International Journal of Multidisciplinary and Current Research ISSN: 2321-3124
Research Article Available at: http://ijmcr.com

GIS, Remote Sensing and Analytical Hierarchy Process-Based Identification of Groundwater Potential Zones in Mokolo, Northern Cameroon

Tsaffo Mbognou Marlene Huguette, Assomo Ngono Gaëlle Sandra and Fossi Donald Hermann*

Institute of Geological and Mining Research, P.O. Box 4110 Yaoundé Cameroon

Received 20 March 2021, Accepted 15 May 2021, Available online 18 May 2021, **Vol.9 (May/June 2021 issue)**

Abstract

In order to identify groundwater potential zones in Mokolo, northern Cameroon, six site-specific groundwater factors in the watershed were assigned weights through Analytical Hierarchy Process. The weighted factors were integrated in GIS environment to outline groundwater potential zones. GWPZ range between 2.02 and 4.20 and have been graded into three categories of GWPZ; low (212.55 km^2), medium (1451.96km^2) and high (100.88 km^2) and covered 12.04, 82.24 and 5.71 per cent respectively. High GWPZ concern the flat terrain of the study area with slope gradients ranging from 0 to 7.59° and covered the largest surface area. Some areas of the hilly terrain with high drainage and lineament density were also included in the high GWPZ.

Keywords: *Groundwater, AHP, GIS, Mokolo Area, Cameroon.*

Introduction

Groundwater, stored below the water table in the pore spaces of soil and rock, is one of the most valuable and important aspects of the natural water cycle (Fitts, 2002). Groundwater has become an indispensable source for meeting the water needs of various sectors, including large water consumers such as households, industries and irrigation. Extraction of groundwater for domestic, agricultural and industrial purposes is estimated at 36%, 42% and 27%, respectively, worldwide (Taylor et al., 2013). Very intensive groundwater development, especially in some parts of Africa has led to overexploitation and continuous fall in groundwater levels. A clear example is the case of the densely populated country of India, where groundwater is used for irrigation of more than 50% of agricultural land. To overcome this global problem, it is essential to properly catalogue the available groundwater resources to put in place groundwater safeguard measures at national, regional and local levels. Groundwater exploration and management has greatly evolved over the years, especially with the advent of powerful modern devices including Remote Sensing (RS) and Geographic Information Systems (GIS) tools (Chowdhury et al., 2009). The combined use of remote sensing and GIS has proven to be an effective means to study groundwater (Krishnamurthy et al., 1996).

*Corresponding author's ORCID ID: 0000-0003-4003-2245
DOI: https://doi.org/10.14741/ijmcr/v.9.3.5

GIS is particularly effective in the collection, storage, management and presentation of spatial data in a simplified form. Remote sensing methods provide rapidly repeatable and systemic coverage of regions; therefore, it is an important tool for acquiring short-term spatiotemporal data over a very large area. Today, the accessibility and extensive use of satellite data with standard maps and field procedures have facilitated the generation of baseline information for the assessment of potential groundwater regions (Ganapuram et al., 2009; Dar et al., 2010). GIS provides a platform to efficiently process complex and comprehensive spatio-temporal information (Wieland and Pittore, 2017). Numerous authors (Mishra and Singh, 2010; Sarup and Singhai, 2011) have used remote sensing and GIS to outline potential groundwater recharge areas and for the identification of appropriate site structures for artificial recharge. However, studies involving the combined use of RS, GIS and Analytical Hierarchy Process (AHP) to identify potential groundwater recharge areas are few, although the method has been shown to produce satisfactory results. Such is the case of (Arulbalaji et al., 2019) who prepared 12 thematic layers using RS and GIS to delineate potential groundwater recharge areas in the Southern Western Ghats, India, with weights calculated using the AHP method assigned to each layer. The resulting map of the study area was validated by cross-checking with borehole information. The AHP method is considered simple, transparent, efficient and reliable for multi-criteria decision analysis (Machiwal et al., 2011a, 2011b). The very rapid depletion of groundwater resources is a major global concern, prompting the need to identify and plan the optimal use and conservation of potential groundwater recharge areas (Hutti and Nijagunappa, 2011). Several geological and geophysical methods for determining the location of groundwater aquifers are considered very reliable, but are very expensive and time-consuming (Israil et al., 2006), especially for the rural agricultural communities in developing for which groundwater represents at times the only source of irrigation water. This emphasizes the need to find and use cost-effective methodologies for delineating potential groundwater recharge areas, which can assist in overall water resource planning and management (Senanayake et al., 2016). Integrating RS with GIS has emerged as an indirect and cost-effective method for mapping groundwater resources, exploration and management systems (Adiat et al., 2012). The present study therefore used RS, GIS and AHP techniques to integrate hydrogeological, geomorphological and climatic data and delineate potential groundwater recharge zone in the locality of Mokolo, within the low altitude Far North region (Cameroon), where water resources demand vary both spatially and temporarily and the inhabitants of the region depend on groundwater for their domestic and agricultural needs. . It seems unlikely that this type of study thought to be very relevant and a crucial for the timely assessment of groundwater potential has been reported in the study area to date. The study highlights the importance of an integrated RS, GIS and AHP model for the implementation of an efficient and cost-effective approach to zoning potential groundwater recharge. The main objective of the delineation of potential groundwater zones in the study area was to develop a prospective map for groundwater exploration/exploitation for the area, as a premise to ensure optimal and sustainable development and management of groundwater resources.

