ISSN 2354-9114 (online), ISSN 0024-9521 (print)
Indonesian Journal of Geography Vol 55, No 2 (2023): 221-234
DOI: 10.22146/ijg.76730 website: https://jurnal.ugm.ac.id/ijg

INDONESIAN JOURNAL OF GEOGRAPHY

REVIEW ARTICLE

Identification of Groundwater Potential Zones Using Remote Sensing and GIS Technique: A Case Study of the Ketungau Basin in Sintang, West Kalimantan

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Received: 2022-10-25
Revised: 2023-02-03
Accepted: 2023-03-10

Keywords: Identification; Groundwater Potential Zones; Remote Sensing; GIS; Ketungau Basin

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Abstract. Groundwater is one of the most valuable natural resources in Sintang, but essential basic information regarding its properties and characteristics is presently unavailable. Currently, systemic and uniform investigations, as well as groundwater potential zones mapping are yet to be conducted within the framework of basin area units to support development activities. Therefore, this study aims to identify and map groundwater potential zones using remote sensing and GIS. The employed data were obtained from drainage density, slope steepness, straightness density, total rainfall, lithology, soil type, and land use land cover. The method applied was an interpretation of secondary data, which included a) identification and evaluation of criteria, b) data collection, c) preprocessing, and e) reclassification, while the analysis technique used was a weighted overlay. The results showed that the study location has five classes of groundwater potential zones, namely highly potential, potential, moderate, non-potential, and highly non-potential with areas of 120,754.08 ha (20.62%), 220,693.71 ha (37.69%), 109,668.44 ha (18.73), 93,404.38 ha (15.95%), and 41,068.31 ha (7.01%), respectively. Highly potential and groundwater potential zones were identified in the central, eastern, and western parts of the Ketungau basin. In contrast, the dominant non-potential and highly non-potential zones were found along the northern basin boundary. Based on the results, remote sensing and GIS approaches are practical tools for identifying groundwater potential zones, which can be used to determine policies related to groundwater utilization.

1. Introduction

One of the most valuable natural resources is groundwater, which supports human health, economic development, and ecological diversity. Also, it plays a role in determining the socioeconomic status of all nations (Yıldırım, 2021) and supplies the water needed by communities in both urban and rural areas of developed as well as developing countries. Groundwater provides half of the water used for domestic purposes by the global population. Additionally, approximately 25% of all water is withdrawn to serve 38% of the world's irrigated land. This natural resource is often poorly understood, undervalued, mismanaged, and even abused despite having enormous importance. Due to the escalating climate change threat to water supplies recently, the significance of groundwater has increased (Aykut, 2021). As water scarcity in many parts of the world rises, groundwater's vast potential and careful management must be considered (Water, 2022).

Surface water bodies such as rivers and ponds can act as recharge zones (Waikar & Nilawar, 2014). Moreover, excessive water withdrawal from aquifers would cause environmental and economic damage to the regions explored (De Stefano & Lopez-Gunn, 2012; Yıldırım, 2021). Overuse of groundwater has led to its depletion in many parts of the world (Sresto et al., 2021). To maintain sustainability, there is a need to identify groundwater potential zones and focus on convenient management. The conservation process must be carried out because groundwater is considered the primary alternative viable resource in these environments (Israil et al., 2006; Razandi et al., 2015; Yıldırım, 2021).

Determination of groundwater potential zones conventionally through drilling, geophysical, and hydrogeological technique is expensive due to the requirement of much time, budget, and specialized knowledge (Israil et al., 2006; Jha et al., 2010; Sresto et al., 2021). The delineation of the zones has become more accessible and effortless with geospatial methods, which have been widely applied recently (Allafta et al., 2021; Murmu et al., 2019; Nampak et al., 2014; E. Şener et al., 2018).

To reduce costs and risks, there is a need to use methods and technologies, including Geographic Information Systems (GIS) and remote sensing, that can accurately detect potential source zones. (Achu et al., 2020; Allafta et al., 2021; Lentswe & Molwalefhe, 2020; Mallick et al., 2019; Murmu et al., 2019; E. Şener et al., 2018; Yıldırım, 2021). GIS is capable of defining groundwater zones by providing a distinct working environment for the efficient processing and storing of georeferenced data compiled from various sources such as satellite imagery, maps, and soil surveys (Lillesand et al., 2015).

The application of remote sensing in hydrogeological investigation and monitoring tends to generate important information on spatial and temporal scales, essential for analyzing, predicting, and effectively validating water resource models (Allafta et al., 2020). The ability of satellite imagery to cover a large spatial scale is crucial for depicting basin physiographic characteristics, such as land use or cover, slope, drainage density, and structural features, including rock straightness, fractures, and faults (Kuria et al., 2012).

GIS is a vital technology for the sustainable development of environmental management (Kadam et al., 2017; Maheswaran et al., 2016; Rajasekhar et al., 2019). GIS analysis for identifying groundwater potential zones can provide decision-makers with clear information, to facilitate more accurate and quicker choices during the decision phase.

Furthermore, remote sensing is a source of information on surface features relevant to groundwater resource management (Rajasekhar et al., 2017; Rajasekhar, Raju, et al., 2018; Rajasekhar, Sudarsana Raju, et al., 2018; Rajaveni et al., 2017; Shailaja et al., 2019). The use of remote sensing and GIS to investigate groundwater potential zones has extremely increased in recent decades (Allafta et al., 2020; Awawdeh et al., 2014; Mukherjee et al., 2012; Swetha et al., 2017; Yeh et al., 2016). This is attributed to their ability to rapidly, precisely, and cost-effectively investigate surface and subsurface water over large areas. Therefore, this study aims to identify and map the distribution of groundwater potential zones with remote sensing and GIS.

2. The Methods

Study Location

The study location is in the Ketungau Basin, Sintang Regency, West Kalimantan Province, which covers three regions, namely Ketungau Hulu, Tengah, and Downstream, with a total area of 585.584,92 ha. Furthermore, its characteristics include a range of drainage density from sparse to very dense and slope steepness from gentle to very steep. The Land Use Land Cover (LULC) comprises primary dryland forest, secondary dryland forest, secondary swamp forest, industrial forest, plantations, settlements, mining areas, and dryland agriculture mixed with shrubs, swamps, shrubs, vacant land, and water bodies. The straightness density varies from very to rare, and the soils are composed of dusty loam inceptisols, loamy ultisols, sandy loam histosols with crumb structures, and loamy oxysols.

Astronomically, the Ketungau basin presented in Figure 1 is located at 110° 53’ 0”-111° 55’ 0” E and 0° 9’ 30”-1° 11’ 30” N. Administratively, it is bordered to the north, east, south, and west by Malaysia, Kapuas Hulu Regency, Sintang District, and Sanggau Regency, respectively.

