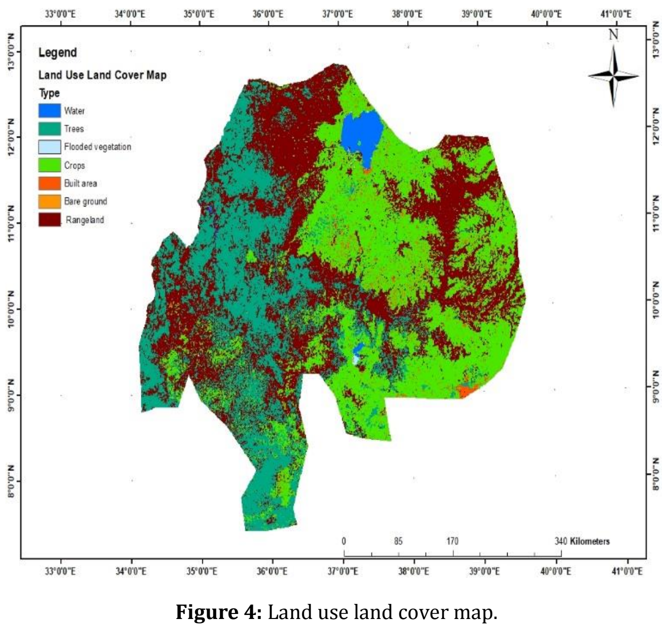


Figure 4: Land use land cover map.

2.2.4 Lineament Density

Lineaments are linear or curvilinear structures that represent the fractured zone, such as faults and dikes in the geological arrangement of an area, arranged as a secondary aquifer in hard rock (Kirubakaran et al., 2016; Nag and Ray, 2015, Mogaji et al., 2016; Selvam et al., 2015). Lineaments are excellent indicators for aquifer recharge in the hydrological systems of a watershed. PCI geomatica 2018 is the essential technique for the extraction of lineaments (Mahmoud and Alazba, 2016). To extract lineaments, the DEM of the study area was used and lineament features were developed using the algorithm librarian-BIT2LINE of PCI Geomatica for lineament extraction. Then, by using a line density algorithm function in the ArcGIS spatial analysis tool, a map of lineament density was created (Figure 5). The value of lineament density ranges from 0.0 km/km2 to 1.58 km/km^2.

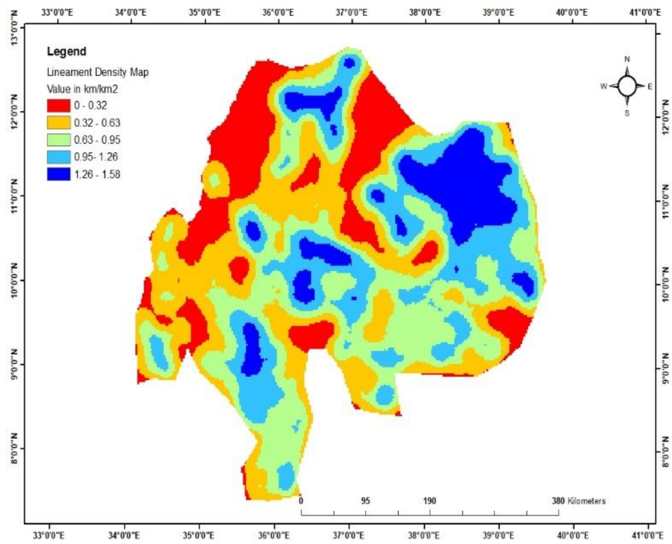


Figure 5: Lineament density map of the study area.

2.2.5 Precipitation

Rainfall is one of the parameters used to estimate groundwater potential zones, and knowing the nature and characteristics of precipitation, its effects on runoff, infiltration and groundwater recharge can be conceptualized (Karami et al., 2016). Aquifer recharge is a function of the amount of rainfall (Mogaji et al., 2016). For hydrological analysis, it is important to know the area distribution of precipitation that may contribute to groundwater recharge and create a potential area. Blue Nile watershed precipitation was extracted from PERSIANN (Precipitation Estimation from Remotely Sensed Information Using Artificial Neural Networks), which was developed by the Center for Hydrometeorology and Remote Sensing (CHRS), available on their website (http://chrsdata.eng.uci.edu//2022/10/28/8:15), and Blue Nile basin rainfall stations acquired from a national metrology agency.

Since the rainfall gauges measure point data, these should be converted to the rainfall in the area via interpolation techniques used to prepare the rainfall map. Rainfall rate data from PERSIANN was estimated at each 0.25° × 0.25° pixel of the infrared brightness temperature image provided using geostationary satellites with coverage of 60° S to 60° N globally. Rainfall data were available from March 2000 to the present as hourly, 3-hour, 6-hour, daily, monthly and yearly. For this study, yearly precipitation records from 2020 to 2021 were extracted from PERSIANN and used for analysis. The annual rainfall of the river basin ranged from 510 to 2572 mm and was classified into five rainfall zones (Figure 6). Zones with low rainfall were classified as very poor groundwater potential and areas with a high amount of rainfall were classified as very good groundwater potential due to the direct influence of rainfall on contributing to the amount of water available for infiltration into groundwater.

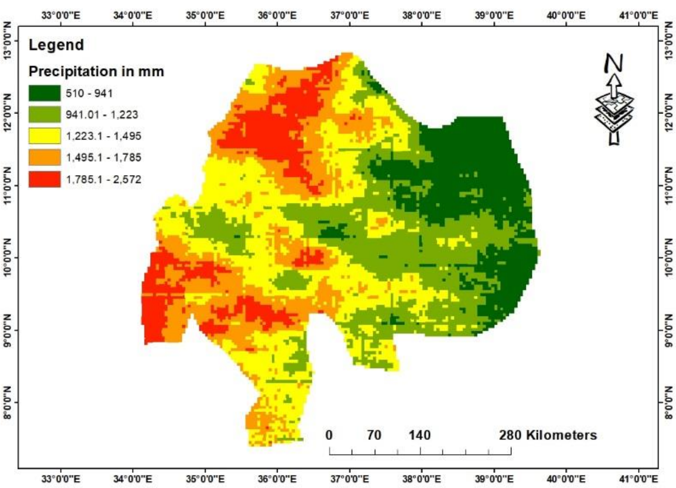


Figure 6: Precipitation map of the study area.

2.2.6 Geology

Groundwater recharge is governed by the geology of the area (Nair et al., 2019). This is due to the fact that porous rocks contribute a high amount of water to groundwater storage and impermeable aquifers contribute a lower amount of water to groundwater storage. Ethiopia contains a mixture of ancient crystalline basement rocks and volcanic rocks of different ages (Smedley, 2001). Water flow in the aquifer is influenced by the geological formation of the area. During geological formation, joints, faults and fractures are created and govern groundwater flow. This watershed consists of different geological formations, such as Cenozoic, Cretaceous and Jurassic, Jurassic, Lower Jurassic, Precambrian, Quaternary, Quaternary volcanic, Tertiary extrusive and intrusive rock, Triassic and Permian, and water bodies. These geological data were extracted from a USGS Geology survey and georeferenced, clipped by study area shadflies, converted to a raster data set, resampled, reclassified, and projected to UTM zone 37 for hydrological analysis using ArcGIS 10.4. Depending on sedimentation, rocks having high porosity were grouped under very good groundwater potential and unconsolidated sediments were grouped into very poor aquifer recharge. The geological map of the study area is presented in Figure 7 below.