2. Study Area

The study area (Figure 1) lies between latitudes 10°19’and 11°03’N and longitudes 13°35’and14°09’E, covering about 1795km² and is one of the drought prone areas of Mayo Tsanaga sub-division. Mokolo is characterized by scant soil cover, sparse vegetation, erratic precipitation and a lack of soil moisture. Recurrent droughts and increased groundwater exploitation contribute to the lowering of the water table, hence it is essential to outline the potential groundwater prone zones in order to implements a better water management plan.

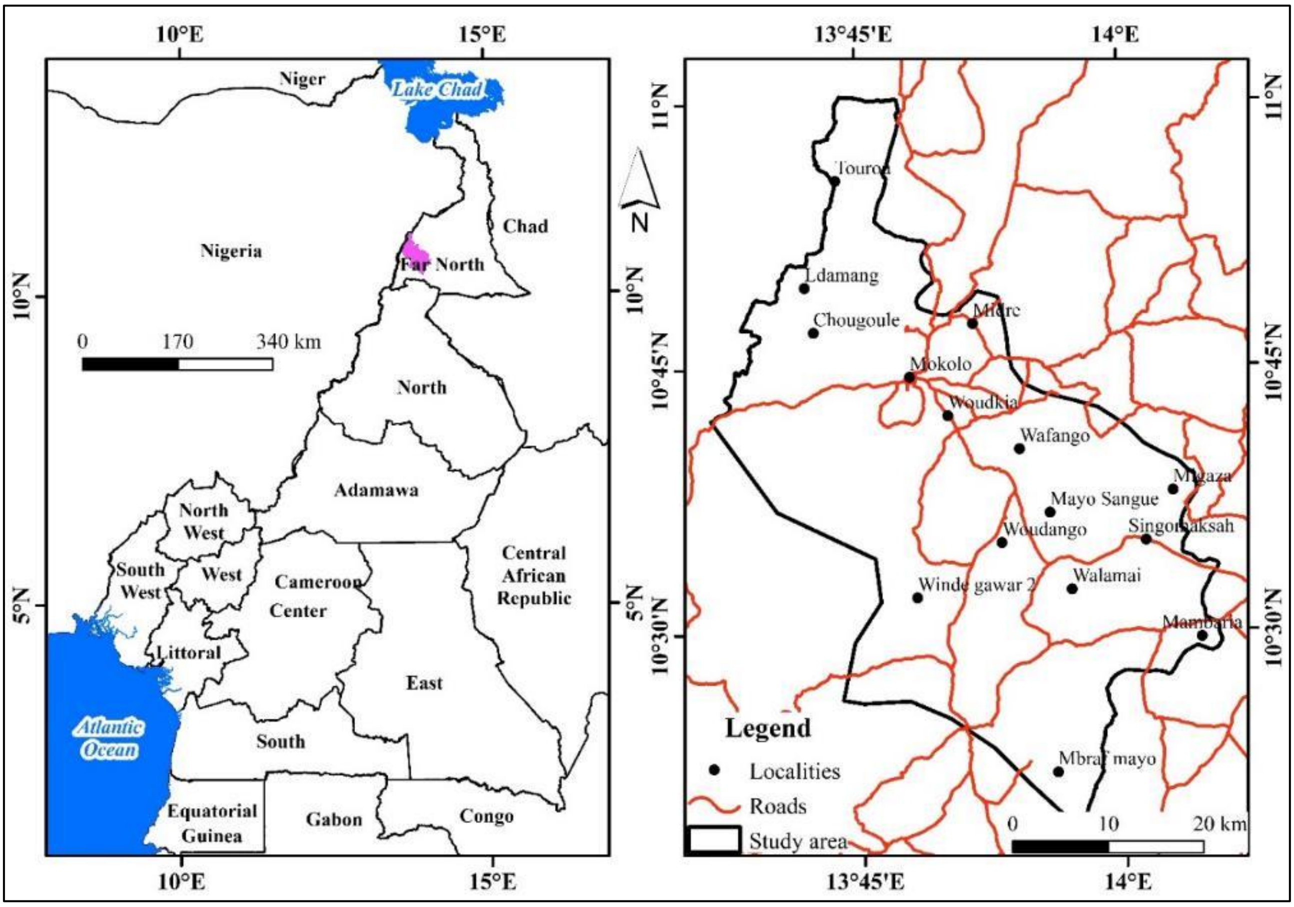

Figure 1: Location map of the study area.

3. Material and Methods

This study combined remote sensing (RS) and Geographic Information System (GIS) database to identified suitable sites for groundwater recharge through a knowledge-based analysis of six factors, namely lineament density, slope, drainage density, land use/land cover, lithology, and geomorphology layers. These factors were examined independently for groundwater recharge zoning to estimate recharge rates.

3.1. Preparation of Input Database

Table 1 summarizes the data types, sources and application. Primary data include digital elevation model (DEM) available from the Shuttle Radar Topography Mission (SRTM) and Landsat 8 multispectral imagery.