Methodology

This study employed the secondary data interpretation method, and the data can be seen in **Table 1**. GIS and remote sensing technique were used to delineate groundwater potential zones of the Ketungau Basin. Furthermore, the applied methodology included six stages, namely a) criteria identification and evaluation, b) data collection, c) preprocessing, d) input dataset preparation, e) reclassification of input layers and f) conduction of a weight sum overlay analysis using ArcGIS tools and ranking of the final value. Figure 2 presents the sequence of the methodology (Rajasekhar, Raju, et al., 2018) with modifications.

Data

This study used seven parameters which are described as follows:

a. Drainage Density is the total length of all streams or rivers per unit drainage area (Etikala et al., 2019; Guru et al., 2017). This denotes the closeness of stream segments

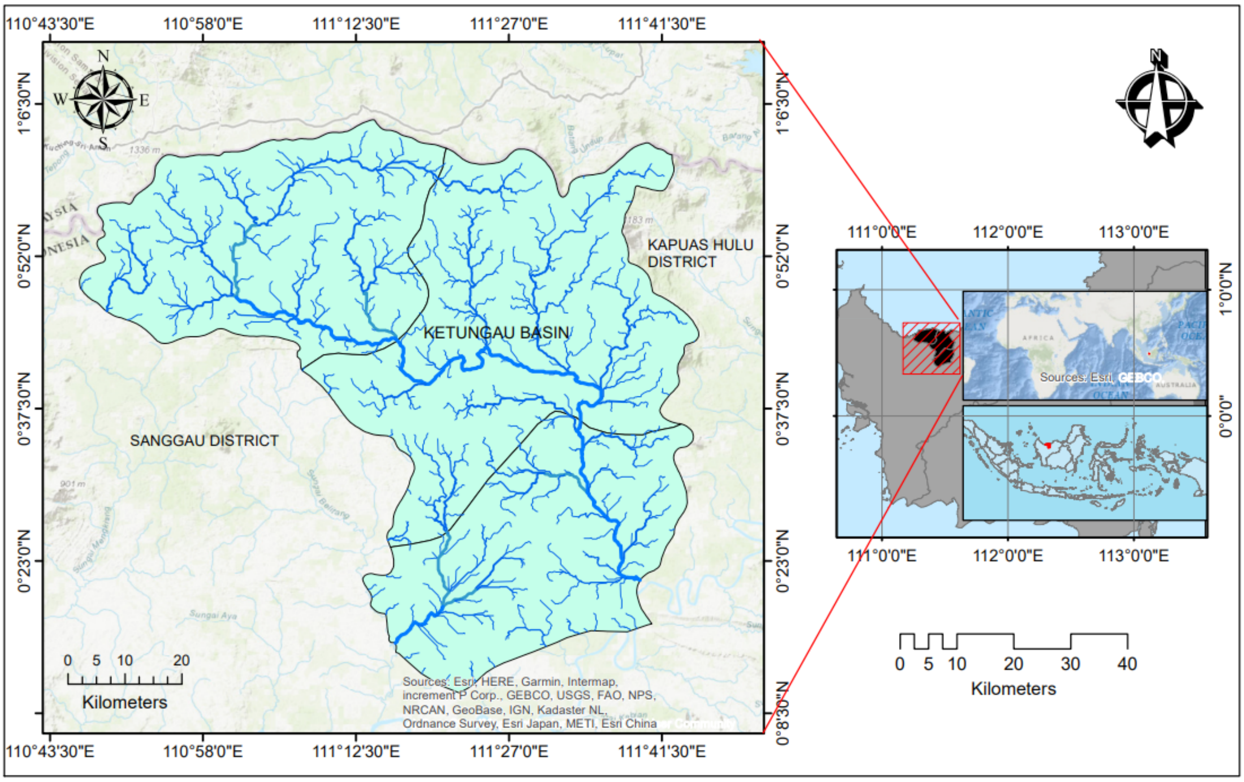

Figure 1. Study Location

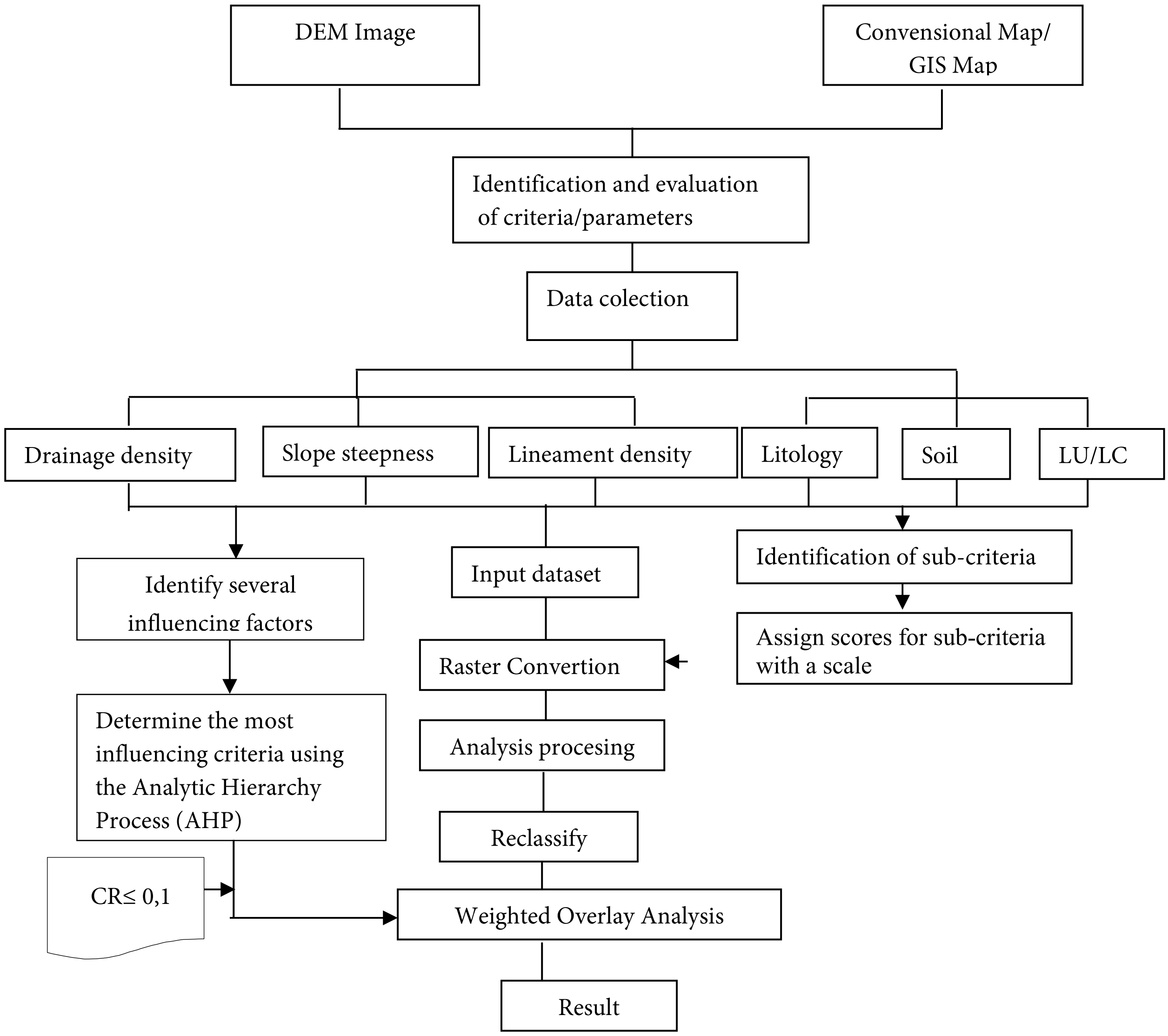

Figure 2. Study Methodology

spatially and affects the infiltration and permeability of a drainage basin, with correlation to the hydrograph's shape. It also provides information on the characteristics of rock, soil permeability, water infiltration, and surface runoff (Burayu, 2022; Etikala et al., 2019). Drainage density plays a role in groundwater potential zones of a place (Guduru & Jilo, 2022). High drainage densities in any area ensure less infiltration compared to low densities, as much of the water becomes runoff. Conversely, areas with low drainage density allow more infiltration, leading to recharge by groundwater system (Burayu, 2022; Etikala et al., 2019; Fashae et al., 2014; Saranya & Saravanan, 2020).

b. Slope steepness, the study location's slope map generated from DEM data using the spatial analysis tool in ArcGIS 10.8 was divided into five classes, including flat, gentle, moderate, high, and steep. Generally, steep slopes are characterized by lower weights, while gentle slopes contain higher weights (Agarwal & Garg, 2016). High-slope regions have high runoff and low infiltration rates that are unsuitable for groundwater recharge as water lacks the sufficient time needed to infiltrate the ground. In gentle slopes, the movement of water is slow, which allows more infiltration. On steep slopes, runoff is significantly faster with lower infiltration (Fashae et al., 2014; Sajil Kumar et al., 2022).

c. Lineament are the simple and complex linear properties of geological structures such as faults, cleavages, fractures, and various surfaces of discontinuities (terraces and ridges). These are arranged in straight lines or slight curves identified by remote sensing (Kindie et al., 2018; O'leary et al., 1976). Lineament were generated from a geology map and DEM using ArcGIS 10.8 with a line density spatial tool. Areas with high lineament density are considered suitable for groundwater potential zones (Guru et al., 2017; Naghibi et al., 2016; Pinto et al., 2017; Rahmati et al., 2016; Sedrette & Rebai, 2016).

d. Lithology encompassing rock properties, plays an essential role in the distribution and presence of groundwater. This can provide insights into the incidence, movement, and storage of groundwater (Achu et al., 2020; Dhinsa et al., 2022) and determine the nature of porosity and permeability (Burayu, 2022).