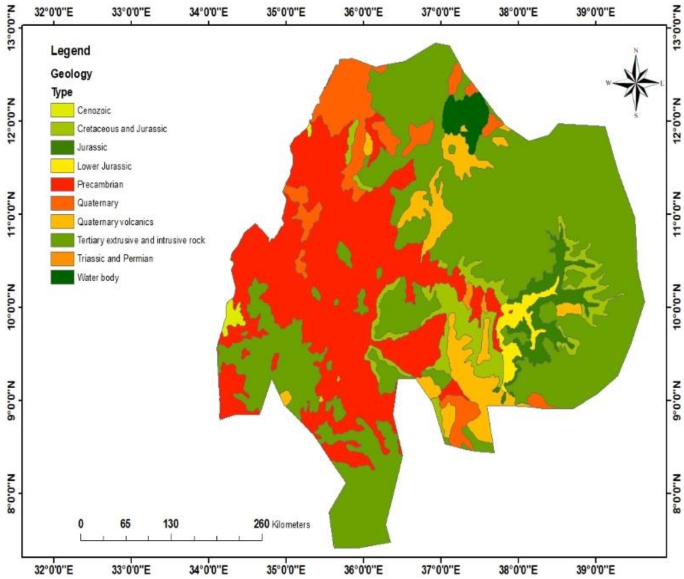


Figure 7: Geological map of the study area.

2.2.7 Slope Gradient

For groundwater potential assessment, slope was an important variable inversely correlated with surface water infiltration (Kirubaran, 2016). GIS was used to create a slope from ASTER GDEM with a 30 m resolution. The watershed had a slope ranging between 0° and 78°. Because of low runoff in flat areas, the groundwater recharge was very good for low slope and very poor for high slope. A slope of less than 5.5° was considered a relatively flat slope that would contribute a very good water supply to the aquifer. A slope greater than 31.7° would contribute very poorly to recharging the aquifer due to rapid runoff. The slope map of the study area is presented in Figure 8 below.

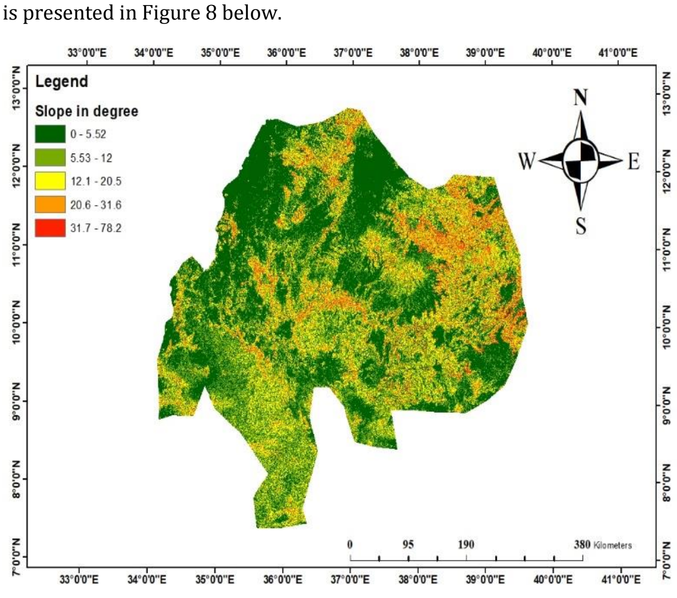


Figure 8: Slope map of the study area.

2.2.8 Soil

Due to the characteristic traits of transmissivity and water-bearing capacity, soil type identifies the recharge rate of the aquifer (Kirubaran, 2016). Due to the direct relations of infiltration, percolation, and permeability, soil type significantly affects the movement of surface water into groundwater systems (Ratnakumari et al., 2012). For this study, the study area's soil map (Figure 9) was extracted from a FAO soil map of the world, converted to a raster dataset, projected, resampled, and reclassified for hydrological analysis. The dominant soil type in the study area included clay loam, clay, water, loam and sandy loam. Suitability ranks for groundwater recharging were assigned to each soil type according to their multiple characteristics (Gumma and Pavelic, 2013; FAO, 2006; Pothirai and Rajagopalan, 2013). Clay soil had low permeability and would contribute a low amount of water to the aquifer, while sandy loam had high permeability and would contribute a high amount of water to the aquifer.

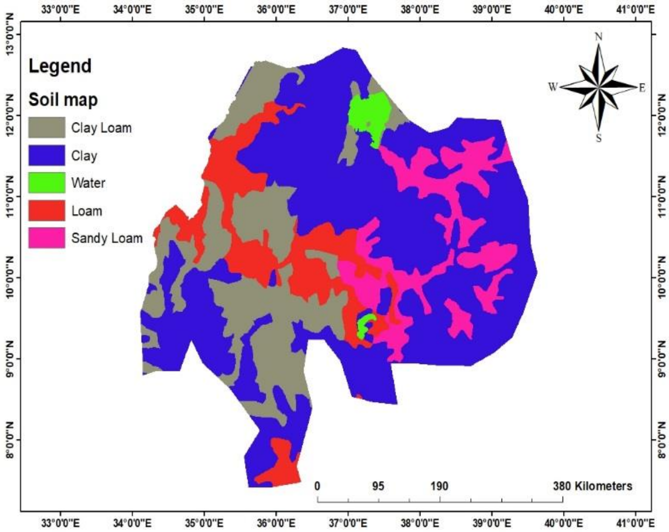


Figure 9: Soil map of the study area.

2.2.9 Drainage Density

Drainage density indicates the nearness of the spaces between stream channels and is inversely related with infiltration and runoff distribution (Jha et al., 2010; Ibrahim and Ahmed, 2016). The drainage lines of the watershed were prepared from ASTER GDEM- 30 m using the hydrology tools of GIS. The prepared drainage density (Figure 10) was classified, resampled and projected for hydrological analysis, ranging from 0.1 km/km^2 to 0.5 km/km^2.

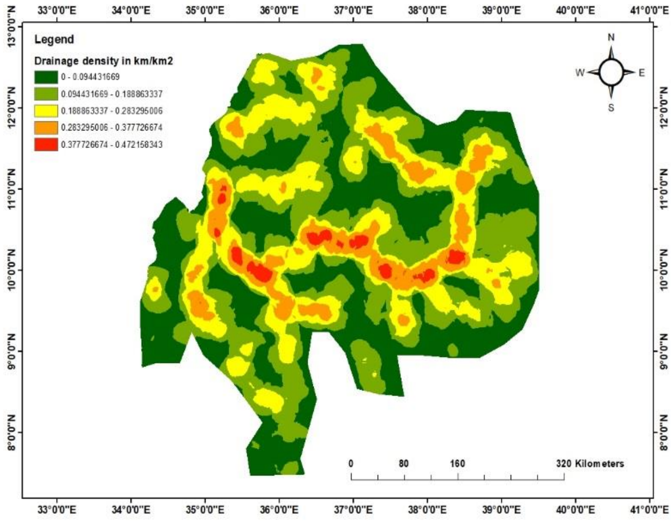


Figure 10: Drainage density of the study area.

2.3 Methods for Identification of Groundwater Potential Zones

Groundwater exploration methods are grouped into several methods but can be generalized into two groups. This method was an advanced and conventional approach. Aquifer potential estimation and conventional approaches utilize earth surveys. Sensitivity analysis and probabilistic approaches are considered conventional methods. Due to complex parameters for the examination of aquifer potential, exploration via conventional techniques has been difficult (Singh et al., 2013, Jose et al., 2012). However, GIS is essential due to its characteristics of storing spatial and non-spatial data integrated into a single system (Prabhu and Venkateswaran, 2015). Remote sensing and ArcGIS are essential for water resource assessment, with applications including aquifer recharge, water quality modeling of subsurface water, and others for water resource optimization and management (Manap et al., 2013). Remote-sensing-based techniques were applied to this research for data analysis by using an analytical hierarchical process (AHM) by overlaying selected thematic layers with the spatial analysis tool of GIS.

2.3.1 Analytical Hierarchical Process (AHP)

Solving the weightage of parameters based on their effect on an objective function is an approach created by Professor Thomas L. Saaty in 1980 using a multi-criterion approach (Zhang et al., 2021).