Table 1: Summary of data, sources and purpose of use

Data Type	Source	Format	Product
Digital elevation model (DEM)	Shuttle Radar Topography Mission (SRTM) data (USGS), Resolution: 30 m	Digital	
Drainage density	Shuttle Radar Topography Mission (SRTM) data (USGS), Resolution: 30 m	Raster	DD
Slope	Developed from SRTM data (resolution: 30 m) in Arc GIS	Digital	SLO
Rainfall	Annual rainfall data (1980–2017) from Institut National de la Météorologie	Table	RN
Land Use/Cover	Prepared from Landsat 8, NIR Band with resolution 30 m	Raster	LU/LC
Lineament density	Landsat 8 data and SRTM (DEM) data (U.S. Geological Survey)	Raster	LD
Lithology		Digital	LI

3.2. Analytical Hierarchy Process (AHP)

AHP was initially proposed as a decision-making method by (Saaty, 1980). This approach allows planners and decision makers to divide a problem into an ordered structure and solve it by using logical knowledge and facts. The AHP thus facilitates disintegration and contrast between pairs, reduces inconsistency, and establishes priority vectors. The AHP typically includes six phases (Hosseinali and Alesheikh, 2008): (1) the characterization of unstructured issues and objectives; (2) the decision-making of point-by-point parameters and choices; (3) the comparison between pairs; (4) the use of the own-value approach to assess the relative weights of the decision elements; (5) the quality analysis of the frameworks; and (6) the assignment of an overall ranking for the decision elements (accumulates the weighted choice variables).

3.2.1. Selection of Factors Influencing Groundwater Recharge Zones

In the first step of the AHP, each factor that influences recharge was given a score between 1 and 9, depending on its significance compared to other factors in pairwise comparisons. For this, a standard Saaty's 1–9 scale was used to describe the relative influence of parameters, where score 1 denotes equal influence of parameters and score 9 denotes extreme influence of a parameter on groundwater recharge compared to the other parameters (Zghibi et al., 2020).

3.2.2. Pairwise Comparison Matrix

The AHP method integrates and transforms spatial data (input) into decision (output), where qualitative information of individual thematic layers and features are converted into quantitative scores based on Saaty's scale. Then, a pairwise comparison matrix (PCM) (authors) is constructed (Equation (3)) using Saaty's scores obtained in the previous step. In the PCM, the matrix column is constructed based on a descending order of parameter influence on recharge. The first element is assigned a score of 1 when compared to itself. Other elements of the rows are filled using the actual Saaty's scores when a more influential parameter is compared with a less influential parameter or the reciprocal of the Saaty's scores score when a less influential parameter is compared to a more influential parameter.

Table 2: Provides the PCM for the parameters examined in this study.

Factors	Lt	Ld	Sl	El	Ld	Dd
Lithology (Lt)	1.00	2	3	4	5	6
Land use land cover (Ld)	0.50	1	2	3	4	5
Slope (Sl)	0.33	0.5	1	2	3	4
Elevation (El)	0.25	0.33	0.5	1	2	3
Lineament density	0.20	0.25	0.33	0.5	1	2
Drainage density (Dd)	0.17	0.17	0.25	0.33	0.5	1

Lithology was selected as the first parameter of the matrix because has a higher influence on recharge potential compared to the other factors. Thus, lithology was assigned the value 6. Land use/land cover was selected as the second most important parameter influencing recharge followed by slope, geomorphology, lineaments, rainfall, and drainage and finally soil parameter in a descending order of influence. Each parameter in the selected set was assigned a Saaty's score based on its influence on recharge relative to lithology.

3.2.3. Estimating Relative Weights

Weights were assigned to the variables based on 'expert' opinion to estimate the relative importance of variables compared to other variables and to quantify the relative influence of each variable on recharge. The layers were assigned weights derived by normalizing the pair comparison matrix (NPCM). The NPCM elements were computed by dividing thematic element values by their corresponding total column values from the PCM (Equation (1)) (see Table 3):

$$X_{ij} = \frac{C_{ij}}{L_{ij}} \tag{1}$$

Where X_{ij} is normalized pair-wise matrix value at i_{th} row and j_{th} column, C_{ij} is the value assigned to each criteria at i_{th} row and j_{th} column and L_{ij} is the total values in each column of the pair-wise matrix.

Table 3. Standardized pairwise comparison matrix and weight factors influencing recharge

	Lt	Ld	Sl	El	Ld	Dd	Eigen Vector
Lithology (Lt)	0.41	0.47	0.42	0.37	0.32	0.29	0.38
Land use land cover (Ld)	0.20	0.24	0.28	0.28	0.26	0.24	0.25
Slope (Sl)	0.14	0.12	0.14	0.18	0.19	0.19	0.16
Elevation (El)	0.10	0.08	0.07	0.09	0.13	0.14	0.10
Lineament density	0.08	0.06	0.05	0.05	0.06	0.10	0.06
Drainage density (Dd)	0.07	0.04	0.04	0.03	0.03	0.05	0.04
Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Subsequently, a standard weight was calculated for variable *i* by dividing each normalized pairwise matrix elements by criterion number (*N*) (Equation (2)).

$$W_i = \frac{\sum X_{ij}}{N} \tag{2}$$

Where W_i is standard weight.