e. Soil is one of the essential factors for delineating groundwater potential zones in study locations due to its ability to control infiltration, percolation, and permeability rates (Burayu, 2022; Kindie et al., 2018; Terzer et al., 2013; Thannoun, 2013; Thapa et al., 2017). Additionally, grain size and types influence the control of these rates (Arun Kumar et al., 2021; Sajil Kumar et al., 2022).

f. LULC is crucial in determining the soil's water-holding capacity and groundwater recharge and discharge (Burayu, 2022; Kindie et al., 2018; Roy & Sahu, 2015). Land cover significantly affects hydrological processes, namely interception, soil infiltration capacity, and runoff (Kindie et al., 2018). Furthermore, forest areas have a high potential for groundwater recharge compared to mining and bare land areas. Since land use primarily controls groundwater recharge, its proper understanding is necessary for sustainable groundwater development (Sajil Kumar et al., 2022). Forests assist in holding runoff because the leaves and trees slow down rainfall before hitting the ground, providing more time for plant roots to infiltrate and join groundwater system. The data and sources used in this study are presented in **Table 1.**

Analysis

In this study, spatial analysis was conducted by superimposing all thematic maps through the weighted overlay methods after assigning rates for different classes in each layer and weights for thematic layers using the ArcGIS 10.8 tool (Abiy et al., 2016; Kindie et al., 2018; Moisa et al., 2022; Tamiru & Wagari, 2021). Parameters related to groundwater potential zones can be seen in the data description. The identified potential zones of groundwater basin were validated with Analytical Hierarchy Process (AHP).

The AHP involved evaluating each factor within a particular cluster simultaneously based on its relative importance, as presented in **Table 2**. AHP technique with normalized weights for thematic layers were selected carefully to guide decision-making during input layers evaluation for delineating groundwater zones using the ArcGIS software.

A pairwise comparison matrix was formed, where aii = 1 and aij = 1/ai, for the determination of weights assigned to different thematic maps and their features based on field experience and expert judgment. This was normalized with the AHP Saaty method (Duguma & Duguma, 2022; Goepel, 2013; A. Kumar & Krishna, 2018) as shown in **Table 3**.

The weight factors for the ranking criteria and resulting sub-criteria were calculated using the right eigenvectors, which were derived from the maximum absolute eigenvalues (λmax). Meanwhile, the principal eigenvalue (λ) was estimated with the eigenvector technique (Duguma & Duguma, 2022; A. Kumar & Krishna, 2018),

Table 1. Data Sources

Groundwater Parameters	Data Source	Software for processing
Drainage density	ALOS PALSAR Image of 10m resolution	
Slope steepness	ALOS PALSAR Image of 10m resolution	
Soil Type	West Kalimantan Soil Type Map, 1:100.000 scale	ArcGIS 10.8
Lithology	West Kalimantan Geology Map, 1:100.000 scale	
Land Use Land Cover	From ESRI's 2020 land use land cover image	
Drainage Density	ALOS PALSAR Image of 10m resolution	PCI Geomatica

Table 2. Pairwise Comparison Matrix

Parameters	Ld	Lith	DD	Slope	Soil	LULC
Ld	5	0.5	0.33	0.25	0.2	0.2
Lith	10	1	0.66	0.5	0.4	0.4
DD	15	2.5	1	0.75	0.6	0.6
Slope	20	2	1.33	1	0.8	0.8
Soil	25	5	2.5	1.66	1	1
LULC	25	5	2.5	1.66	1	1
Sum	100	16	8.32	5.82	4	4

