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Evaluation of Groundwater Potential Zones in Sg. Seguntor, Sandakan, Sabah, Malaysia by Using the Geographical Information System (GIS) Method

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ABSTRACT

This study was conducted to determine the groundwater potential zone by using the Geographical Information System (GIS) method in Sungai Seguntor, Sandakan, Sabah, Malaysia, and its surroundings. The study area consists of the Sandakan Formation, the Volcanic Breccia and the Quaternary Alluvium. The ArcGIS 10.5 and Global Mapper software were used in this study. Eight thematic maps have been produced: lithological map, rainfall map, drainage density map, lineament density map, soil type map, landuse map, elevation map and slope steepness map. GIS methods were used during the spatial analysis stage. All the thematic maps are weighted based on their emphasis on the existence of groundwater. During the map integration stage, the Raster Calculator is used based on the Eigen Vector of each parameter. The final map produced shows that almost 30% of the study area has high groundwater potential, most of which is in lowland alluvium areas with relatively high drainage density. This final map also shows significant results with tube well data obtained from the Department of Minerals and Geosciences, Sabah, Malaysia.

INTRODUCTION

This research consists of two main aspects, which are the general geology and mapping of groundwater potential zones within the study area at Sungai Seguntor, Sandakan, Sabah. The preliminary part of this research was focused on general geology that covered some aspects of geography, geomorphology, stratigraphy, and structural geology. The other aspect of the research was continued in mapping technique on the groundwater potential through the Analytic Hierarchy Process (AHP) by using the ArcGIS 10.5 software.

The study area was located in the eastern part of Sabah. It consists of the Sandakan Formation, Volcanic Breccia, and Quaternary Alluvium. Haile & Wong (1965) stated that the Sandakan Formation (Late Miocene) overlaps and has an unconformity with the mélange (Middle Miocene). The presence of mélange in this study area presents a challenge due to its unique characteristics, which do not impact groundwater availability. In contrast, areas composed of sandstone or alluvium have the potential to store groundwater effectively (Isnain & Musta 2022).

Sandakan town was located about 335 km from Kota Kinabalu, the capital of Sabah. The study area consists of about 192 km^2. The longitude and latitude of the study area are 117°99’ E - 118°08’ E and 5°49’ N to 5°55’ N (Fig. 1).

The AHP method used during the analysis is based on the complex structure of decision-making that is built on a hierarchical structure, where the parameters used are divided into sub-parameters (Saaty 1980). The study was conducted based on

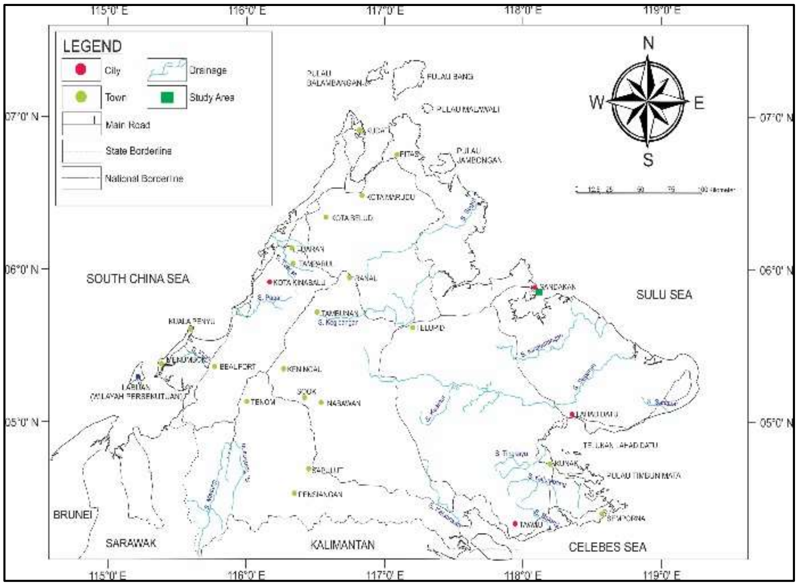

Fig. 1: Map showing the study area.

existing data such as the satellite images, geological map, topography map, and fieldwork data. The preparation of different geo-spatial factors maps as thematic maps of the ground area from different data sources is helpful for mapping groundwater potential zones (Isnain & Musta 2022).

MATERIALS AND METHODS

The use of GIS methods typically involves five main stages: the collection of basic data, analysis of satellite data, GIS processing, production of thematic maps, and the weighting and integration of these thematic maps (Isnain & Mokhtar 2022) The primary data sources utilized are a topographic map from 1996 and Google Earth images with a resolution of 15-30 meters per pixel. The data limitations are certainly not comparable to paid data, such as LIDAR data, which has higher resolution and clarity. Financial constraints in the study limit the acquisition of better-quality data.

Alternatives within the hierarchy structure will be distinguished and combined using the pairwise method. Results from the pairwise will be simplified by using the matrix symmetry. Some calculation was done to determine the position between the parameter, sub-parameter, and alternatives before a decision can be made.

The weightage method in AHP analysis was combined with the GIS technique, which can show that every parameter been used has its own value (Fig. 2). Each parameter and sub-parameter were not equally important to the decision for every stage of hierarchy, and every alternative was different on each parameter (Malczewski 1999, Ahmed et al. 2024).

There are three main steps stated by Saaty (1980), but were modified by Md. Nazri (2006), such as: (1) Determine the AHP hierarchy, (2) Compare the criteria using the Pairwise Comparison Method, and (3) put weightage on each criterion. Parameters chosen on the multi-parameter approach were not the same between each other (Wan Yusryzal 2008). To calculate the weightage on each parameter prepared, Saaty & Vargas (2012) have introduced a new method using the Pairwise Comparison Method (PCM). PCM is to produce the calculation involving the matrix ratio in AHP. This method was also connected with the procedure of decision-making based on GIS (Wan Yusryzal 2008).

The AHP technique is an approach of decision-making based on choice in parameters that has its own importance in this study. Relative importance that was created by Saaty is based on a scale of 1 to 9 that has been used in the process of AHP where odd number scale (1, 3, 5, 7, 9) has the define as distinguish value while the even number (2, 4, 6, 8) define as an intermediate value. Table 1 shows the scale for pairwise comparison introduced by Saaty (1980).