Then, Eigen vector and eigenvalue calculations help determine the percentage of effect of the thematic layers and the classification of the constraints (Table 4). The eigenvector was calculated by dividing column elements by the column sum in Table 3. The principal Eigen vector was obtained by averaging across the rows to quantify relative weights of each parameter. A consistency vector was obtained by multiplying two different matrix values from selected thematic layers (Equation (3)), namely, pair-wise comparison matrix value and normalized pair-wise matrix value.

$$\lambda = \sum(C_{ij}X_{ij}) \tag{3}$$

Table 4. Calculation of the principal Eigenvalue to rank parameter influence

Thematic Map	(1) Total Relative Weight of Each Factor (from Table 2)	(2) Eigenvector Value of Each Factor (from Table 3)	Eigenvalues (1) × (2)
Lithology (Lt)	2.45	0.38	1.08
Land use land cover (Ld)	4.25	0.25	0.94
Slope (Sl)	7.08	0.16	0.89
Elevation (El)	10.83	0.10	0.92
Lineament density	15.5	0.06	1.03
Drainage density (Dd)	21	0.04	1.18
Principal Eigenvalue (λmax)			6.05

The sum of eigenvalues called principal eigenvalue (λ_{max}) is a measure of matrix deviation from consistency (authors). According to Saaty, for a pairwise comparison matrix to be consistent it must have a principal eigenvalue (λ_{max}) greater than or equal to the number of the parameters considered (n). The principal eigenvalue of 8.62 was obtained for the 8 × 8 matrix (Table 4), which was used for the calculation of consistency index.

3.2.4. Assessing Matrix Consistency

Normalized factor weights were determined and the Consistency Ratio (CR) was tested:

$$CR = \frac{CI}{RI} \tag{4}$$

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{5}$$

Where, *CI:* consistency index, λ_{max}: highest matrix Eigenvalue, *n:* number of variables (thematic layers), *CR*: consistency ratio and *RI*: Random Index value based on the number of variables.

A perfectly consistent decision maker should always yield *CI* = 0 but small values of inconsistency may be tolerated if the *CI* < 0.1. We obtained an acceptable *CI* value of 0.01. Also, if the *CR* is greater than 0.1, the pairwise comparison judgments must be re-evaluated. With a matrix of eight variables, the *RI* is 1.49 (Table 5). The applied weighting yielded a *CR* of 0.008, which shows that the weights (Table 4) assigned to GIS thematic layers of parameters are consistent.

Table 5: Random inconsistency indices (authors)

n	2	3	4	5	6	7	8	9
RI	0	0.58	0.9	1.12	1.24	1.32	1.41	1.49

3.2. Delineation of Groundwater Potential Zones

Groundwater Potential Zones (GWPZ) is a dimensionless quantity in an area that forecasts future groundwater zones (Rahmati et al., 2015). To calculate the Groundwater Potential Index (GWPI), the weighted linear combination approach (Malczewski, 1999) was used.

$$GWPI = \sum_{i=1}^{n} \sum_{w=1}^{m} (W_i \times X_j) \quad (6)$$

Where W_i is the normalized weight of the j thematic layer, Xj is the rank value of each class with respect to the j layer, m is the total number of thematic layers, and n is the total number of classes in a thematic layer. The GWPI for each grid was calculated using Eq. (7) below:

$$GWPI = GE_w GE_r + SC_w SC_r + DD_w DD_r + SL_w SL_r + LC_w LC_r + LD_w LD_r + GM_w GM_r \quad (8)$$

where GE, geology; SC, soil cover; DD, drainage density; SL, slope; LC, land use and land cover; LD, lineament density; and GM, geomorphology. The subscripts 'w' and 'r' represent the weight of a feature and the rate of individual subclasses of a feature based on their relative importance for groundwater potentiality. The rating ranges of 1–5 were taken, where the rates of 1, 2, 3, 4 and 5 represent very poor, poor, moderate, good and very good, respectively, in-term of groundwater storage potential (Kumar et al., 2014).

4. Results and Discussion

4.1. Drainage density

Drainage density is an important hydrogeological factor in groundwater recharge, the fill feature of the hydrological tool available in ArcGIS software was used for the drainage network to reduce the Digital Elevation Model (DEM) error. By decreasing excessive high elevation pixels and filling in sinks, this fill feature improved the grid cells. The direction of surface flow and water accumulation using the hydrological tool in ArcGIS were determined from the enhanced DEM. Results were calibrated and compared with the Ngaoundere Map sheets to validate the existence of the outlined streams. The topographic state and size of a region saturated by surface runoff are defined by the drainage density. The closer to drainage, the higher the potential of groundwater recharge. In the study area, it varies from 0 to 13.76 km/km^2 and were reclassified to prepare a drainage density map and categorized into five namely, categories very low (< 1.40), very low (1.40-2.96), medium (2.95-4.96), high (4.96-8.42) and very high (8.42-13.74) km/km^2 (Figure 2b).