Table 3. Normalized Pairwise Comparison Matrix

Parameters	Ld	Lith	DD	Slope	Soil	LULC	Priority	Eigenvalue	Weight (%)
Ld	0.05	0.03125	0.039663	0.042955	0.05	0.05	0.043	4.397	5
Lith	0.1	0.0625	0.079327	0.085911	0.1	0.1	0.087	1.407	10
DD	0.15	0.15625	0.120192	0.128866	0.15	0.15	0.142	1.186	15
Slope	0.2	0.125	0.159856	0.171821	0.2	0.2	0.176	1.024	20
Soil	0.25	0.3125	0.300481	0.285223	0.25	0.25	0.274	1.098	25
LULC	0.25	0.3125	0.300481	0.285223	0.25	0.25	0.274	1.098	25
Sum	1	1	1	1	1	1	1	10.213	100

λmax = 10,213, CI = -0.297712816, RCI_6 = 1.24, and CR = -0.24009098≤0.1.

$$\lambda max = \sum_{wi}^{n} \frac{1}{n} \frac{(AW)i}{wi},$$

$$\begin{Bmatrix} a11 & a12 \ldots \ldots & a1n \\ a21 & a22 \ldots \ldots & a2n \\ an1 & an2 \ldots \ldots & ann \end{Bmatrix} \begin{Bmatrix} w1 \\ w2 \\ w3 \end{Bmatrix} \quad \ldots\ldots\ldots\ (1)$$

where W is the corresponding eigenvector of λmax, wi (i = 1, 2, ..., n) is the weight value for ranking, and in this study, λmax = 10.214. The consistency of the decision matrix must be evaluated by calculating the consistency index (CI) (Duguma & Duguma, 2022; Goepel, 2013; Ş. Şener et al., 2011), which is defined as:

$$CI = \frac{\lambda maks}{n-1} \quad \ldots\ldots\ldots\ldots\ (2)$$

where CI is the consistency index, λmax is the maximum or principal eigenvalue of the scoring matrix which can be easily calculated from the matrix, and n is the matrix order (Duguma & Duguma, 2022; Goepel, 2013; Ş. Şener et al., 2011). The coefficient of consistency ratio (CR) is evaluated using equation (3).

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

where RCI is the random consistency index, its value is obtained from a Saaty scale of 1–9. Also, the CR value must be less than 0.1, indicating the overall compactness of the pairwise comparison matrix (Duguma & Duguma, 2022; Goepel, 2013; Ş. Şener et al., 2011) for consistent weights. In case CR exceeds 0.1, the weights should be double-checked to ensure accuracy and avoid inconsistencies. The weight of each parameter is presented in **Table 4**.

Table 4. Score and Weight of Each Groundwater Potential Zones Parameter

Parameters of Groundwater Potential Zones	Classification	Score	Weight
Drainage Density (Km/Km2)	0-38.00	1	
	38.00-77.09	2	
	77.09-120.53	3	15
	120.53-170.48	4	
	170.48-276.89	5	
Slope	>45	1	
	25-45	2	
	15-25	3	20
	8-15	4	
	0-8	5	
Liniemant Density (Km/Km2)	0-0.077	5	
	0.077-0.236	4	
	0.236-0 .451	3	5
	0.451-0.753	2	
	0.753-1.306	1	
Lithology	Igneous rock	1	
	Green Skis	2	
	Sandstone	3	10
	Alluvium	4	
Soil Type	Ultisol	1	
	Inceptisol	2	
	Histosol	3	25
	Oxisol	1	
LULC	Bare land, mining areas	1	
	Shrubs, swamp	2	
	Dryland farming	3	
	Plantation, settlement, and transmigration areas	4	25
	Secondary dryland forest, and secondary swamp forest	5	
	Dryland forest	6	
	Primary industrial forest, waterbody	7	

3. Result and Discussion

Drainage Density

Drainage density is influenced by topographical conditions and geological permeability (Gao et al., 2022). Areas containing a flat slope usually have high to very high permeability with very low drainage density. The drainage density was generated from Digital Elevation Model (DEM) using the line density tool in ArcGIS 10.8. The density level is very poor, with the majority located at the sub-watershed boundary. The Upper Ketungau area is predominantly located in the center, while the Lower Ketungau is found in several places. The areas at the foot of the slopes exhibit poor density levels, but high to very high-density levels are mostly scattered near the main river.

Drainage density increases with increasing altitude in areas with a flat surface but decreases rapidly with increasing altitude on a steep mountainous surface. It is an inverse function of permeability and an essential parameter in assessing groundwater potential zones. Moreover, *flow density* is a crucial morphometric indicator that can provide further information on the response of a watershed to runoff processes. Supposing the runoff is high, both infiltrated water potential and reserves for groundwater will become low. Once the runoff is low, infiltration and groundwater potential zones tend to be high (Ajay Kumar et al., 2020; Harini et al., 2018). The drainage density of the study location is presented in **Figure 2**.