In this process, every parameter will be given its value based on its importance on a scale of 1 to 9. Every parameter and its sub-parameter were considered as not equally important to each other and led to different ratios.

AHP is a method for Multi-Criteria Decision Analysis (MCDA) that is run by the GIS software, which characterizes the weightage for every parameter. AHP was first developed by Saaty (1980). A few analyses have been done to ensure the groundwater potential zones by using the AHP method.

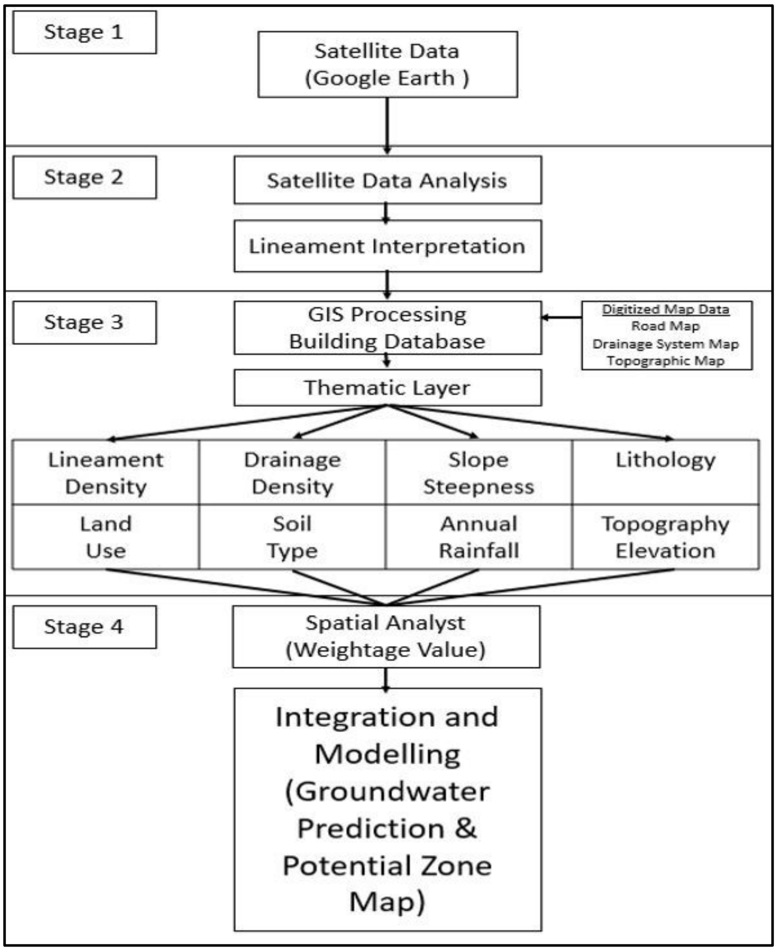

Fig. 2: The Diagram shows the pathway of combining AHP and GIS in this study. (Edited from Khairul et al. 2005).

Table 1: Scales for the pairwise comparisons method.

Intensity of Importance	Definition	Explanation
1	Equal importance in a pair	Two criteria contribute equally to the objective
3	Moderate importance	Judgment and Experience slightly favor one criterion over another
5	Strong importance	Judgment and Experience strongly favor one criterion over another
7	Very strong importance	Judgment and Experience very strongly favor one criterion over another
9	Extreme importance	The evidence favoring one criterion over another is of the highest possible validity.
2, 4, 6, 8	Intermediate values	When compromise is needed
Reciprocals	Values for inverse comparison	If criterion i had one of the above numbers assigned to it when compared with criterion j, then j has the reciprocal value when compared with i

Table 2: Random Inconsistency Index for N = 10 (Saaty 1980).

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.46	1.49

N = No. of parameter used

RI = Random Inconsistency

The AHP method can help manage the conflicting judgments. The Pairwise Comparison Matrices (PCMs) are a useful starting point for determining a ranking of a set of data in multicriteria decision making. The AHP method depends on the development of a PCMs. Saaty (1980) proposes a scale from 1 to 9 for PCM components, where an estimation of 1 shows that the standards are similarly significant, and an estimation of 9 demonstrates that the basis viability is critical compared to different parameters. PCM incorporates a consistency check where judgment errors have been differentiated, and a consistency proportion is determined (Table 2).

Three fundamental stages to settle on choices dependent on PCM in the AHP strategy tasks are:

i) The assurance of the significant measures in the issue (water gathering destinations).

ii) The appraisal of the overall significance of every basis to one another. This is normally done by specialists utilizing a scale from 1 to 9.

iii) The evaluation of the consistency through pairwise correlations to allocate the Consistency Ratio (CR).

Adopted Selection Criteria

With the opinions of the local experts and some reading on past research, GIS were used to define the occurrence of groundwater site selection parameters. Eight physical parameters were used in this study, which include the rainfall distribution, slope steepness, drainage and lineament density, topographic elevation, land use, soil type, and lithology, as shown in Table 3.

During preparation to determine the relative importance of each parameter, local experts have selected and subjected to a review of the parameters. Parameters that were used will be calculated based on their importance by using the Pairwise Comparison method, then every parameter will be subjected to a score determination process (weightage) based on its comparison value (Eigen Vector). Finally, calculate the consistency value using the Analytic Hierarchy Process (AHP) formula and examine the Consistency Ratio (CR) for every parameter that has been chosen before.

Consistency Ratio (CR) was used to measure and ensure the value of the scale ratio (that was given to each parameter) for calculating the main vector, whether

Table 3: Pairwise Comparison Matrices (PCM) for all the parameters used in this study.

Criteria	**More Important<<< Equally Important >>> Less Important**																	**Criteria**
Parameter	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Parameter**
Litology	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Rainfall Distribution
Litology	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Drainage Density
Litology	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Lineament Density
Litology	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Soil Type
Litology	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Topographic Elevation
Litology	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Slope Steepness
Litology	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Landuse
Rainfall Distribution	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Drainage Density
Rainfall Distribution	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Lineament Density
Rainfall Distribution	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Soil Type
Rainfall Distribution	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Topographic Elevation
Rainfall Distribution	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Slope Steepness
Rainfall Distribution	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Landuse
Drainage Density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Lineament Density
Drainage Density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Soil Type
Drainage Density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Topographic Elevation
Drainage Density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Slope Steepness
Drainage Density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Landuse
Lineament Density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Soil Type
Lineament Density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Topographic Elevation
Lineament Density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Slope Steepness
Lineament Density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Landuse
Soil Type	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Topographic Elevation
Soil Type	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Slope Steepness
Soil Type	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Landuse
Topographic Elevation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Slope Steepness
Topographic Elevation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Landuse
Slope Steepness	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Landuse

Table 4: Position given to eight parameters to measure the potential of groundwater accordingly.