2.3.2 Calculation and Normalization of Weights

The analytic hierarchy process (AHP) is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. It was developed by Thomas L. Saaty in 1970s. AHP techniques based on ArcGIS have been utilized worldwide to conduct academic research for evaluating complex spatial issues (Rahmati et al., 2015). By reasonable assessment, weights are assigned to each established parameter using AHP (Saaty, 1987).

The steps used to assign weights via the AHP method are shown below:

1. The groundwater potential zone mapping goal is defined.
2. According to Saaty, the occurrence and movement of groundwater for each factor are decided and their weight, scaled from 1 to 9 for each factor, is defined depending on the degree of influence in Table 1 below.

Table 1: Fundamental Scale of Saaty for Evaluation.

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; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
2,4,6,8	Can be used to express intermediate values	

Source: (Zhang et al., 2021).

The pairwise comparison matrix (M) was established based on the relative weight of the selected factors.

$$M = \begin{bmatrix} m_{11} & m_{12} & \cdots & m_{1n} \\ \vdots & & \ddots & \vdots \\ m_{n1} & m_{n2} & \cdots & m_{nn} \end{bmatrix} \quad (1)$$

where m_{nn} represents the relative scale weight of the pairwise factor.

For pairwise comparison, the matrix geometric mean was calculated as follows:

$$GMn = \sqrt{m1n * m2n \ldots\ldots mnN} \quad (2)$$

where GMn indicates the geometric mean of the nth row's elements.

The normalized weights (Wn) were estimated from the matrix as follows:

$$Wn = \frac{GMn}{\sum_{n=1}^{N} GMn} \quad (3)$$

The consistency index was estimated as follows (Kaur et al., 2020):

$$\text{Consistency Ratio}(CR) = \frac{Consistency\ Index(CI)}{Random\ consistency\ Index(RCI)} \quad (4)$$

Random consistency indices were taken from Saaty's standards and are presented in Table 2 below:

Table 2: Saaty's Consistency Indices of Randomly Generated Reciprocal Matrices.

Order of the Matrix	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
RCI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Source: (Machiwal et al. 2011).

Consistency index values were calculated using the following equation.

$$CI = \frac{\lambda max - n}{n-1} \quad (5)$$

where λmax is the principal eigenvalue calculated through the eigenvector calculation process. A CR of less than or equal to 0.1 indicates that AHP analysis should be continued, and if CR is greater than 0.1, it is necessary to modify the evaluation to determine the cause of inconsistency and then correct it until CR is less than or equal to 0.1.

2.4 Integration of Thematic Layers

The evaluation of aquifer potentials is a dimensionless parameter used to understand groundwater in an area (Rahmati et al., 2015). By using conversion tools, all data used for the research were converted from a vector map to a raster. To appraise the groundwater zone (GWPZ), a weighted linear order approach was used to evaluate the overall derived weights of the factors; then, the factors were normalized and then overlaid using GIS according to Equation (6) below (Gdoura et al., 2015; Krishnamurthy et al., 1996; Malczewski, 1999; Foster and Chilton, 2003; Arshad et al., 2020; Roy et al., 2020):

$$GWPZ = \sum_{i=1}^{n}\sum_{w=1}^{m}(w_i * X_j) \quad (6)$$

where W_i is the normalized weight of the j thematic layer, X_j is the rank value of each class with respect to the j layer, and m is the total number of the thematic layer. GWPZ was calculated for each grid by using Equation (7) below.

$$GWPZ = L_{cw} * L_{cr} + D_{dw} * D_{dr} + L_{dr} * L_{dw} + S_{cw} * S_{cr} + S_{lw} * S_{lr} + G_{ew} * G_{er} + R_{fw} * R_{fr} \quad (7)$$

where L_C is land use land cover, D_d is drainage density, S_l is slope, L_d is lineament density, G_e is geology, S_c is soil type, and R_f is rainfall. The subscripts "w" and "r" indicate the weight of a feature and the rate of the individual sub-classes of a feature based on their relative influence for groundwater potentiality, as shown in Table 3 below.

Table 3: Groundwater Storage Potential Rating Ranges.

Range	**Description**
1	Very poor
2	Poor
3	Moderate
4	Good
5	Very good

Sources:(Mu and Pereyra 2017, Kumar et al. 2014).

2.5 Sensitivity Analysis

Sensitivity analysis can be calculated by ignoring individual parameters used in the AHP. There is significant change due to the ignorance of a specific feature in the result of aquifer potential evaluation (Mandal et al., 2016). The sensitivity analysis was calculated using Equation (8) below.

$$SVA_i^{\ j} = \frac{S_i^{\ j} - S_F^{\ j}}{S_F^{\ j}} * 100 \quad (8)$$

where i is parameter number and j is type of potential zone. $SVA_i^{\ j}$ is change in percentage (±) in the j^{th} type of groundwater potential zone area due to the ignorance of n of the i^{th} feature. $S_i^{\ j}$ is the jth type of groundwater potential zone area due to the absence of n of the i^{th} feature and $S_F^{\ j}$ is the j^{th} type of groundwater potential zone area using all features.

2.6 Multi-Collinear Analysis

For ground water potential assessment to be carried out, multi-collinearity among the parameters needs to be assessed. Multi-collinearity is when at least one input factor of a multivariate model is highly correlated with the combination of other input factors. The multi-collinearity among all variables was estimated using the R-square value to estimate the variance and the tolerance inflation factor of the given input parameters by using Equation (9, 10) as below (Mukherjee and Sing, 2020). R-square shows the fitness of a regression equation to the variables. The higher the R-square value, the lower the tolerance for multi-collinearity, which shows that the variable is well fitted by the combination of other variables and the multi-collinearity is severe. The variance inflation factor is the degree to which multi-collinearity inflates the variance of estimated regression. The variance inflation factor must be less than 10, corresponding to a tolerance greater than or equal to 0.1, but when the variance inflation factor is greater than 10 and the tolerance is less than 0.1, then there is a multi-collinearity problem and the selected variable must be excluded (Saha, 2017).

$$Tolerance = 1 - R^2 \quad (9)$$

$$\text{Variance inflation factor} = \frac{1}{Tolerance} \quad (10)$$

For the study area, 500 points were randomly selected using ArcGIS tools to estimate the multi-collinearity of the selected variable for ground water potential zone mapping by taking one parameter as dependent and others as independent variables to perform linear regressions by using XLSTAT.

3. Result

3.1 Analytical Hierarchy Process (AHP) Weightage Assessment of the Thematic Layers

Table 4: Assigned Ranks for Selected Thematic Layer.

	Criteria		More important?	Scale
J	A	B	A or B	(1-9)
2	Lineament Density	Precipitation	A	3
3		Geology	A	3
4		Drainage Density	A	6
5		LULC	A	7
6		Slope	A	5
7		Soil	A	9
3	Precipitation	Geology	A	3
4		Drainage Density	A	9
5		LULC	A	9
6		Slope	A	7
7		Soil	A	5
4	Geology	Drainage Density	A	3
5		LULC	A	3
6		Slope	A	5
7		Soil	A	7
5	Drainage Density	LULC	A	2
6		Slope	A	3
7		Soil	A	4
6	LULC	Slope	A	3
7		Soil	A	1
7	Slope	Soil	A	2

By using AHP for the selected parameters, weights were assigned to each thematic layer (Manap et al., 2013; Machiwal et al., 2011; Chowdhury et al., 2010). Based on the relative influence of the thematic layer on groundwater potentiality, rank assessment was carried out for each class (Kumar et al., 2014). Rankings from 1 to 5 were adopted (Sleight et al., 2016). This is because all variables did not equally contribute to the ground in an area, as presented in Table 3 (Saaty 1980). As indicated in the procedure, the normalized weights for the selected thematic layers were calculated using Equation (3). Weights were assigned to each parameter from 1 to 9 (Table 1) for groundwater potential zone mapping based on parameter influence with regard to contributing to groundwater recharging and these are presented in Table 4. Then, by using a pairwise comparison matrix, all the thematic layers were analyzed, and for individual thematic layers, normalized weights were calculated and are presented in Table 5 below.