4.2. Land use/ Land cover

In monitoring soil infiltration rate and surface runoff, land use and land cover (LULC) characteristics are important (Kidane et al., 2012). It is derived from the Landsat-8 (TM) satellite imagery and the interpreted LULC map prepared using ArcGIS 10.5 maximum likelihood classification. The different LULC groups in the study area were split into five large categories, as shown in Figure 2c, including water bodies (166.46km^2), vegetation (385.80 km^2), built-up bodies (263.87 km^2), wasteland (524.47 km^2) and agricultural land (449 km^2).

4.3. Slope

Due to variation in climatic conditions, elevation was chosen to assess changes in the characteristics of soil and vegetation types (Aniya, 1985) (Figure 2c). Slope angle describes the surface runoff phase of groundwater recharge (Prasad et al., 2008). To produce elevation and slope maps of the Mokolo area, DEM was used. Slope is the topography's elevation change and is typically expressed as a proportion or in degrees. In solating precipitation and runoff, the slope of an area is a significant factor. Although the slope is directly proportional to the amount of runoff, the penetration of surface water into groundwater becomes inversely proportional (Satapathy and Syed, 2015). The slope of the study area varies between 0 and 39.24°, so the map is divided into five classes (Figure 3d) and varies from <2.93°, 2.93-7.59, 7.59°–13.97°, 13.97°–21.90° and >21.90% (very steep).

4.4 Lithology

The lithology of an aquifer substance has an important impact on its porosity and permeability. To investigate its importance in groundwater recharge, the geology of study area was extracted from the Geological map of North-western Cameroon (Figure 3a), which reveals that the study area hosts quaternary deposit (alluvions), pre- to syn tectonic granitoids (TTG), undifferentiated gneisses intercalating with metapelites and metabasites (Houketchang Bouyo et al., 2015). The Quaternary deposits are good for groundwater recharge, whereas mixed lithology of hard rocks (gneisses and TTG), have very low porosity. Note: This interpretation is strictly theoretical based on common knowledge. However, the porosity of rocks is determined by much more complex factors than just their lithology. Hence, it would be very interesting to analyses samples using petrography to confirm this trend or refer to articles which have done so practically.