No.	Parameter	Position
1	Lithology (LI)	1
2	Rain Distribution (RD)	2
3	Drainage Density (DD)	3
4	Lineament Density (LD)	4
5	Soil Type (ST)	5
6	Topography Elevation (TE)	6
7	Slope Steepness (SS)	6
8	Landuse (LU)	7

it is suitable and rational to prevent any unreasonable excuses. Every consistency value that is accepted will ascertain whether the data can be trusted by the decision maker to dictate the weight of each set of criteria used (Samsam 2010). If the value of CR is less than or equal to 10%, inconsistency can be accepted, but if the CR is more than 10%, subjective judgment will be revised (Saaty 1980).

Every parameter will be arranged accordingly to its hierarchy. Every issue can be broken down into some element that will be divided into two: alternatives and criteria. Each parameter used for this research is to determine which main factor will have the greatest impact that shown the groundwater potential in that area. Table 4 shows the hierarchy according to the previous studies and reading material, such as articles.

RESULTS AND DISCUSSION

After the arrangement of hierarchy (according to its parameter that will be used during the AHP analysis), the PCM analysis will be done. Eight parameters were compared in relation to their importance and weightage that have been given (Table 5). This method was an evaluation that was done to know the relative importance of two elements on every level and their relationship with the level above a particular parameter (Table 6). Scale 1 to 9 is the scale of importance that is used to express opinion (Saaty 1980). These weightage values will be inserted into Pairwise Comparison Matrices

Table 5: Pairwise Comparison for every parameter that contributed to the groundwater potential.

Criteria	More Important <<< Equally Important >>> Less Important																	Criteria
Parameter	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Parameter
Lithology	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Rainfall Distribution
Lithology	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Drainage Density
Lithology	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Lineament Density
Lithology	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Soil Type
Lithology	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Topographic Elevation
Lithology	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Slope Steepness
Lithology	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Landuse
Rainfall Distribution	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Drainage Density
Rainfall Distribution	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Lineament Density
Rainfall Distribution	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Soil Type
Rainfall Distribution	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Topographic Elevation
Rainfall Distribution	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Slope Steepness
Rainfall Distribution	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Landuse
Drainage Density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Lineament Density
Drainage Density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Soil Type
Drainage Density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Topographic Elevation
Drainage Density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Slope Steepness
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Lineament Density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Soil Type
Lineament Density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Topographic Elevation
Lineament Density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Slope Steepness
Lineament Density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Landuse
Soil Type	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Topographic Elevation
Soil Type	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Slope Steepness
Soil Type	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Landuse
Topographic Elevation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Slope Steepness
Topographic Elevation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Landuse
Slope Steepness	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Landuse

Table 6: Pairwise Comparison Matrices for every parameter.

Parameter	LI	RI	DD	LD	ST	TE	SS	LU
LI	1	2	3	4	5	6	6	7
RD	0.50	1	2	3	4	5	5	6
DD	0.33	0.50	1	2	3	4	4	5
LD	0.25	0.33	0.50	1	2	3	3	4
ST	0.20	0.25	0.33	0.50	1	2	2	3
TE	0.17	0.20	0.25	0.33	0.50	1	1	2
SS	0.17	0.20	0.25	0.33	0.50	1.00	1	2
LU	0.14	0.17	0.20	0.25	0.33	0.50	0.50	1
Total	2.76	4.65	7.53	11.42	16.33	22.50	22.50	30.00

Table 7: Normalization Matrices for every parameter.

Parameter	LI	RI	DD	LD	ST	TE	SS	LU	Total
LI	0.36	0.43	0.40	0.35	0.31	0.27	0.27	0.23	2.61
RD	0.18	0.22	0.27	0.26	0.24	0.22	0.22	0.20	1.81
DD	0.12	0.11	0.13	0.18	0.18	0.18	0.18	0.17	1.24
LD	0.09	0.07	0.07	0.09	0.12	0.13	0.13	0.13	0.84
ST	0.07	0.05	0.04	0.04	0.06	0.09	0.09	0.10	0.55
TE	0.06	0.04	0.03	0.03	0.03	0.04	0.04	0.07	0.35
SS	0.06	0.04	0.03	0.03	0.03	0.04	0.04	0.07	0.35
LU	0.05	0.04	0.03	0.02	0.02	0.02	0.02	0.03	0.23
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	8.00

LI = Lithology, RD = Rain Distribution, DD = Drainage Density, LD = Lineament Density, ST = Soil Type, TE = Topography Elevation, SS = Slope Steepness, LU = Landuse

(PCM) and then will be used to produce the Normalization Matrices (Table 7) for each of the eight parameters that have been the main factor.

Consistency Ratio (CR) was calculated as shown in Table 8 to ensure the value of the scale ratio given to each parameter was rational and to prevent uncertainty (unreasonable excuses). If the CR value is less than 0.10 (10% consistency), the ratio scale given will make sense, and the priority vector is accepted. The CR value obtained from this study was 0.0212; thus, the value can be accepted and used.

Considering the CR value was less than 0.10, it can be used in the process of implementing the Weighted Linear Combination (WLC) technique, which includes standardizing the suitability maps, assigning the weightage of relative importance to the suitability maps, and then combining the weightage. And finally, obtaining the groundwater potential map.

ArcGIS software is generally used to help generate maps, edit data editing and present the results of an analysis. Thematic maps that have been produced for this study are the rain distribution map, lithology map, drainage density map, lineament density map, soil type map, landuse map, slope steepness map, and topography elevation map.

All this map was then given the weightage value, which was relevant to its remuneration towards potential groundwater in the study area (Table 8). Then, a detailed study and reading in the related field were done to give a rational weightage value to each of the thematic maps according to their contribution to the formation of groundwater, respectively. Therefore, the weightage value given in this study was a modified comparison weightage value that was used by the previous researcher, Krishnamurthy et al. (1996

Table 8: The compound values of weights (Eigen Vector), CI, RI, and CR for groundwater potential.