Based on the influence of the thematic layer, the variance influence factor was calculated using Equation 10 and the results show that the variance inflation factor for all variables was less than 10 and the tolerance values were greater than 0.1, which indicates that there was no collinearity between the selected seven variables, so uncertainty in the model result is not significant (Saha, 2017). The average consistency vector for this study was 7.72. The estimated consistency index was 0.32, the consistency ratio for all variables was 0.089, which is less than 0.1, and the pairwise index was 0.133. The consistency ratio is acceptable and shows that the result is validated by further data analysis for matrices higher than 4x4 (Saaty, 1980). So, the weights of 0.37, 0.3, 0.14, 0.07, 0.05, 0.04 and 0.03 can be assigned to the variables of lineament density, precipitation, geology, drainage density, land use land cover, slope and soil type, respectively. They are presented in Table 5 below.

Table 5: The Calculated Normalized Weightage for Each of The Seven Parameters.

Factors		Lineament Density	Rainfall	Geology	Drainage Density	Land use Land cover	Slope	Soil	Normalized Principal Eigenvector
		1	**2**	**3**	**4**	**5**	**6**	**7**	
Lineament density	**1**	**1**	3	3	6	7	5	9	37 %
Rainfall	**2**	1/3	**1**	3	9	9	7	5	30%
Geology	**3**	1/3	1/3	**1**	3	3	5	7	14%
Drainage density	**4**	1/6	1/9	1/3	**1**	2	3	4	7%
Land use land cover	**5**	1/7	1/9	1/3	½	**1**	3	1	5%
Slope	**6**	1/5	1/7	1/5	1/3	1/3	**1**	2	4%
Soil	**7**	1/9	1/5	1/7	¼	1/1	½	**1**	3%

3.1.1 Weightage of Lineament Density for Identification of Groundwater Potential Zones

Lineament density (Figure 5) was extracted from DEM with PCI Geomatica 2018 using the algorithm librarian-BIT2LINE for lineament extraction. By using the GIS line splitting algorithm, the line was split at its vertices. Then, by using the GIS line algorithm, the lineament density for the study area was calculated and reclassified (Figure 11). The weightage for lineaments was reclassified into five classes and a rank for each class was assigned. For lineaments, the density range from 0 to 0.316 km/km^2 is very poor for aquifers, classified as rank 1; from 0.317 to 0.632 km/km^2 is a poor contribution, classified as rank 2; a range from 0.633 to 0.948 km/km^2 is moderate, classified as rank 3; from 0.949 to 1.26 km/km^2 is good, classified as rank 4; and the very good range is from 1.27 to 1.58 km/km^2, classified as rank 5. This is due to the direct relation of lineament density to aquifer recharging (Bhuyaneswaran et al., 2015; Al-Djazouli et al., 2021). The calculated weight for lineament density was 0.37.

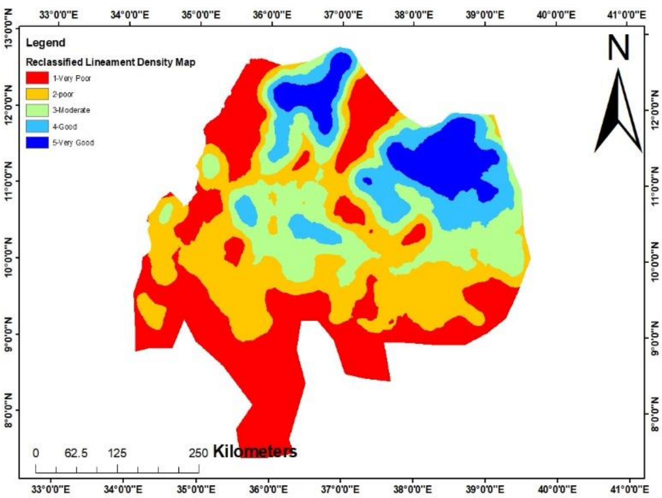


Figure 11: Reclassified lineament density of the study area.

3.1.2 Weightage of Land Use Land Cover for Identification of Groundwater Potential Zones

Land use gives necessary information regarding infiltration, soil moisture and surface runoff, which affects groundwater occurrence (Pinto et al., 2015). Crop land reduces surface runoff, while barren and settlement areas increase runoff (Muralitharan, 2015). The classified land use land cover presented in Figure 4 was reclassified (Figure 12) into five classes and ranked based on contribution towards ground water recharging from 1 to 5. Water bodies were considered as very good, classified as rank 5; flooded vegetation was considered as good, classified as rank 4; crops/trees were considered as moderate, classified as rank 3; rangeland contributes poorly to aquifer recharging and was considered as poor, classified as rank 2; and built area/barren ground contributes very little water to an aquifer and was considered as very poor with regard to groundwater contribution, classified as rank 1. The calculated weight for land use type was 0.05.

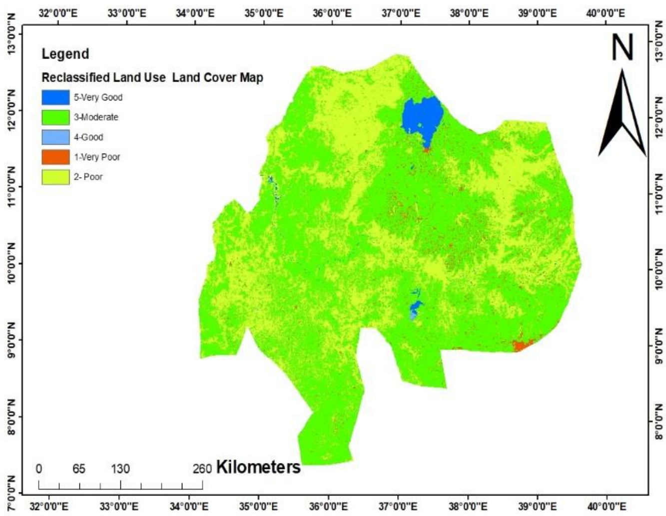


Figure 12: Reclassified land use land cover map of the study area.

3.1.3 Weightage of Soil Type for Identification of Groundwater Potential Zones

Soil properties affect the relationship between surface runoff and infiltration rates, which in turn controls the degree of permeability, which determines groundwater potential zones (Tesfaye, 2010). Soil texture is a medium that controls the vulnerability of groundwater. Textural classes in the study area included clay, clay loam, loam, sandy loam and water bodies. For each class, a rank was given based on its infiltration rate and the permeability of the soil with relation to aquifer recharging. Clay soil has low permeability and contributes very little water to aquifers, so it was classified as rank 1; clay loam conducts better than clay and was considered to poorly contribute to aquifer recharging, so it was classified as rank 2; loam soil contributes moderate water to aquifers and was classified as rank 3; sandy loam has higher permeability and contributes well to aquifer recharging, so it was classified as rank 4; and finally, water bodies contribute very well to aquifer recharging and were classified as rank 5. The reclassified soil map is shown in Figure 13. The calculated weight for soil was 0.03.

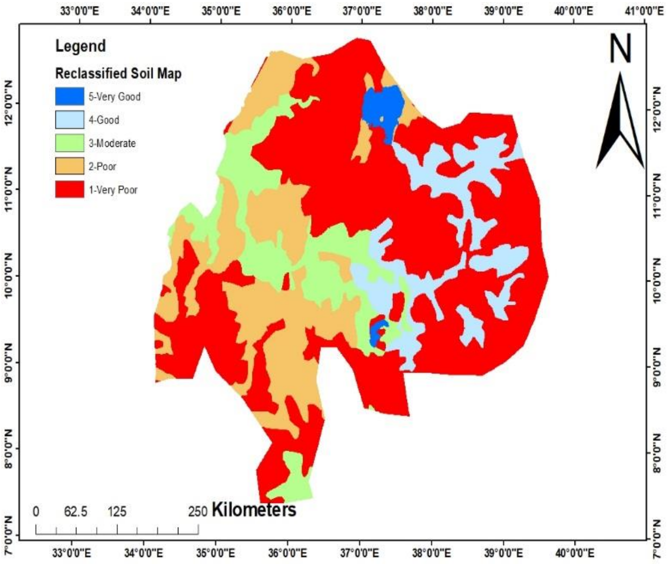


Figure 13: Reclassified soil map of the study area.