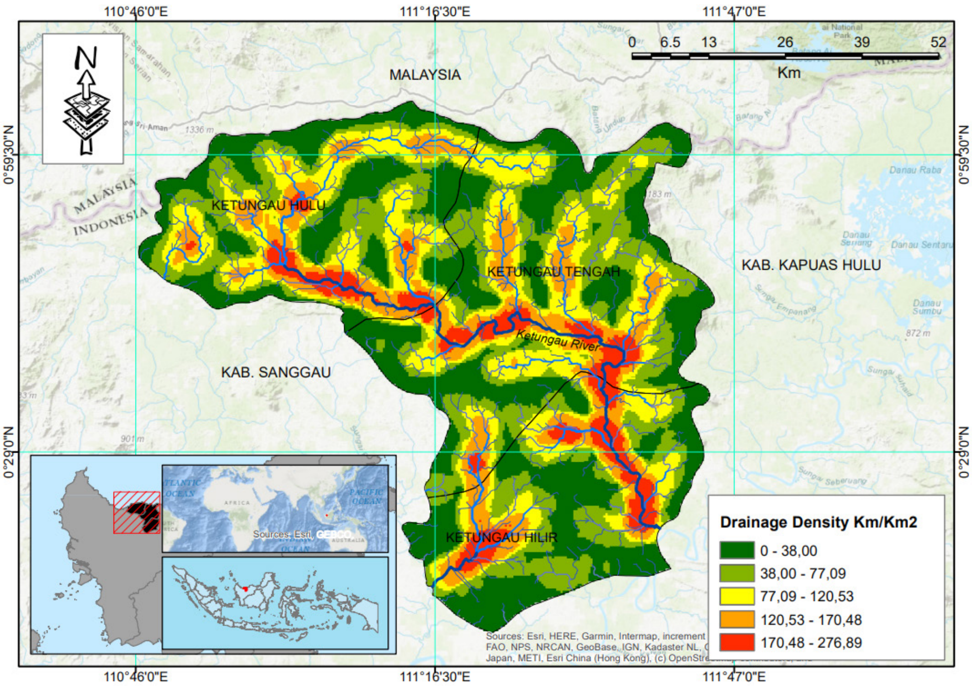

Figure 2. Drainage Density of Ketungau Basin

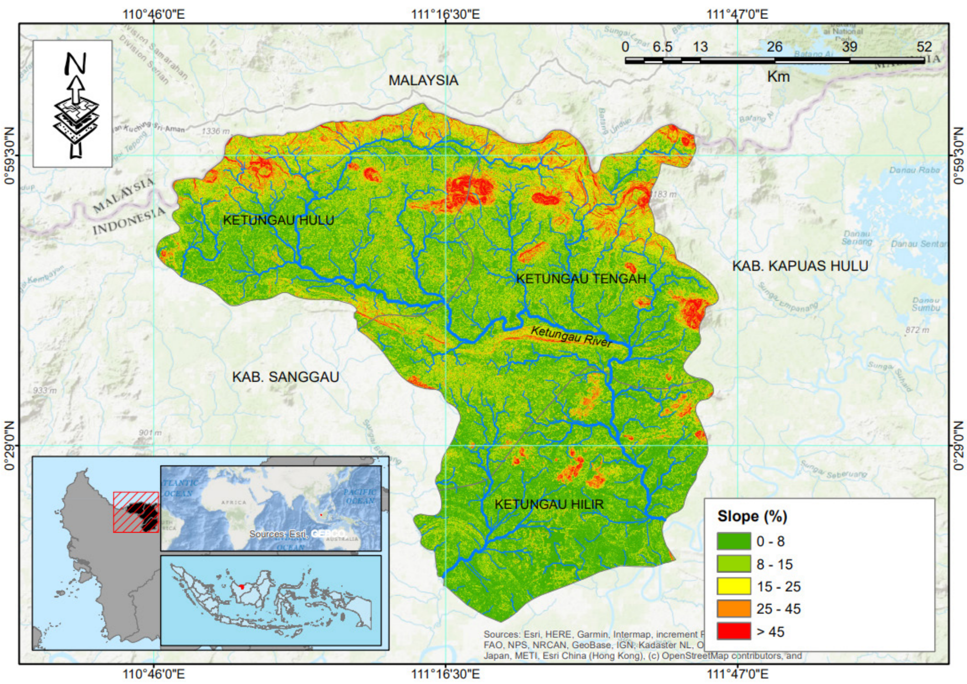

Figure 3. Ketungau Basin Slope

Slope

The slope refers to the steepness or the change in elevation between two locations, and it directly impacts groundwater recharge. This is also described as the variation in elevation across a particular area, which influences the movement of water runoff (Naghibi et al., 2016; Duguma & Duguma, 2022; Harini et al., 2018; Kattimani et al., 2018; Rafati & Nikeghbal, 2017).

The slope is an essential parameter in groundwater investigations because infiltration is inversely proportional to soil steepness. Normally, a steeper slope leads to lower velocities of surface water flow and greater infiltration into the soil. Conversely, a less steep slope increases surface runoff and decreases groundwater percolation (Duguma & Duguma, 2022).

The slope in the study location varies from 0 to >45 % and is dominated by low values of 0-3% and 3-8%, as presented in **Figure 3**. The high-sloped areas are predominantly situated on the north side, parts of the west, and the central region. The western side is hilly, with watershed edges and a less comprehensive distribution of large slopes compared to the north. Steepy areas are scattered across Central and Lower Ketungau, while places with a low slope are found mainly in the central and southern parts of Upper, Middle, and Lower Ketungau.

Lineament Density

Lineament are linear and curved features caused by tectonic forces, which can be easily observed on satellite images (Duguma & Duguma, 2022; T. Kumar et al., 2014) and are capable of indicating main joints, fractures, and faults. These also provide insights into the linearity and topography of formations, vegetation cover, infrastructure such as roads and bridges, straight stream valleys, and boundaries between different lithology units (K. G. Berhanu & Hatiye, 2020). High lineament density supports groundwater potential zones compared to less lineament density (Duguma & Duguma, 2022).

The excessive density of lineament lengths is an indication of huge secondary porosity that represents sectors with high groundwater potential zones (Al-Abadi & Al-Shamma'a, 2014) and permeability (Yeh et al., 2016). *Alignment density* as an important geological formation affects groundwater potential zones and recharge. Areas with higher alignment density permit better infiltration and groundwater absorption (Kabeto et al., 2022), leading to their suitability for the development of groundwater potential.

According to the delineation results, the northern slope and the southern tip of the basin have the highest lineament density. The characteristic straight line on the north is solid but short, while on the south side, it is relatively narrow and short. Lineament in the middle has a different character, where the straightness is tenuous and longer compared to the north and south sides. Analysis indicated that groundwater potential zones *is high in areas with great lineament density. Groundwater exploitation can be considered in several places with high lineament density structures.* Lineament density in the study location is presented in **Figure 4.**

Lithology

The sedimentary rocks in the study location are alluvium, siltstone, mudstone, sand, gravel, and plant remains. The metamorphic consists of greenschist and amphibolite, while the igneous comprises dolerite, diorite, basalt, andesite, tuff, and breccia. Sedimentary rocks are porous because the bonds between the grains are tenuous, while metamorphic rocks have porosity due to the cracks contained. Porosity and permeability are the high-sensitivity variables that influence the availability of groundwater potential zones *within the area. Porosity decides the amount of water that can be absorbed, and permeability determines the ease of extracting water for use* (Dhinsa et al., 2022). This phenomenon *occurs because of the intense pressure force that causes metamorphic rocks to form and fracture. As for igneous rocks, only a few have porosity because of their massive structure.*