Parameter	Weightage (Eigen Vector)	λ_{ave}	CI	RI	CR
Lithology	0.33	8.21	0.03	1.41	0.0212
Rain Distribution	0.23				
Drainage Density	0.16				
Lineament Density	0.10				
Soil Type	0.07				
Topography Elevation	0.04				
Slope Steepness	0.04				
Landuse	0.03				

Table 9: Distribution of weightage value for each of the lithology units in the study area.

Lithology Unit	Weightage value
Volcanic Breccia	10
Sandakan Formation	20
Quaternary Alluvium	30

& 1997), and calculated by using the Analytical Hierarchy Process (AHP) method.

The study area at Seguntor River and its surrounding only had three different lithologies: Sandakan Formation, Volcanic Breccia, and Quaternary Alluvium, as shown in Fig. 3 and Table 9. According to the Department of Minerals and Geosciences (JMG), Sabah, the availability of groundwater aquifer is more significant at the Sandakan Formation because it consists of a thick layer of sandstone. The most potential aquifer contributing to the groundwater source of recharge was from the alluvium deposition.

However, there is a vice versa for Volcanic Breccia. Volcanic Breccia consists of a mix of rock, and this type of rock is not conducive to any groundwater existence because it does not have any geological structure that could contribute to that aspect. A rock formation that contains water will be known as an aquifer.

Suppose the lithology had a high percentage of porosity and a lower percentage of permeability, so it is only suitable to be an impermeable stratum. However, a high rate of groundwater discharge will need the same high rate of recharge, and this depends on the amount of permeability in the rock formation. Permeability is the ability of soil, sediment, and rocks to accept and give way for water between the unsaturated zone (ventilation zone) and the saturated zone (Khairul et al. 2001). Ibrahim & Juhari (1990) describe porosity as the ratio of voids compared to the total volume of the rock itself.

Water movement and groundwater placement are affected by permeability and porosity factors. This type of nature for an aquifer depends on the composition and texture of the rock itself. A high percentage of porosity could determine that the rock formation can impound a huge amount of groundwater.

As of Fig. 4, basic data of rain distribution in the study area were acquired from the Sabah Meteorological Department. Rain gives a drip effect towards the surface of exposed soil, and then seeps through the pores until reaching the catchment area. Rainwater that flows will be absorbed as much as possible and enhance the potential of groundwater in that area.

Rain distribution in the study area was studied with only one station, which will make it limited for interpretation of data (Table 10). The total rain distribution was based on the given data, that is, 3,376 mm per year. The weightage value given for its thematic map was the same for every area since the data retrieved were located only at one station at the Sandakan International Airport.

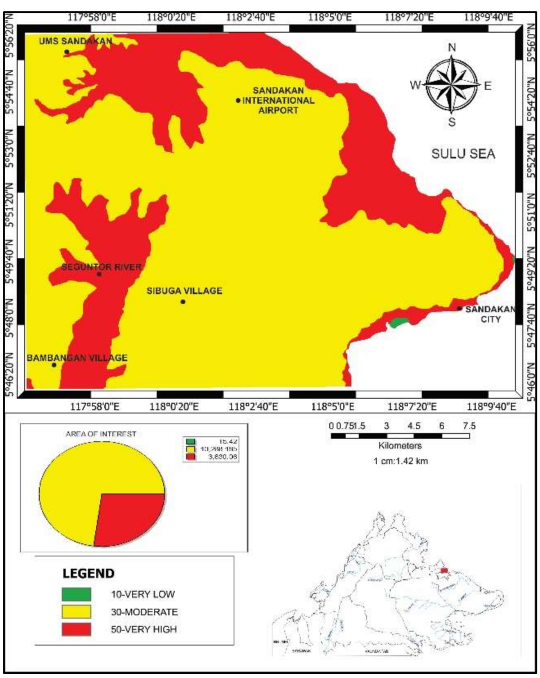


Fig. 3: A lithology weightage map in the study area.

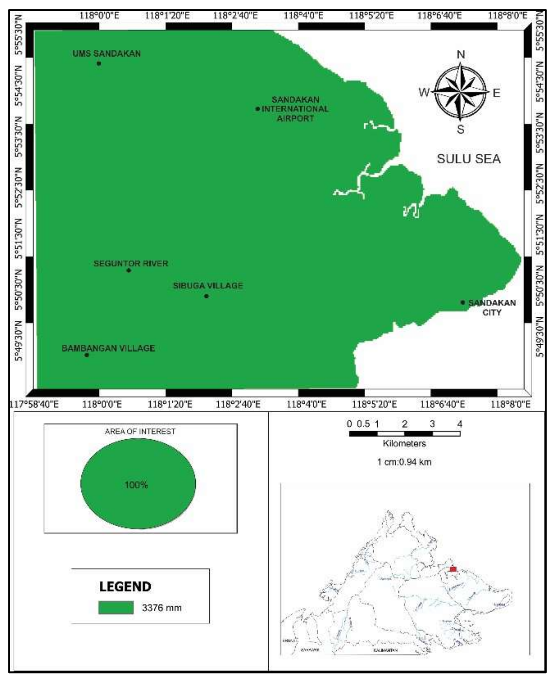


Fig. 4: A rainfall distribution weightage map in the study area.

Table 10: Distribution of weightage value of the rain density in the study area.

Rainfall Distribution	Weightage value
3376 mm	50

Typically, the presence of water on the surface is due to rainfall. All sources of groundwater arise either directly or indirectly from rainfall, particularly in areas that depend on it (Robinson & Ward 1990). The water table was close to the surface if that area has a high average of rainfall and vice versa. In other words, contributions from rainfall distribution were high for groundwater occurrence.

The existence of rivers and lakes on the Earth's surface gives a preliminary description of the existence of groundwater nearby. This is because lakes and rivers could illustrate the groundwater level. Groundwater level is usually found at a few meters, but for lakes, swamps, the ocean, and rivers, the groundwater level is near the surface (Khairul et al. 2001).

Drainage density maps were acquired by using an existing map of the study area, and the drainage was traced using ArcGIS 10.5. This drainage system will be assimilated according to its density using "line density". According to the base map of the study area, water bodies were so dense that they consist of streams and other drainage (Fig. 5). There is a main river that contributes more to river flow, which is the Seguntor River, located on the north and south of the study area.