3.1.4 Weightage of Slope Type for Identification of Groundwater Potential Zones

As presented in Figure 8, the study area has varying degrees of slope value from 0 to 78⁰. Flat areas are capable of holding rainfall and increasing groundwater compared to steep sloped areas where water moves quickly. For further analysis, the generated slope was reclassified into five classes and a rank was given to each class based on its steepness and groundwater contribution (Sisay, 2022). For this study, the slope ranges from 0 to 5.5 were considered to have very good contribution, classified as rank 5; from 5.5 to 12 was considered as good, classified as rank 4; from 12 to 20.5 was considered as moderate, classified as rank 3; from 20.5 to 31.6 was considered as poor, classified as rank 2; and greater than 31.6 was considered to have poor groundwater contribution, classified as rank 1. The reclassified slope map is presented in Figure 14. The calculated weight for slope was 0.04.

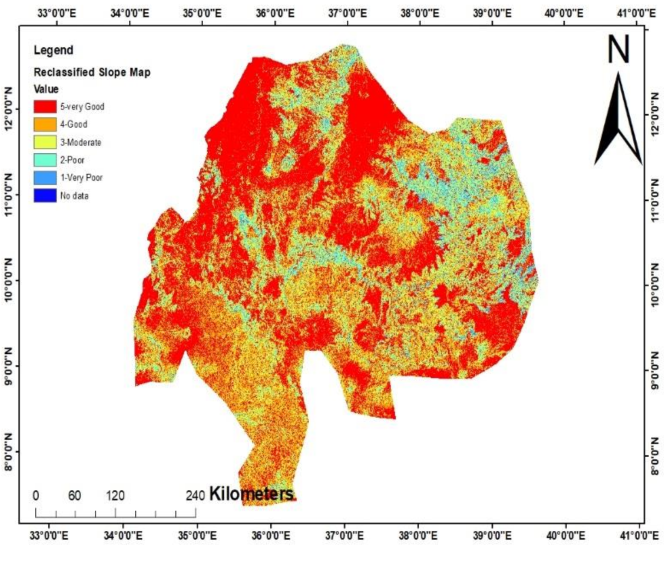


Figure 14: Reclassified slope for the study area.

3.1.5 Weightage of Geology for Identification of Groundwater Potential Zone

The generated geological map (Figure 7) was reclassified (Figure 15) into five classes and values for each given geological type. The classification was as follows: Cretaceous, Jurassic/Jurassic/Lower Jurassic/Triassic and Permian were very poor, classified as rank 1; Tertiary extrusive and intrusive rock were poor, classified as rank 2; Quaternary/Quaternary volcanic was moderate, classified as rank 3; Precambrian/Cenozoic was good, classified as rank 4; and water was very good, classified as rank 5. Hydraulic conductivity and permeability were determined from different, related work regarding these layers of geological formation. The calculated weight for geology was 0.14.

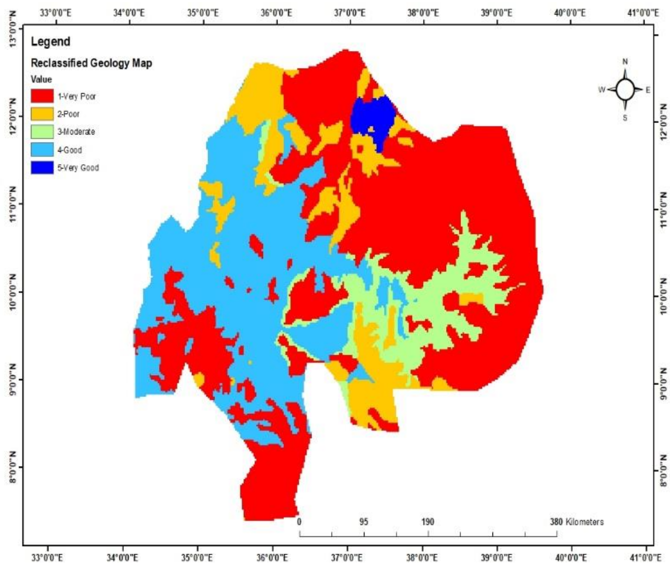


Figure 15: Reclassified geological map of the study area.

3.1.6 Weightage of Precipitation for Identification of Groundwater Potential Zones

River basin precipitation changes from place to place due to environmental conditions. Precipitation is one of the most important variables that affects groundwater recharging, and the water that could percolate into groundwater is a function of the amount of precipitation (Mogaji et al., 2016). One-year precipitation data were used for this study to estimate groundwater potential zones. Due to the direct relation of precipitation to recharge, aquifer recharging rank was given to each class. Precipitation ranging from 510 to 941 mm was considered as very poor, classified as rank 1; from 941.1 to 1223 mm was considered as poor, classified as rank 2; from 1224 to 1495 mm was considered as moderate, classified as rank 3; 1496 to 1785 mm was considered as good, classified as rank 4; and from 1786 to 2572 mm was considered to have very good groundwater contribution, classified as rank 5. The calculated weight for precipitation was 0.3. The prepared map (Figure 6) was georeferenced, resampled and reclassified into five classes and is shown in Figure 16 below.

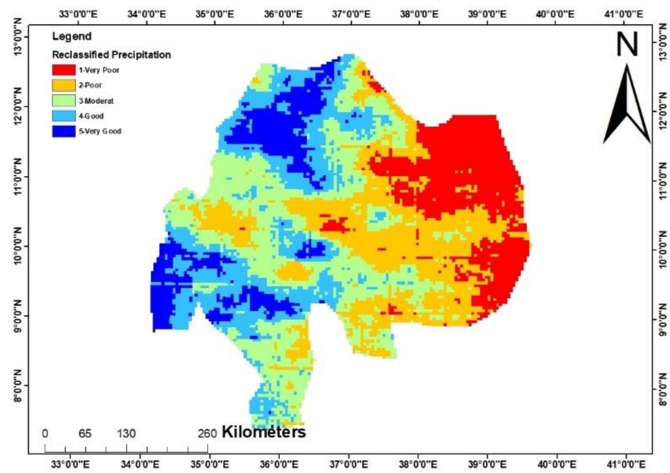


Figure 16: Reclassified precipitation of the study area.

3.1.7 Weightage of Drainage Density for Identification of Groundwater Potential Zone

Drainage density has an inverse relationship with permeability, which plays an important role in runoff and infiltration. As presented in Figure 10, drainage density was determined, georeferenced, resampled, and reclassified into five classes. The greater the concentration of drainage density, the higher the runoff and the lower the recharging of aquifers; the lower the drainage density, the more water for aquifer recharging (Deep et al., 2016). Rank was assigned to each class based on the concentration of drainage density. A range from 0 to 0.1 km/km² was very good, classified as rank 5; from 0.1 to 0.2 km/km² was good, classified as rank 4; from 0.2 to 0.3 km/km² was moderate, classified as rank 3; from 0.3 to 0.4 km/km2 was poor, classified as rank 2; and from 0.4 to 0.5 km/km² was very poor, classified as rank 1. The calculated weightage for drainage density was 0.3 and the reclassified drainage density is presented in Figure 17 below.