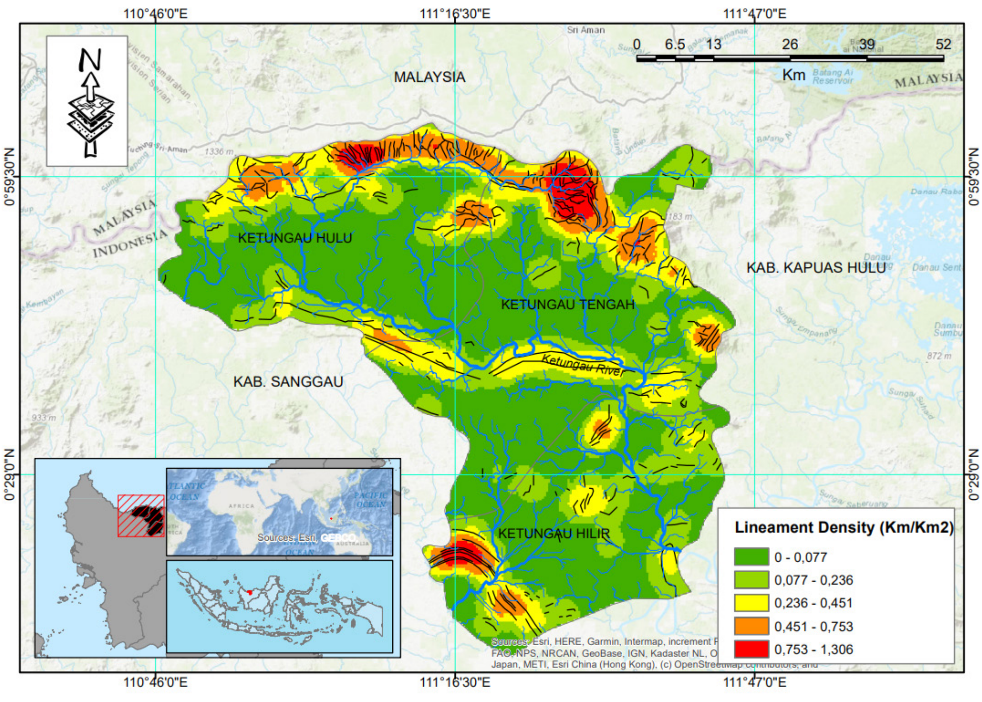

Figure 4. Ketungau Basin Lineament Density

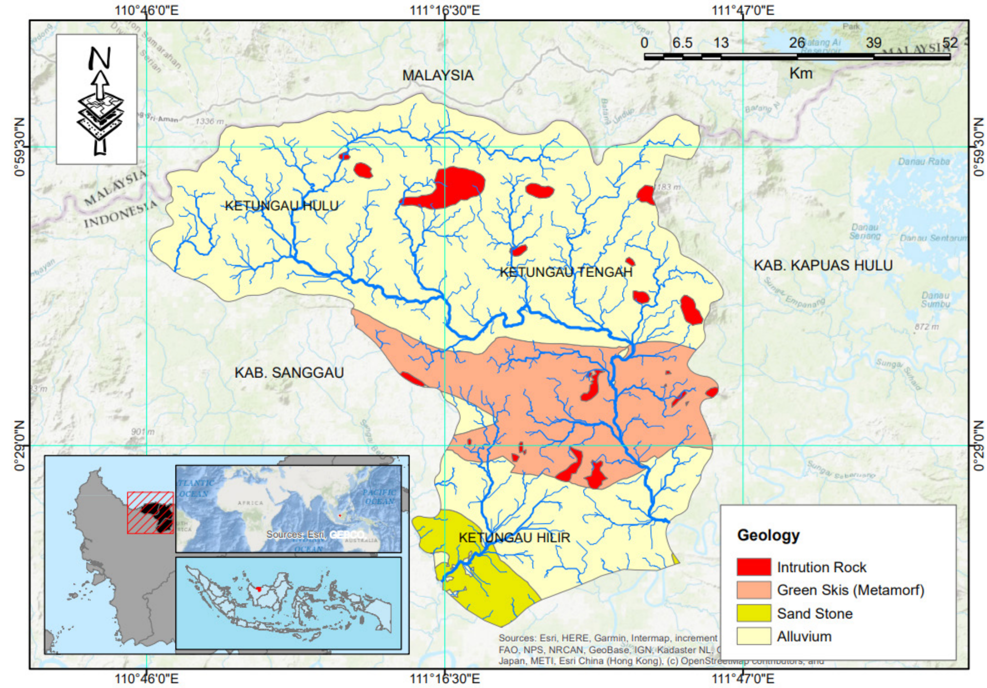

Figure 5. Ketungau Basin Lithology

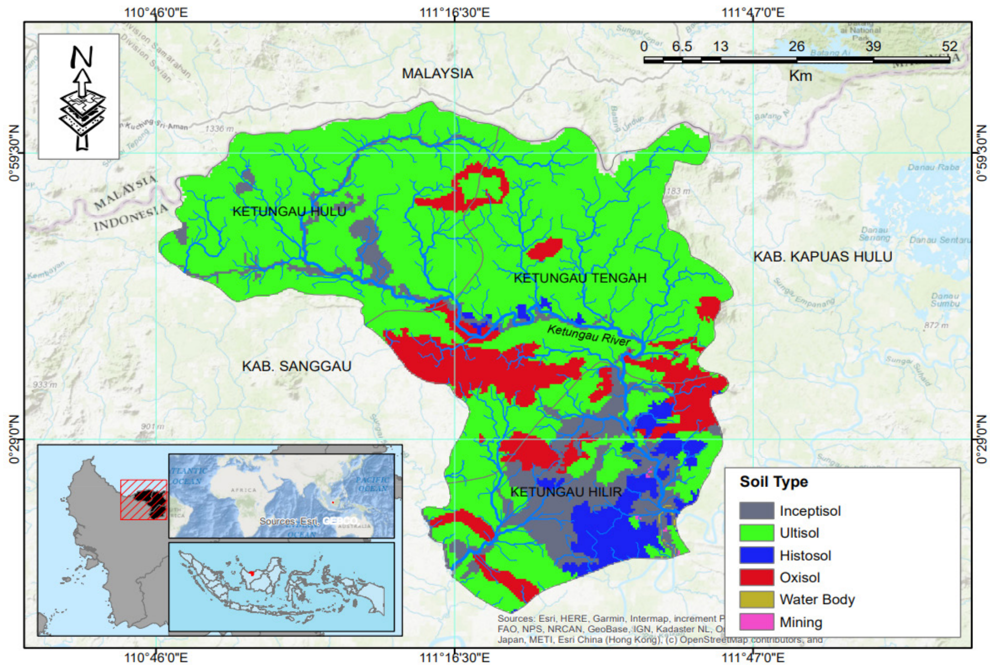

Figure 6. Ketungau Basin Soil Type

During the Eocene to Oligocene period, the Ketungau Basin experienced a high level of clastic sediment supply, leading to the deposition of fluvial conglomerate units. This was caused by the basin subsidence due to sediment infill at the boundary between the linear granite zones and the schist in the north (Semitau Tinggi). Such a high level of clastic sediment supply is commonly observed in well-developed basins (Hall & Nichols, 2002; Smith et al., 1990).

The Ketungau Formation is 900 m thick, consisting of claystone, shale, silt, fine sandstone, and a thin layer of coal at the top (Santy & Panggabean, 2013; Teichmüller & Teichmüller, 1982). Claystone layers usually contain fine silt or sand, which can become good aquifers for hydrogeological purposes. Therefore, groundwater potential zones in the Ketungau basin is significant when considering the geology of its constituents. The lithology of the Ketungau Basin Lithology is presented in **Figure 5**.