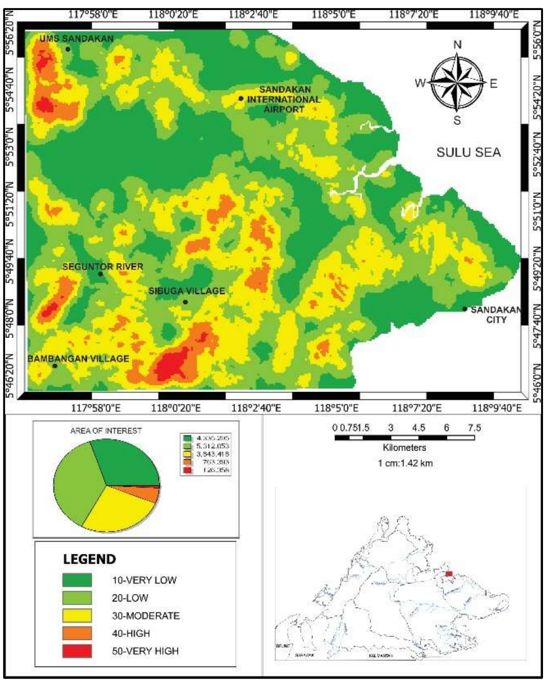


Fig. 5: Drainage density weightage map in the study area.

Table 11: Classification of weightage for drainage density thematic map.

Drainage Density [m.m^{-2}]	Weightage value
<2055 m.m^{-2}	10
2055-4110 m.m^{-2}	20
4110-6165 m.m^{-2}	30
6165-8220 m.m^{-2}	40
>8220 m.m^{-2}	50

The weighting values (Table 11) are given according to the density of drainage to contribute to the presence of groundwater. Density is the ratio of the total length of all river channels (out of order) in one basin to the area of the basin (Ibrahim & Juhari 1990). In the high-density drainage zone, the water runoff on the surface is high, so the rate of water absorption into the catchment area is high, and the weighting value given becomes high, but the opposite situation occurs in the low-density drainage zone.

Lineament density maps (Fig. 6) were generated through image reference Shuttle Radar Topography Mission (SRTM)

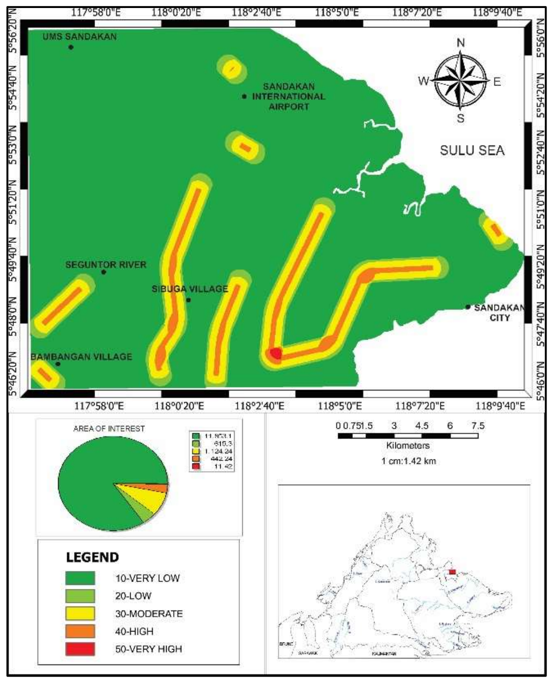


Fig. 6: Lineament density weightage map in the study area.

Table 12: Classification of weightage for lineament density thematic map.

Lineament Density [m.m^{-2}]	Weightage value
<202 m.m^{-2}	10
202-404 m.m^{-2}	20
404-606 m.m^{-2}	30
606-808 m.m^{-2}	40
>808 m.m^{-2}	50

and Triangular Irregular Networks (TIN) to see the presence of positive lineament in the study area and then traced. After tracing, it is assimilated according to density through line density. Lineaments are interpreted as a straightforward, large-scale, and clear feature found on the Earth's surface. There are two types of lineaments, namely positive and negative lineaments. In this study, positive lineament is used and considered because negative lineaments are drainage and river currents on the Earth's surface.

Lineament that has the highest weight in contributing to groundwater are in the range of more than 808 $m.m^{-2}$ (Table 12). The range is the most potential area and is more prone to groundwater because there are various types of faults, whether major or minor, as well as cracks in various rocks.

Soil type maps are produced through land type trace maps from the Sabah Branch Agriculture Department

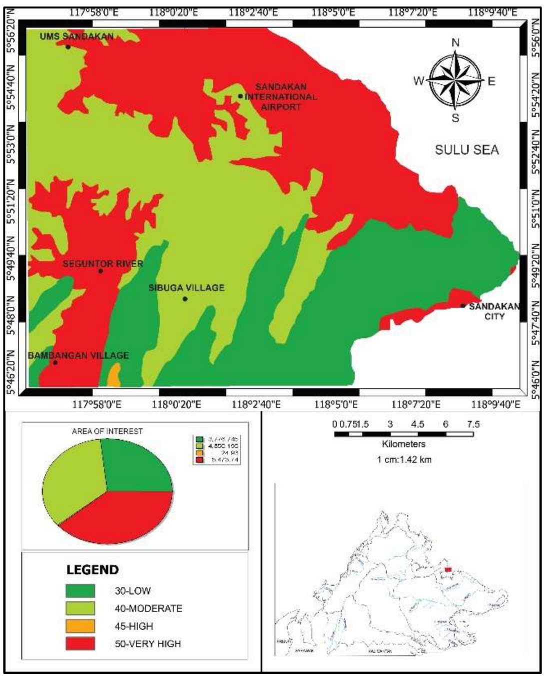


Fig. 7: Soil type weightage map in the study area.

(Fig. 7). The weighting value of the soil type map is based on the nature of porosity and soil permeability found in the study area. Other factors, such as soil type and sedimentation area, are also considered and used as a measure for weighting. To determine the presence of groundwater, the nature of the porosity and permeability of every type of soil is important. It plays a significant role because it could retain or allow water flow to form groundwater below the surface. Thus, the influence of soil type can contribute to the existence of groundwater.