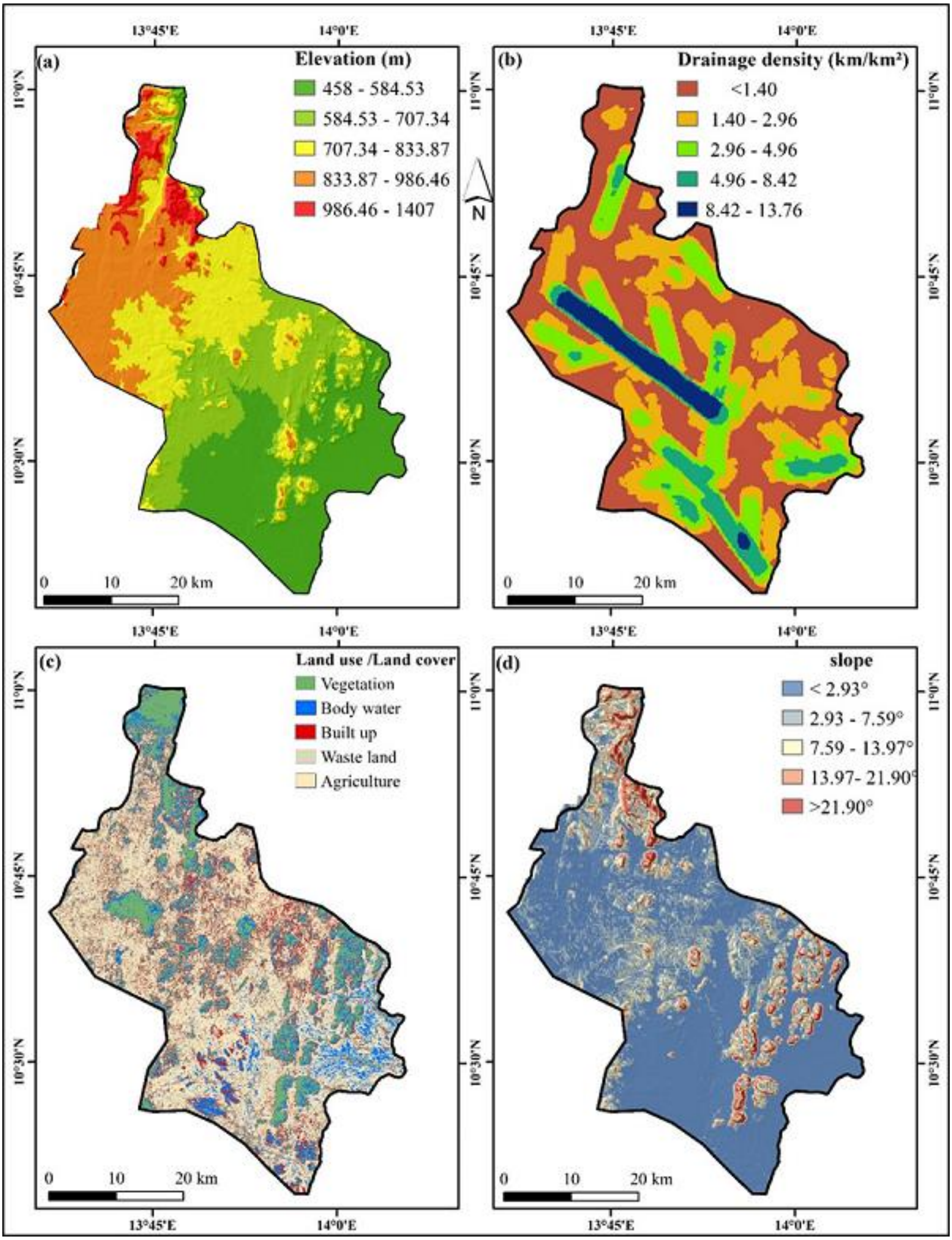

Figure 2: Factors of groundwater potential: (a) elevation, (b) drainage density, (c) land use/land cover, and (d) slope

4.5. Lineament density

Lineaments are important for mapping the capacity of groundwater because they play a key role in regulating the movement and occurrence of groundwater (Satapathy and Syed, 2015), by controlling the flow of water between the surface and the subsurface via faults and dykes. Lineament density was therefore chosen to be a significant conditioning factor for GWPZ. In order to increase water retaining capability, joints and fractures in a rock raise its secondary porosity and permeability. Lineaments of the study area are derived from the

Landsat 8 Oli image treatment (Takodjou Wambo et al., 2016). The intensity of fracturing is very high in high lineament density areas, where probability for groundwater targeting is maximum. Line densities vary between 0 and 17.14 km/km^2 (Figure 3b), that was classified into five categories, namely, very high (>10 km), high (7–10), moderate (5–7), low (2–5) and very low (<2) and most of the region (>80%) belongs to the very low density classNormal, linear or curvilinear characteristics are the lineaments shown on the diagram. A higher density implies a higher potential on the diagram, and a lower density indicates a lower groundwater potential. Four major sets of lineaments, with trends in the NE-SW, NW-SE, N-S and E-W directions, were identified in the study area.

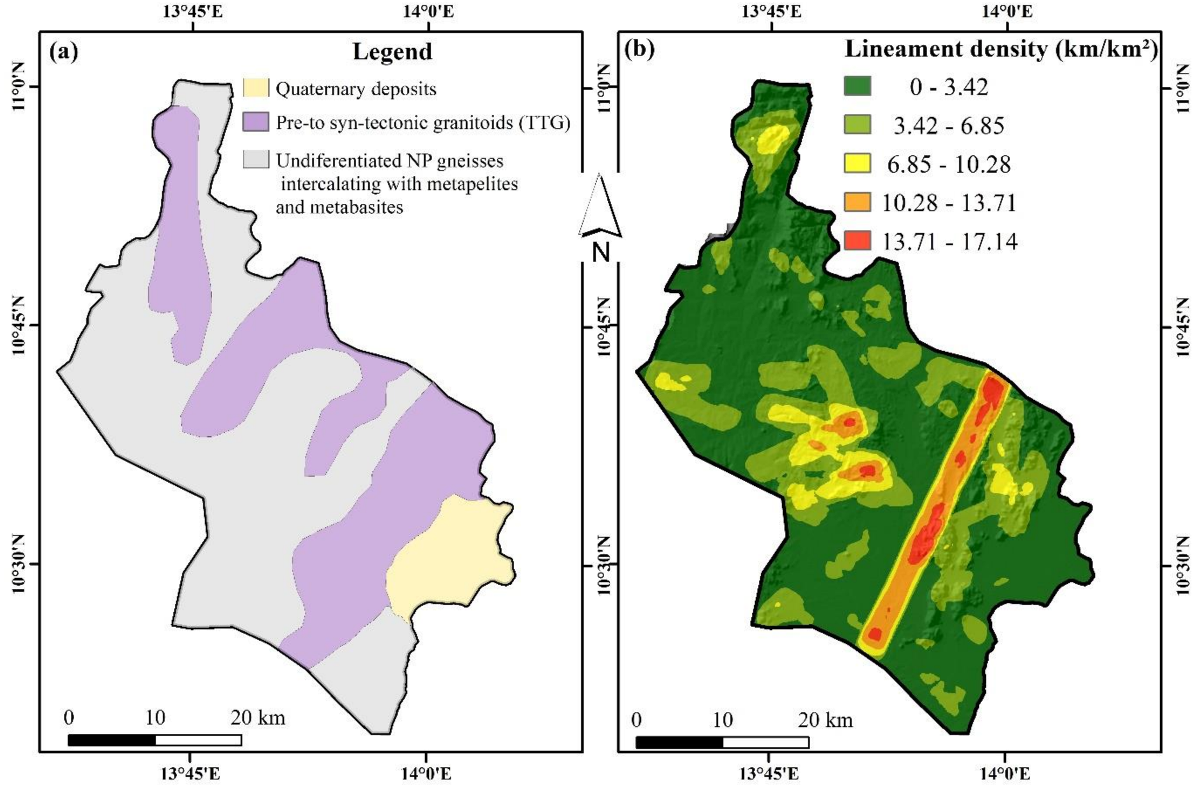

Figure 3: Factors of groundwater potential in the Mokolo area. (a) Lithology and (b) lineament density