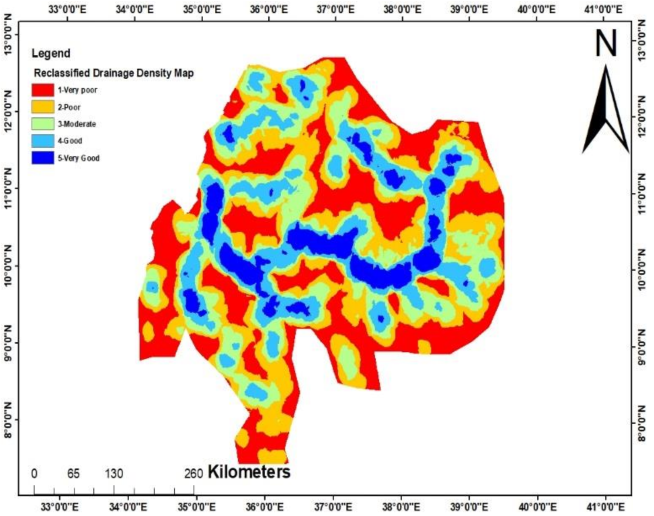


Figure 17: Reclassified drainage density of the study area.

3.2 Groundwater Potential Zone Identification

All parameters were prepared, changed to raster data sets, reclassified, projected, and resampled for groundwater potential mapping (Waikar and Nilawar, 2014; Ayele et al., 2014; Dev, 2015; Rose and Krishnan, 2009). Weightages for each thematic layer were calculated via AHP methods using Equation (3) based on Table 1. After ranking based on Table 3, each class of parameters was assigned based on its influence on aquifers and integrated using GIS. Then, a ground water potential map was prepared using equation 2.7 and the result was classified into five classes. This includes very good (311.5 km^2), good (18,557 km^2), moderate (131,323 km^2), poor (58913.1 km^2) and very poor (1295.33 km^2). Geology and soil type are two variables that influence the occurrence of groundwater. Cross-correlations were carried out. They show that the normalized weights of soil type and geology in the study area were 0.03 and 0.14, respectively, as shown in Table 5.

According to geological formation, clay-loam and loam soils were mainly formed during the Precambrian/Cenozoic era, while sandy loam soils were cretaceous and Jurassic era. Because of this cross-correlations between soil type and geology to the contribution of groundwater was observed and it indicates that very poor to poor groundwater potential zones were found in clay soil, clay loam, Precambrian/Cenozoic era, Quaternary, Quaternary, volcanic, moderate to good groundwater potential zone was found in loam soil and sandy loam as well as Tertiary extrusive and intrusive rock, Triassic, Permian, Cretaceous and Jurassic geologies and very good groundwater potential zones was found in water bodies. In the study area, the groundwater potential zones were dominated by moderate and poor groundwater potential zones, and a very small area was covered with very good and very poor ground water potential zones. The results are presented in Figure 18 below.

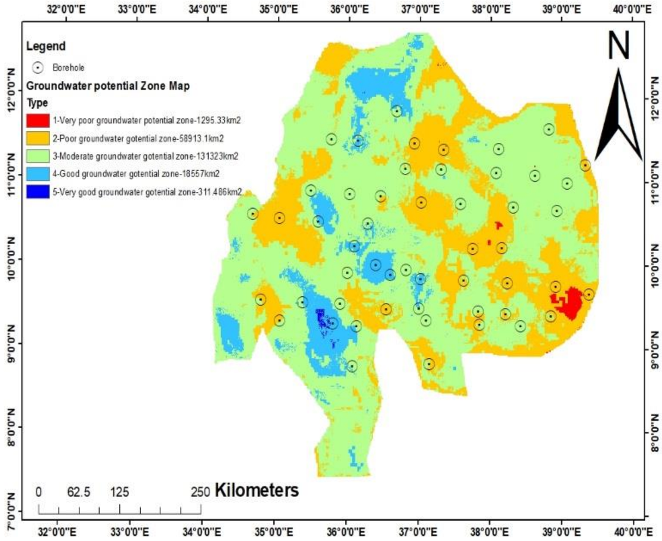
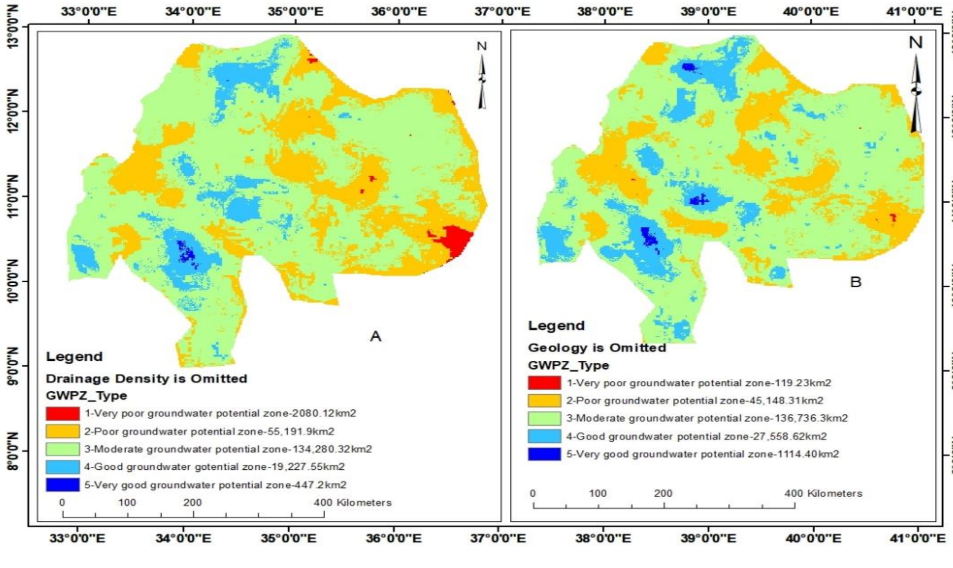


Figure 18: Groundwater potential zone map using all thematic layers.

3.3 Sensitivity Analysis

By omitting each thematic layer, sensitivity analysis was estimated using equation 2.8 to identify the sensitivity of each thematic layer related to groundwater potential mapping (Mandal et al., 2016). For this study, the influence of each thematic layer was estimated, and the results are presented in Table 6. Positive values indicate an increase in area due to the omission of layers, whereas negative values indicate a decrease in area due to the removal of individual parameters. The result indicates that the removal of precipitation increases the area of the good groundwater potential zone by 12.4%, reduces the area of the very poor, poor, moderate, very good groundwater potential zone by 2.9%, 1.2%, 3.37 %, 3.3% respectively. Elimination of lineament density increases the area of the good groundwater zone by 21.3%, the poor by 5%, and the very poor by 0.19%.

The exclusion of geology increases the area of the moderate groundwater potential zone by 12.00%, good by 14.10% and very good by 9.30% and decreases very poor by 2.8% and poor by 4.58%. The removal of drainage density increases the area of very poor by 9.23%, moderate by 10.50%, good by 9.20% and very good by 8.86% and decreases poor by 1.3%. The omission of land use increases moderate groundwater potential zone by 11.00%, good by 6.71%, very good by 3.70% and decreases very poor by 3.10% and poor by 1.7%. The elimination of slope increases the groundwater potential zone by 4.00% for very poor, 3.70% for moderate, 4.50% for good and 0.20% for very good and decreases the poor groundwater potential zone by 1.6%. The exclusion of soil increases the area of the groundwater potential zone by 1.87% for moderate, 4.00% for good and 0.26% for very good and decreases very poor by 2.9% and poor by 1.97%. The summarized sensitivity analysis is presented in Figure 19 below.