The weighting value based on the remuneration for the presence of groundwater can be determined through the determination of the forming material of the soil series. Soils with a high percentage of clay provide high remuneration due to the presence of groundwater. However, sand is more porous and has higher permeability. Table 13 shows the types of soil available in the study area and the division of weight values for each of these soil types.

The soil in the study area is divided into several groups according to different types. Table 14 shows the groups and types of soils available in the study area.

Khairul et al. (2001) state that the thickness of a soil zone is different and depends on the type of soil and plants. The texture of a soil depends on the relationship between the soil type and the presence of groundwater. Soil texture is the relative rate of sand, silt, and clay found in particle size analysis. This is because particle size has a direct effect on the porosity and permeability of a soil.

Topographic altitude maps are generated from the contours and images of the Digital Elevation Model (DEM), as shown in Fig. 8. Most study areas have low topographic features and are characterized by alluvial deposits and the formation of the Sandakan Formation. Alluvial areas have a high probability of contributing to the presence of groundwater. Rainwater flowing from high areas to low areas makes these low areas more potential to groundwater.

The lower areas have dense drainage (rivers and lakes). Topographic elevation maps for this area are in the contour range of 0 to 260 m and are classified into five groups. High

Table 13: Classification of weightage for soil type thematic map.

Soil Type	Weightage value
Weston	50
Brantian	50
Kepayan	50
Kinabatangan	50
Tungku	45
Silabukan	40
Maliau	30

Table 14: Group and soil type in the study area.

Series No.	Group	Soil Type
1	Weston	Sulfur Alluvium
12	Brantian	Alluvium
13	Kepayan	Alluvium
5	Kinabatangan	Alluvium
17	Tungku	Calcareous Alluvium
25	Silabukan	Alluvium and mudstone
48	Maliau	Sandstone and mudstone

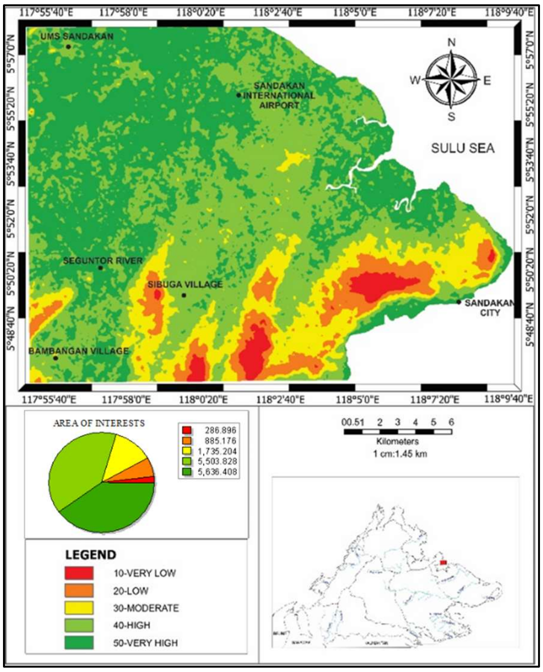


Fig. 8: Topography Elevation weightage map in the study area.

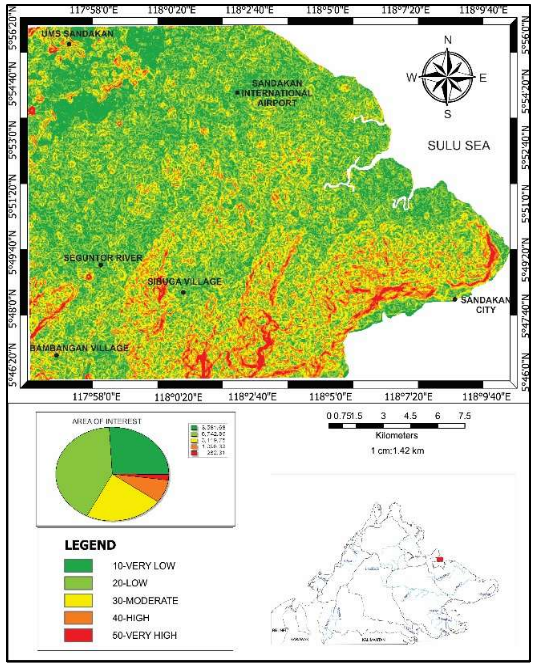


Fig. 9: Slope Steepness weightage map in the study area.

weighting values are given to areas with low topography based on remuneration to the presence of groundwater, as shown in Table 15.

Slope analysis using Slope Tools on ArcMap to classify slopes according to the desired degree of slope can be done based on a GIS method. The slope factor is one of the factors that contribute to the potential of groundwater. To produce a gradient map, a generated DEM raster image will be used. Height and gradient play a significant role in controlling terrain stability.

Slopes can affect the direction and amount of runoff in surface and subsurface drainage. Slopes can have a dominant effect on rainfall overflow. Land flow period, infiltration, as well as flow in the subsurface, is controlled by slopes (Fig. 9).

Slopes with high and steep degrees are less prone to water infiltration compared to slopes with low slope degrees. In this gradient analysis, 5 sub-groups were produced, i.e., angles less than 3°, 3 to 8°, 8 to 14°, 14 to 23° and 23 to 66° (Table 16). The relationship between slope shape and lithology, structure, soil type, and drainage is essentially defined as a combination of slope angles. Steeper slopes are more susceptible to surface runoff, while flat terrain is more susceptible to water accumulation.

The type of land use is important in producing an AHP analysis, for example, as the land covered by plants serves as a water infiltration area. Landuse maps in the study area are traced from the basic maps generated from satellite images sourced from Google Earth (Fig. 10). Based on the information obtained, the study area is divided into forestry and agriculture, urbanization, housing, industry, water bodies and mangrove swamps.

The weighting value is given based on the information, and the high weighting value is given to the body area of water and mangrove swamps, as shown in Table 17. Urban and industrial areas are given the lowest weight because the water runoff in these areas is high and not able to hold a lot of water due to various sloping structures, compared to forestry and agricultural areas.

Table 15: Classification of weightage for topography elevation thematic map.

Topography Elevation	Weightage value
<13 m	50
13-40 m	40
40-82 m	30
82-143 m	20
143-260 m	10

Table 16: Classification of weightage for slope steepness thematic map.