4.6. Groundwater potential

LULC, Lineament, slope, drainage density and geology maps have been converted to a raster format. In the analysis and classification of these maps, the analytical hierarchy procedure (AHP) was used to analyse and to reclassify them in ArcGIS version 10.5. With the aid of equation (2), GIS and AHP techniques were used for the study area to determine groundwater potentials (GWPZs). GWPZ range between 2.02 and 4.20 and have been graded into three categories of GWPZ; low (212.55 km^2), medium (1451.96km^2) and high (100.88 km^2) and covered 12.04, 82.24 and 5.71 per cent respectively (Figure 4). High GWPZ concern the flat terrain of the study area with slope gradients ranging from 0 to 7.59° and covered the largest surface area. Some areas of the hilly terrain with high drainage and lineament density were also included in the high GWPZ. Groundwater exploration areas were influenced by factors such as geomorphology, geology, land use and cover, slope, lineament density and drainage density (Ajay Kumar et al., 2020).

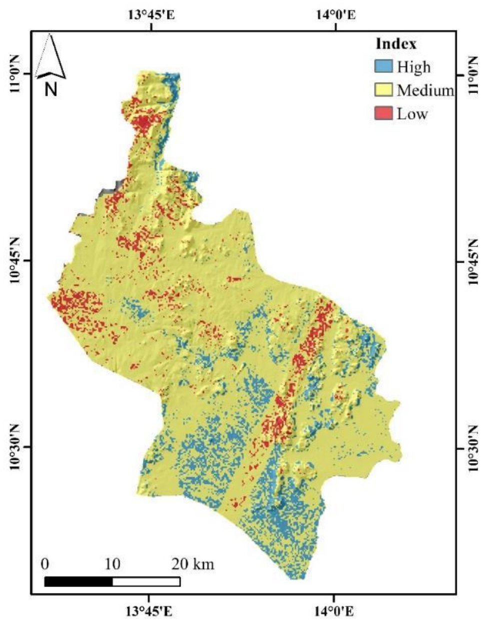

Figure 4: Zones with different groundwater potential

Conclusion

The study analysed the factors of groundwater potential in the Mokolo area in Cameroon. The Remote sensing and Geographic Information System (GIS) approach is very constructive because this integrates various geospatial information, especially in groundwater potential zone mapping. The study has focused on the effectiveness of remote sensing and GIS in the identification and delineation of groundwater potential zones of study area. The digital elevation model also used for geomorphologic mapping and identification of the potential for using landforms to interpret zones suitable for groundwater development in addition to lineament delineation. Remote sensing and GIS tools are less time consuming and cost effective, which provide sufficient support in groundwater studies where the region lacks previous hydrogeological investigations and data. The overall results demonstrate that remote sensing and GIS provide potentially powerful tools for studying groundwater resources and designing a suitable exploration plan. The integrated map could be useful for various purposes such as sustainable development of groundwater as well as identification of priority areas for implementation of water conservation projects and programmes in the area.

Acknowledgements

The authors are thankful to the anonymous reviewers and the Editor-in-Chief for their constructive comments and valuable suggestions in improving the overall quality of the manuscript.

References

[1]. Adiat, K.A.N., Nawawi, M.N.M., Abdullah, K., 2012. Assessing the accuracy of GIS-based elementary multi criteria decision analysis as a spatial prediction tool–a case of predicting potential zones of sustainable groundwater resources. Journal of Hydrology 440, 75–89.

[2]. Ajay Kumar, V., Mondal, N.C., Ahmed, S., 2020. Identification of Groundwater Potential Zones Using RS, GIS and AHP Techniques: A Case Study in a Part of Deccan Volcanic Province (DVP), Maharashtra, India. J Indian Soc Remote Sens 48, 497–511. https://doi.org/10.1007/s12524-019-01086-3

[3]. Aniya, M., 1985. Landslide-susceptibility mapping in the Amahata river basin, Japan. Annals of the Association of American Geographers 75, 102–114.

[4]. Arulbalaji, P., Padmalal, D., Sreelash, K., 2019. GIS and AHP techniques based delineation of groundwater potential zones: a case study from southern Western Ghats, India. Scientific reports 9, 1–17.

[5]. Chowdhury, A., Jha, M.K., Chowdary, V.M., Mal, B.C., 2009. Integrated remote sensing and GIS-based approach for assessing groundwater potential in West Medinipur district, West Bengal, India. International Journal of Remote Sensing 30, 231–250.

[6]. Dar, I.A., Sankar, K., Dar, M.A., 2010. Remote sensing technology and geographic information system modeling: an integrated approach towards the mapping of groundwater potential zones in Hardrock terrain, Mamundiyar basin. Journal of Hydrology 394, 285–295.

[7]. Fitts, C.R., 2002. Groundwater science. Elsevier.

[8]. Ganapuram, S., Kumar, G.V., Krishna, I.M., Kahya, E., Demirel, M.C., 2009. Mapping of groundwater potential zones in the Musi basin using remote sensing data and GIS. Advances in Engineering Software 40, 506–518.

[9]. Hosseinali, F., Alesheikh, A.A., 2008. Weighting spatial information in GIS for copper mining exploration. American Journal of Applied Sciences 5, 1187–1198.