Soil Type

Various soil types covering the Ketungau Basin include inceptisol, ultisol, histosol, and oxisol, which are respectively characterized by dusty loam, loam, sandy loam with a crumb structure, and loam textures. Loams and sandy loams possess a better infiltration capacity and groundwater potential zones *than clays* (Duguma & Duguma, 2022). *According to a study conducted by the University of Addis Ababa, soils with good textures such as loam, clay loam, and sandy loam have good infiltration capacity and groundwater potential* zones (B. Berhanu et al., 2013).

Ultosol is the dominant soil covering 74.06% of the study location and scattered in the northern and central regions. Oxysol has an area of 10.67% spread over the central and western parts. Inceptisols and histosols are primarily distributed across the south with an area of 9.28% and 5.99%, respectively. The soil types of the Ketungau Basin soil can be seen in **Figure 6**.

Land Use Land Cover (LULC)

There are 13 land uses in the study location, namely primary dryland forest, secondary dryland forest, secondary swamp forest, industrial forest, plantations, settlements, mining areas, dryland agriculture mixed with shrubs, shrubs, swamps, deforested land, transmigration areas, and water bodies.

The distribution of primary and secondary dry forests lies in the northern part of the study location. Secondary swamp forest is mainly scattered on both sides of the main river and in the south. Industrial plantation forests are found in the Upper, Middle, and Lower parts. Most of the plantation area is in the south, with settlements on the river's right and left. Mining areas and former mines are scattered along the main river and on the southern side. Agricultural land use in wetlands mixed with shrubs is spread across the southernmost tip of the study location, while bushes are scattered on the south side, specifically in Ketungau Hilir. Most of the open land is in the north, namely in Upper Ketungau, while the transmigration areas are in Ketungau Hilir. The area of each land use is presented in **Table 5**.

Table 5. The area of Land Use Land Cover Ketungau Basin

Land Use Land Cover	Area (ha)	%
Primary dryland forest	29,444.23	5.03
Secondary dryland forest	88,535.48	15.12
Secondary swamp forest	34,548.54	5.90
Industrial forest	10,372.4	1.77
Plantation	26,352.31	4.50
Settlement	1.98,62	0 .03
Mining areas	34.97,45	0.60
Dryland farming mixed shrubs	338,963.08	57.88
Shrubs	23,174.2	3.96
Swamp	11,399.56	1.95
Bare land	14,344.06	2.45
Transmigration areas	44.01	0.01
Waterbody	4,710.98	0.80
Total Area	585,584.92	100.00

Land use land cover in Ketungau Basin can be seen in **Figure 7.**

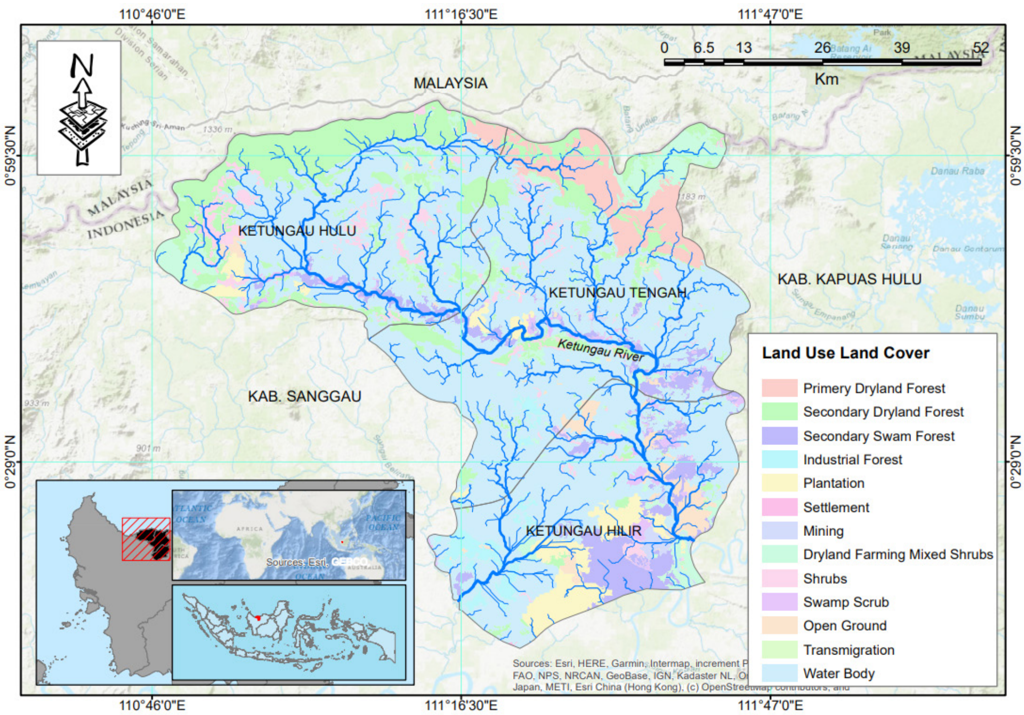

Figure 7. Ketungau Basin Soil Type

GIS and RS are used to identify and map groundwater potential zones, both in India and globally (Arulbalaji et al., 2019). Different methods have been employed to determine potential of groundwater, such as the weighting method involving AHP. Assigning weights accurately is crucial to obtain good results (Arunbose et al., 2021; Sajil Kumar et al., 2022).

AHP was implemented to assign weights and reclassify the maps obtained in the ArcGIS version 10.8 environment. A final groundwater thematic map was prepared by overlaying all maps. According to Table 4, each class in the thematic layers was valuated based on relative importance to groundwater potential. The factors used during identification process were geology, soils, LULC, slope, lineament, and drainage density (Muthu & Sudalaimuthu, 2021). Each thematic layer was assigned a weighting along with its subclasses, namely lineament density (5%), lithology (10%), drainage density (15%), slope (20%), soil (20%), and LULC (25%), as presented in Table 5.

Potential map's accuracy depends on how precisely the weights are assigned to each layer (Machiwal et al., 2011; Sajil Kumar et al., 2022). The overlay methods were used in providing accurate weights to the thematic layers (Abrar et al., 2021; Dar et al., 2021; Doke et al., 2021; Kaliraj et al., 2014; Sajil Kumar et al., 2022). The weights assigned to various factors influencing groundwater or thematic layers and their corresponding normalized values estimated with the AHP technique are presented in Table 4.