Slope Steepness [^{o}]	Weightage value
0-3	50
3-8	40
8-14	30
14-23	20
23-66	10

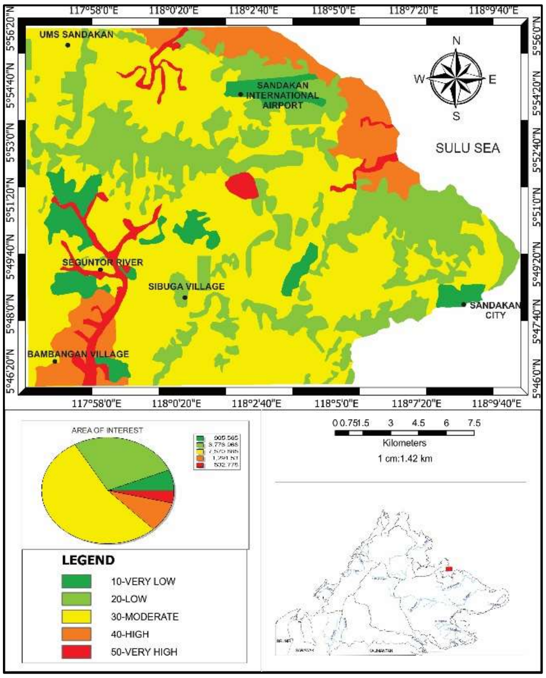


Fig. 10: Landuse weightage map in the study area.

The water present on the surface indicates that the surface level of the water is adjacent to the surface. Meanwhile, low weighting values such as urbanization and industry do not contribute to the existence of groundwater. Land use near the sea will be prone to saltwater injections or groundwater pollution. The settlement also has a high water runoff process.

The high sediment content in the soil, as well as the growth of fertile vegetation along certain zones, is part of the formation of shallow aquifers (Morgan 1993). Based on land use, coverage on a flat surface determines the presence of groundwater in the study area. It will increase the presence of groundwater if the area is covered with forest or plants because the soil of this area allows water to infiltrate through runoff.

Groundwater Potential Suitability Analysis

Finally, when all thematic maps have been given weighting values (Table 18), these thematic maps will be integrated by combining space data (pixels) from all thematic maps to produce a groundwater potential forecast map in the study area. Determination of groundwater potential is done based on the technique "Spatial Analyst" in GIS format, based on the eight parameters produced.

Table 17: Classification of weightage for land-use thematic map.

Landuse	Weightage value
Water Bodies	50
Mangrove swamp	40
Forest/Agriculture	30
Housing area	20
Urbanization area	10
Industrial area	10

Table 18: Summary of the results from the Final Groundwater Potential Map of the study area.

Position	Criteria	Condition	Weight
1	Lithology	Quaternary Alluvium Sandakan Formation Volcanic Breccia	0.33
2	Rainfall Distribution	<1688 mm 1688-3376 mm >3376 mm	0.23
3	Drainage Density	<2055 $m.m^{-2}$ 2055-4110 $m.m^{-2}$ 4110-6165 $m.m^{-2}$ 6165-8220 $m.m^{-2}$ >8220 $m.m^{-2}$	0.16
4	Lineament Density	<202 $m.m^{-2}$ 202-404 $m.m^{-2}$ 404-606 $m.m^{-2}$ 606-808 $m.m^{-2}$ >808 $m.m^{-2}$	0.10
5	Soil Type	Weston Brantian Kepayan Kinabatangan Tungku Silabukan Maliau	0.07
6	Topography Elevation	< 13 m 13-40 m 40-82 m 82-143 m 143-260 m	0.04
6	Slope Steepness	$0\text{-}3^0$ $3\text{-}8^0$ $8\text{-}14^0$ $14\text{-}23^0$ $23\text{-}66^0$	0.04
7	Landuse	Water Bodies Mangrove swamp Forest/Agriculture Housing area Urbanization area Industrial area	0.03

The resulting maps will be weighted according to the analysis of the AHP model and generated using "conversion to Raster," which converts the traced map to a raster in GIS format. All eight analyses will be multiplied together with their respective weights and produce final raster data showing the existence of groundwater. The weighting result of all the parameters placed is then added and calculated using the "Raster Calculator". The formula used for the analysis of groundwater potential is based on Isnain & Juhari (2017).

Groundwater Potential

[(Lithology) * 0.3267 + (Rainfall) * 0.2267 + (Drain Density) * 0.1553 + (Lineament Density) * 0.1048 + (Soil Type) * 0.0692 + (Topography Elevation) * 0.0440 + (Gradient) * 0.0440 + (Landuse) * 0.0293]

The results of the analysis show that 17% of the study area is categorized as very low groundwater potential, 36% as low groundwater potential, 20% as moderate groundwater potential, 13% as high groundwater potential, and the highest contributing is as much as 14% to the potential underground water. This map has been modified from the original map generated through ArcGIS software, as there are several alluvial deposits near the sea.

The seawater penetration factor must be considered to obtain good water quality for the use of the population. Integration maps have been produced along with pie charts for a clear understanding of the existence and potential of groundwater in the study area (Fig. 11).

The study area covers more high areas that have a predominance of sandstone, alluvial sedimentary plain, thick mudstone areas, as well as a mixture or interval between sandstone and mudstone. The accuracy of the final result of the groundwater potential forecast map is based on the weighted values given to each

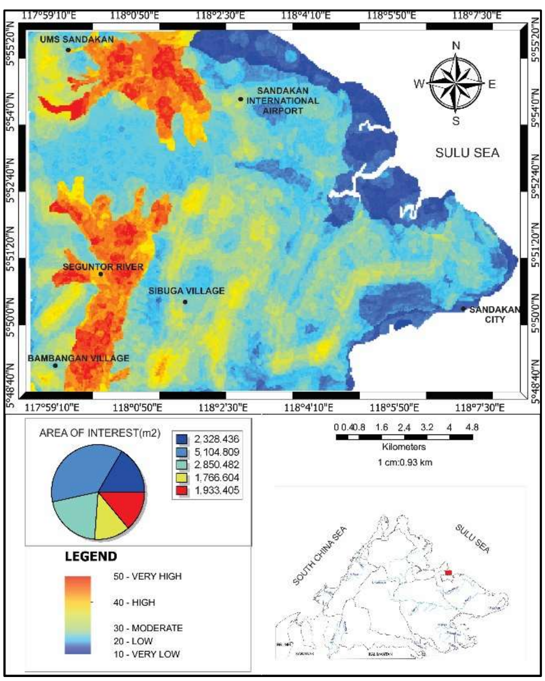


Fig. 11: A groundwater potential zone map of the study area.

parameter based on its contribution to the presence of groundwater.