[10]. Houketchang Bouyo, M., Zhao, Y., Penaye, J., Zhang, S.H., Njel, U.O., 2015. Neoproterozoic subduction-related metavolcanic and metasedimentary rocks from the Rey Bouba Greenstone Belt of north-central Cameroon in the Central African Fold Belt: New insights into a continental arc geodynamic setting. Precambrian Research 261, 40–53. https://doi.org/10.1016/j.precamres.2015.01.012

[11]. Hutti, B., Nijagunappa, R., 2011. Identification of groundwater potential zone using geoinformatics in Ghataprabha basin, North Karnataka, India. International Journal of Geomatics and Geosciences 2, 91.

[12]. Israil, M., Al-Hadithi, M., Singhal, D.C., 2006. Application of a resistivity survey and geographical information system (GIS) analysis for hydrogeological zoning of a piedmont area, Himalayan foothill region, India. Hydrogeology Journal 14, 753–759.

[13]. Kidane, Y., Stahlmann, R., Beierkuhnlein, C., 2012. Vegetation dynamics, and land use and land cover change in the Bale Mountains, Ethiopia. Environmental monitoring and assessment 184, 7473–7489.

[14]. Krishnamurthy, J., Venkatesa Kumar, N., Jayaraman, V., Manivel, M., 1996. An approach to demarcate ground water potential zones through remote sensing and a geographical information system. International journal of Remote sensing 17, 1867–1884.

[15]. Kumar, Tarun, Gautam, A.K., Kumar, Tinu, 2014. Appraising the accuracy of GIS-based Multi-criteria decision making technique for delineation of Groundwater potential zones. Water Resour Manage 28, 4449–4466. https://doi.org/10.1007/s11269-014-0663-6

[16]. Machiwal, D., Jha, M.K., Mal, B.C., 2011a. GIS-based assessment and characterization of groundwater quality in a hard-rock hilly terrain of Western India. Environmental monitoring and assessment 174, 645–663.

[17]. Machiwal, D., Jha, M.K., Mal, B.C., 2011b. Assessment of groundwater potential in a semi-arid region of India using remote sensing, GIS and MCDM techniques. Water resources management 25, 1359–1386.

[18]. Malczewski, J., 1999. GIS and Multicriteria Decision Analysis. John Wiley & Sons.

[19]. Mishra, A.K., Singh, V.P., 2010. A review of drought concepts. Journal of hydrology 391, 202–216.

[20]. Prasad, R.K., Mondal, N.C., Banerjee, P., Nandakumar, M.V., Singh, V.S., 2008. Deciphering potential groundwater zone in hard rock through the application of GIS. Environmental geology 55, 467–475.

[21]. Rahmati, O., Nazari Samani, A., Mahdavi, M., Pourghasemi, H.R., Zeinivand, H., 2015. Groundwater potential mapping at Kurdistan region of Iran using analytic hierarchy process and GIS. Arab J Geosci 8, 7059–7071. https://doi.org/10.1007/s12517-014-1668-4

[22]. Saaty, T.L., 1980. The analytic hierarchy process: planning, priority setting, resource allocation. McGraw-Hill International Book Co., New York; London.

[23]. Sarup, J., Singhai, A., 2011. Image fusion techniques for accurate classification of Remote Sensing data. International Journal of Geomatics and Geosciences 2, 602–612.

[24]. Satapathy, I., Syed, T.H., 2015. Characterization of groundwater potential and artificial recharge sites in Bokaro District, Jharkhand (India), using remote sensing and GIS-based techniques. Environ Earth Sci 74, 4215–4232. https://doi.org/10.1007/s12665-015-4474-8

[25]. Senanayake, I.P., Dissanayake, D., Mayadunna, B.B., Weerasekera, W.L., 2016. An approach to delineate groundwater recharge potential sites in Ambalantota, Sri Lanka using GIS techniques. Geoscience Frontiers 7, 115–124.

[26]. Takodjou Wambo, J. didero, Ganno, S., Afahnwie Ngambu, A., Negue, E., Ondoa, J., Nzenti, J.P., 2016. Use of Landsat 7 ETM+ data for the geological structure interpretation: Case study of the Ngoura-Colomines area, Eastern Cameroon. Journal of Geosciences and Geomatics 4, 61–72. https://doi.org/10.12691/jgg-4-3-3

[27]. Taylor, R.G., Todd, M.C., Kongola, L., Maurice, L., Nahozya, E., Sanga, H., MacDonald, A.M., 2013. Evidence of the dependence of groundwater resources on extreme rainfall in East Africa. Nature Climate Change 3, 374–378.

[28]. Wieland, M., Pittore, M., 2017. A spatio-temporal building exposure database and information life-cycle management solution. ISPRS International Journal of Geo-Information 6, 114.

[29]. Zghibi, A., Mirchi, A., Msaddek, M.H., Merzougui, A., Zouhri, L., Taupin, J.-D., Chekirbane, A., Chenini, I., Tarhouni, J., 2020. Using Analytical Hierarchy Process and Multi-Influencing Factors to Map Groundwater Recharge Zones in a Semi-Arid Mediterranean Coastal Aquifer. Water 12, 2525.