In this study, the coefficient values of CI and CR were -0.297712816 and -0.24009098, which means <0.1, indicating the overall compactness of the pairwise comparison matrix (Duguma & Duguma, 2022; Goepel, 2013; Ş. Şener et al., 2011) for consistent weights. Also, RCI6 = 1.24 due to the use of six criteria including lineament density, lithology, drainage density, slope, soil, and LULC.

The CR was -0.24009098 (≤0.1), meaning the overall matrix weight indicates a consistent value that can be used in calculating and determining factors. Based on paired AHP calculations for each parameter, the dominant factors affecting groundwater in the Ketungau Basin were hierarchically found to be LULC, soil type, slope, drainage density, and lineament density.

The overlay analysis results were obtained after assigning weights and ratings to all the influential factors. According to Figure 8, the five classes of groundwater potential zones in the study location are highly potential, potential, moderate, non-potential, and highly non-potential.

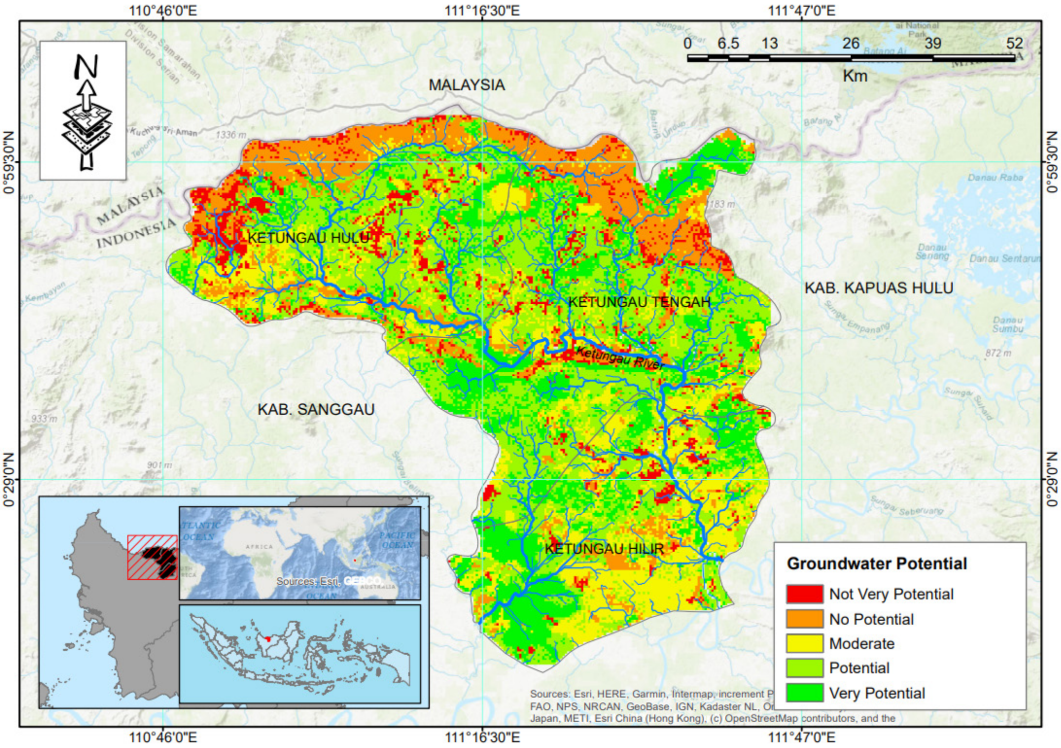

Figure 8. Groundwater Potential Zones of Ketungau Basin

Table 6. Groundwater potential zones classes and their quantitative values

Groundwater potential zones	Occupying study location (km^2)	Area in percent (%)
Highly Non-Potential	410.64	7.01
Non-Potential	934.04	15.95
Moderate	10.96,68	18.73
Potential	22.06,94	37.69
Highly Potential	1,207.54	20.62

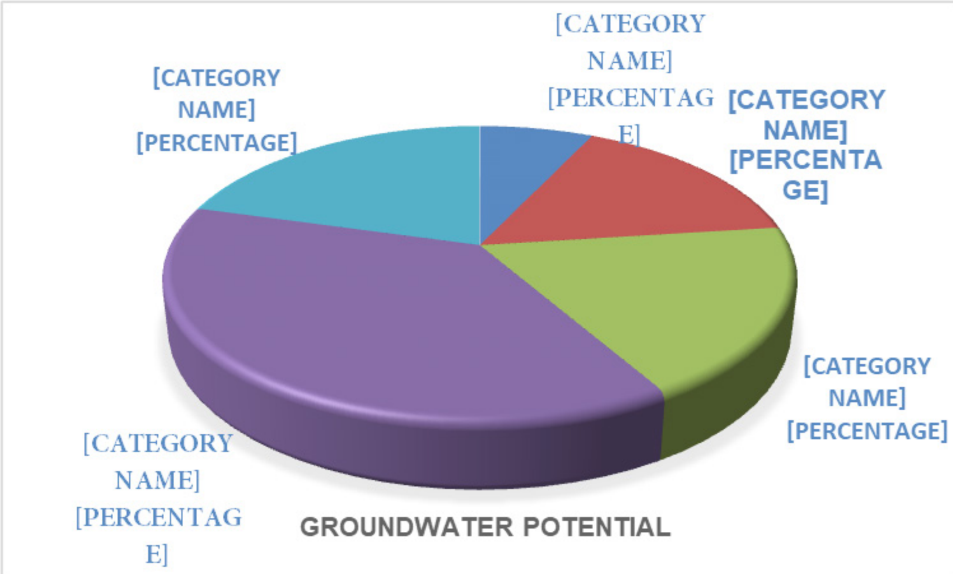

Figure 9. Pie Chart For Groundwater Potential Zones Classification

Based on **Figure 8**, the highly potential and potential zones of groundwater were identified in the central, eastern, and western parts of the Ketungau basin. In contrast, the non-potential and highly non-potential zones were predominantly found along the basin boundary in the north.

Conclusion

The study location has five classes of groundwater potential zones, namely highly potential, potential, moderate, non-potential, and highly non-potential. The highly potential and groundwater potential zones were identified in the central, eastern, and western parts of the Ketungau basin. This was due to the characterization by low gradient area, slope and drainage density, plain topography, and alluvium and granular sediment rock, contributing to high runoff and more infiltration. In contrast, the non-potential and highly non-potential zones were predominantly found along the northern basin boundary.

The Ketungau Basin soil, dominated by clay and sandy loam with a crumb structure, exhibits a better infiltration capacity than clay. Sandy loam and loam textures possess good groundwater potential zones compared to clay (Duguma & Duguma, 2022). According to a study by the University of Addis Ababa, soils with good texture such as loam, clay loam, and sandy loam, have good infiltration capacity and groundwater potential zones (B. Berhanu et al., 2013).

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