The results of the forecast map found that some areas in the study area have a high potential to have groundwater, especially those close to the Seguntor River. It is estimated that 14% of the study area has a very high potential, and 13% has a high groundwater potential. Both areas can be studied deeply, and possibly the construction of wells for the locals. The remaining 73% have relatively moderate, low and very low potentials. Among the areas with high potential to have groundwater are the areas around Bambangan village and other settlements adjacent to this river.

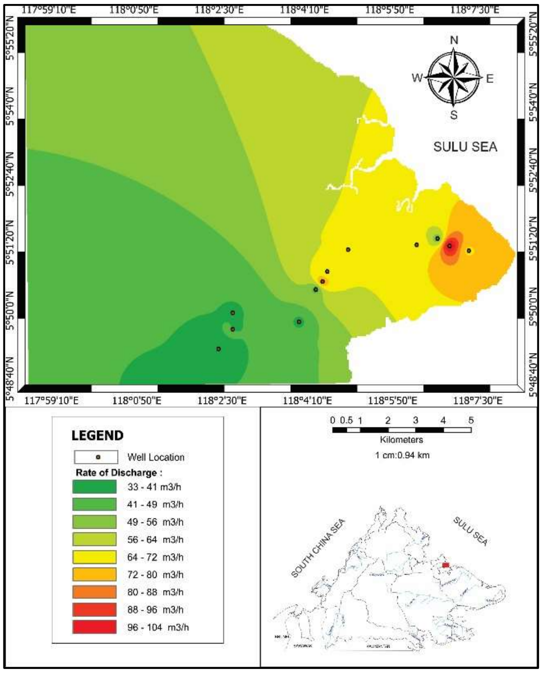
It is found that most areas of very high potential zones are located in alluvial areas, as most Sandakan areas are composed of this type of soil. The Sandakan Formation is the next position to have the potential to store groundwater. Alluvium is indeed one of the formations that acts as a good aquifer, but the Sandakan Formation is the most productive groundwater aquifer according to the Department of Minerals and Geosciences (JMG) because it consists of a thick layer of sandstone. The Volcanic Breccia is in a low-lying area with no potential due to shattered rocks and landslides.

Comparison Between Final Groundwater Potential and Ground Data

Based on the forecast map that has been produced, it is found that it coincides with the data resulting from the fieldwork that has been carried out previously. As a result of fieldwork that has been carried out in the study area, it was found that the area around Sandakan has tube wells that have been excavated by the Department of Minerals and Geoscience (JMG) as a water supply to the locals. Residents around Sandakan do not have an adequate clean water supply, probably due to the growing human population and urbanization.

The growing human population has led to an increased demand for clean water for various purposes. In the study area, which includes Kuala Sibuga, China Valley, Ulu Sibuga, and Hill Top, approximately 15 tube wells have been constructed. The average depth of these wells exceeds 120 meters. Utilizing data collected, an isopach map was created using GIS methods to compare with the groundwater potential forecast map (see Fig. 12). The correlation between the predicted groundwater levels and the tube wells in the study area demonstrated significant results, with discharge rates ranging from 33 to 104 $m^3.h^{-1}$.

The analysis of the laboratory study that has been conducted is an analysis of the distribution of grain size based on BS 1377: 1190, test 7. The soil sample taken in the study area for the purpose of this analysis is divided into 6 types,



(Source: Mineral and Geoscience Department)

Fig. 12: Well-location map and rate of discharge in the study area.

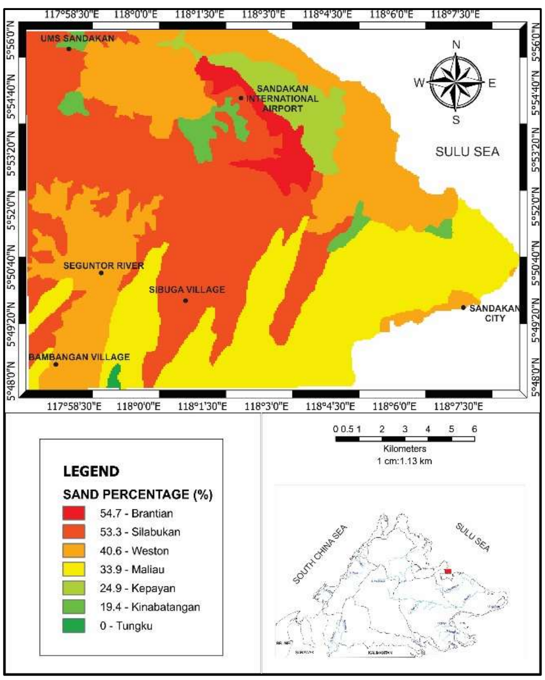


Fig. 13: Sand Percentage Map according to soil type in the study area.

namely Weston, Kinabatangan, Kepayan, Brantian, Maliau and Silabukan, according to the soil type of the Sandakan area (Department of Agriculture Malaysia), as shown in Fig. 13.

The classification that has been produced according to the distribution of grain size shows that the Silabukan type soil is sandy clay made from mud and alluvial rock. Weston, on the other hand, is a soil made from sulfurized alluvium and is classified as loam in the grain size distribution. Meanwhile, Maliau is made of sandstone and mudstone and is classified as clay. Brantian is classified as sandy clay loam, Kepayan is classified as muddy loam, and Kinabatangan is classified as clay. All three types of soil are the result of the formation of alluvial deposits.

CONCLUSIONS

The groundwater potential zones in the study area can be determined based on several parameters, including lithology, drainage density, lineament density, rainfall density, topography, and slope steepness. It has been observed that the areas with the highest groundwater potential are primarily located in alluvial and sandstone regions characterized by high drainage density in low-lying areas. Additionally, the groundwater potential map reveals significant correlations with tube well data obtained from the Department of Minerals and Geosciences in Sabah, Malaysia.

The findings from this study are valuable not only for addressing basic needs in the area but also for enhancing the overall socio-economic status. Without access to a clean water source, residents struggle to carry out their daily activities effectively. Furthermore, these findings/methods can serve as a reference for other locations, provided that the parameters are adjusted to fit the local geology.

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