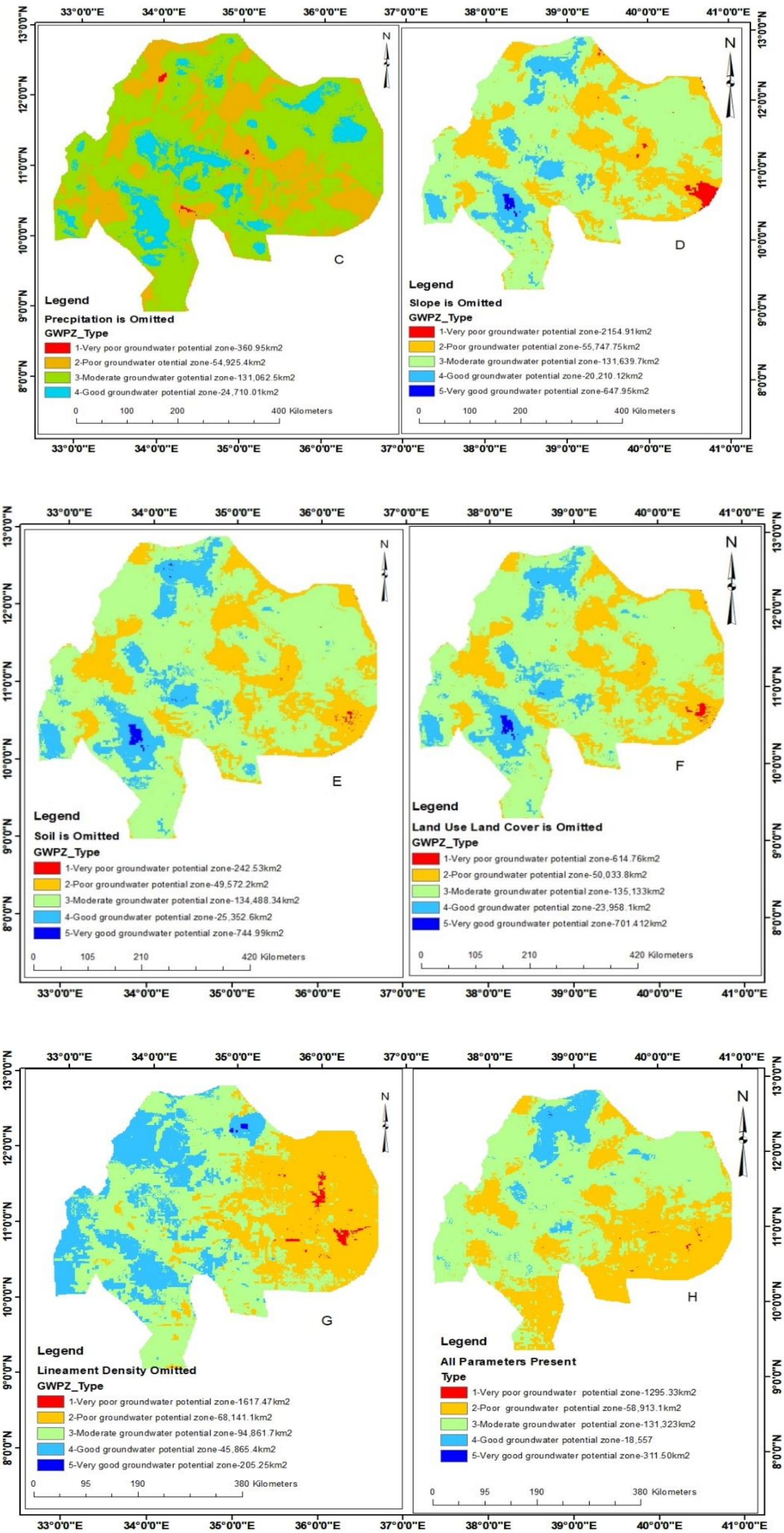


Figure 19: Sensitivity map of the study area ((**A**). GWPZM omitting drainage density, (**B**). GWPZM omitting geology, (**C**). GWPZ omitting precipitation, (**D**). GWPZM omitting slope, (**E**). GWPZM omitting soil, (**F**). GWPZM omitting land use land cover and (**G**). GWPZM omitting lineament density. (**H**). Without omitting any parameter).

Table 6: Sensitivity Analysis Result for Groundwater Potential Mapping.

Type of Parameter Omitted	Class of GWPZ	Type GWPZ	Area (km²)	Change in Area of GWPZ Type due to Absence of n Parameters	Sensitivity Analysis in Percent
All parameters present	1	Very poor	1295.33		
	2	Poor	58,913.1		
	3	Moderate	131,323		
	4	Good	18,557		
	5	Very good	311.50		
Lineament density is omitted	1	Very poor	1617.47	322.14	0.19%
	2	Poor	68,141.1	9228.00	5.00%
	3	Moderate	94,861.7	−36461.30	−17.90%
	4	Good	45,865.4	27308.4	21.30%
	5	Very good	205.25	−106.23	-3.40%
Precipitation is omitted	1	Very poor	360.95	-934.38	-2.90%
	2	Poor	54,925.4	−3987.7	−1.20%
	3	Moderate	131,062.5	−260.5	−3.370%
	4	Good	24,710.01	6153.01	12.40%
	5	Very good	0	−311.50	−3.30%
Geology is omitted	1	Very poor	119.23	−1176.1	−2.80%
	2	Poor	45,148.31	−13764.8	−4.58%
	3	Moderate	136,736.3	5413.30	12.00%
	4	Good	27,558.62	9001.62	14.10%
	5	Very good	1114.40	802.90	9.30%
Drainage density is omitted	1	Very poor	2080.12	784.79	9.23%
	2	Poor	55,191.9	-3721.2	−1.30%
	3	Moderate	134,280.32	2957.32	10.50%
	4	Good	19,227.55	670.55	9.20%
	5	Very good	447.2	135.71	8.86%
Land use is omitted	1	Very poor	614.76	−680.57	−3.10%
	2	Poor	50,033.8	−8879.3	−1.70%
	3	Moderate	135,133	3810	11.00%
	4	Good	23,958.1	5401.1	6.71%
	5	Very good	701.412	389.93	3.70%
Slope is omitted	1	Very poor	2154.91	859.58	4.00%
	2	Poor	55,747.75	−3165.35	-1.60%
	3	Moderate	131,639.7	316.7	3.70%
	4	Good	20,210.12	1653.12	4.50%
	5	Very good	647.95	336.50	0.20%
Soil is omitted	1	Very poor	242.53	−1052.8	−2.90%
	2	Poor	49,572.2	−9340.9	−1.97%
	3	Moderate	134,488.34	3165.34	1.87%
	4	Good	25,352.6	6795.6	4.00%
	5	Very good	744.99	433.50	0.26%

3.4 Validation

Changing groundwater potential zones have been influenced by groundwater tables that are found under the soil surface. The fluctuation of groundwater depth is different in time and space. A shallow depth of groundwater indicates very good groundwater potential while, on the other hand, a deeper depth of the groundwater table shows poor groundwater potential due to aquifer capacity (Singh, 2014; Soumen, 2014; Olutoyin et al., 2014). For the study area, 150 well points were collected. Out of these 80, boreholes were considered for validation, and the rest were omitted from the test due to insufficiency. To check correlations, the locations of the boreholes were overlaid with ground water potential zone maps. For the study area, the validation results confirm that the highest groundwater potential zones coincide with areas of higher yield, while the lowest groundwater potential zones fall within lower borehole yield, as presented in Figure 18.

The validation results show that borehole yields from 30 to 100 l/se occurred within very good ground water potential zones, from 20 to 30 l/se within good groundwater potential zones, from 10 to 20 l/se within moderate groundwater potential zones, from 7 to 10 l/se within poor groundwater potential zones, and less than 7 l/se of borehole yield was found within very poor groundwater potential zones. The maximum well depth for the study area was 250 m below ground level, which was within a very poor groundwater potential zone with a yield of 0.2 l/se, and the minimum depth was 15 m below ground level, falling in a very good groundwater potential zone with a yield of 40 l/se. Based on the validation results, we found that the generated groundwater potential zones are reliable and representative for the study area. The proposed method can be successfully used for groundwater monitoring and assessment studies.

4. Discussion

The estimation of groundwater potential mapping is very essential for groundwater optimization and monitoring. Seven thematic layers such as geology, precipitation, soil, lineament density, drainage density, slope and land use land cover were generated from a geospatial database using a spatial analysis extension for ArcGIS 10.4 software. All thematic layers were converted into a raster grid of 30 m by 30 m cells in an (x, y) coordinate system. Then, all thematic layers were reclassified into five classes. Rankings from 1 to 5 were adopted for each class (Sleight et al., 2016). To estimate groundwater potential zones for changing topographic areas, weightage assignments for geology and topographic features were often high, whereas for groundwater recharging, rainfall was assigned either high or low weightage based on environmental condition (Shankar and Mohan, 2006, Oikonomidis et al., 2015, Shao et al., 2020).

Before integration of the selected thematic layers, weight was assigned to each variable using AHP (Chowdhury et al., 2010; Machiwal et al., 2011; Manap et al., 2013). The weight estimated for each thematic layer was the result of pair-wise comparison of each layer based on the relative influence of the thematic layer on groundwater potentiality. A rank assessment was carried out for each class (Mandal et al., 2016). This is because all variables do not equally contribute ground in an area, as presented in Table 3 (Saaty, 1980). As indicated in the procedure, the normalized weights for the selected thematic layers were calculated using Equation (3). Reclassification of soil attributes was performed based on textural classes depending on their infiltration rate and permeability. Sandy soil is highly permeable and highly contributes to groundwater formation, whereas clay soil is less permeable and less important when it comes to contributing to groundwater occurrence.

Pair-wise comparison was carried out based on this compaction and the reclassified map is presented in Figure 13. For geological classification, geology was classified based on formation in terms of transporting and storing groundwater. According to formation of tertiary geological formations is more important than quaternary sedimentation from a groundwater occurrence point of view (Al-Abadi and Al-Shamma'a, 2014). Pair-wise compilation was carried out and the reclassified map is presented in Figure 15. Reclassification of land use land cover was carried out based on the area covered by the land cover types. When an area is covered by forest, this increases the ability of the soil to increase infiltration and reduce runoff, whereas areas with built area and bare land increase runoff and reduce infiltration in the area. Pair-wise comparison was carried out and rank was assigned based on this condition, which is presented in Figure 12.

Reclassification of lineament density was performed based on the fact that a high lineament density due to faults, fractures or joints allows for a high infiltration of water to join groundwater, whereas a low concentration of lineament density has less fractures and has low contribution to groundwater formation. Then, a pair-wise comparison was performed, weighted and ranked and the reclassified map is presented in Figure 11. Reclassification of precipitation was performed based on intensity of precipitation. High precipitation contributes to high groundwater formation and low precipitation contributes to low groundwater formation. Pair-wise comparison was carried out, weighted and ranked and the reclassified map is presented in Figure 16. Reclassification of drainage density depended on the drainage density, as when drainage density is higher, its contribution to groundwater formation is lower, whereas low drainage density contributes to high groundwater formation.

Pair-wise comparison was performed to assign weight, then ranked, and the reclassified map is presented in Figure 17. Reclassification of slope depended on the steepness and flatness of slopes. When a slope is flat, the movement of water over the land surface is slow, which increases infiltration, whereas for steep slopes, the runoff is high and the contribution of steeper slopes to groundwater formation is low. Pair-wise comparison was carried out for slope to assign weight and ranking. The reclassified slope is presented in Figure 14. According to the results, the average consistency vector for this study is 7.72. The estimated consistency index is 0.32, the consistency ratio for all variables was 0.089, which is less than 0.1, and the pairwise index is 0.133. The consistency ratio is acceptable, showing that the results are validated by further data analysis for matrices higher than 4 × 4. So, the weights assigned to each variable are 0.37, 0.3, 0.14, 0.07, 0.05, 0.04 and 0.03 for lineament density, precipitation, geology, drainage density, land use land cover, slope and soil type, respectively; these are presented in Table 5 (Saaty, 1980).

All weights were assigned to all thematic layers and the data sets were integrated using a weighted overlay of ArcGIS 10.4 based on Equation (7). The final groundwater potential map (Figure 18) shows the detailed spatial distribution of groundwater potential zones ranging from very low groundwater potential zones to very high groundwater potential zones. The groundwater potential mapping result shows that very good areas cover 311.5 km², good (18,557 km²), moderate (131,323 km²), poor (58,913.1 km²) and very poor (1295.33 km²). As presented in Figure 18, the study area is dominated by a moderate groundwater potential zone and very little of the area is covered by very good groundwater potential zones. Sensitivity analysis was carried out to understand which parameter was more sensitive for groundwater generation by omitting one variable at a time from the selected thematic layers and analyzing the groundwater potential map, and the results show that the removal of precipitation generated four groundwater potential zones, showing that precipitation is the most sensitive parameter for contributing to groundwater in the study area. The results for sensitivity analysis are presented in Table 6. Valuation was carried out and the validation results show that a borehole yield from 30 to 100 l/se occurs within very good ground water potential zones, 20 to 30 l/se within good groundwater potential zones, 10 to 20 l/se within moderate groundwater potential zones, 7 to 10 l/se within poor groundwater potential zones, and a less than 7 l/se borehole yield occurs within very poor groundwater potential zones.

Estimation of groundwater potential zones using ArcGIS and remote sensing can simply assess groundwater potential zones for any complex topographic area using different selected variables. However, groundwater potential zone mapping based on an AHP method is an indirect method. This method is also important to access and manipulate large data coverage and inaccessible areas within limited time intervals. However, since this method is indirect, it has its limitations; as groundwater potential mapping is the output of the overlaying of thematic layers, the resolution of raster maps, classification of land use and assignment of weight to each parameter can significantly affect the accuracy of the result. To fully understand groundwater, it is important to incorporate different subsurface hydrological variables, but these hydrological variables are not easily available in most areas, including the study area, and this could affect the results.

5. Conclusion

This research examines groundwater potential zones in the Abbay River Basin using GIS, AHP and remote sensing methods. Seven different parameters were selected to calculate aquifer potential, those being land use, soil, lineament density, drainage density, geology, precipitation and slope. Weight was assigned to each parameter depending on the effect of the parameters in hydrological data analysis and calculated using an analytical hierarchy method. The obtained results were 37% for lineament density, 30% for precipitation, 14% for geology, 7% for drainage density, 5% for land use, 4% for slope and 3% for soil. The consistency ratio estimated for this study was 0.089, which was accepted for next steps to evaluate groundwater potential zones. Combining all parameters in GIS to generate a groundwater potential map, the result was five zones of groundwater potential.

Very poor groundwater potential characterized an area of 1295.33 km², 58,913.1 km² was considered as poor, 131,323 km² was moderate, 18,557 km² was good and 311.5 km² was very good. Sensitivity analysis was performed by controlling each parameter to identify its influence. According to the results, the most affecting parameters were drainage density, geology, lineament density and land use land cover. The results were validated using borehole data collected for the study area and correlated with estimated groundwater potential zones. This study presents and demonstrates the importance and cost-effectiveness of GIS and remote sensing methods to identify the groundwater potential map of the Abbay River basin as having varying topographic features. This method is an indirect method for groundwater estimation and simply considers spatial and temporal variation, using limited data depending on the interests of researchers regarding groundwater potential mapping.

This method is also important to access and manipulate large data coverages and inaccessible areas within limited time intervals. However, as this method is indirect, it has its limitations; as groundwater potential mapping is the output of the overlaying of thematic layers, the resolution of raster maps, classification of land use and assignment of weight to each parameter can significantly affect the accuracy of the result. To fully understand groundwater, it is important to incorporate different subsurface hydrological variables, but these hydrological variables are not easily available in most areas, including the study area, and this could affect the output of the result. Generally, for the study area, most of the areas were covered under moderate and poor groundwater potential zones, but very good and very poor groundwater potential zones accounted for a small area of coverage. Moderate to high groundwater potential zones will have a key role in the development of the water supply and irrigation in the river basin. So, this finding will help with groundwater monitoring and optimization in the study area.

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