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Nature Environment & Pollution Technology

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Original Research

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

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Key Words	GIS, Thematic maps, Integration, Groundwater potential
DOI	https://doi.org/10.46488/NEPT.2025.v24i04.D1748 (DOI will be active only after the final publication of the paper)
Citation for the Paper	Isnain, Z. and Azahar, M. S., 2025. Evaluation of groundwater potential zones in Sg. Seguntor, Sandakan, Sabah, Malaysia by using the Geographical Information System (GIS) method. *Nature Environment and Pollution Technology*, 24(4), p. D1748. https://doi.org/10.46488/NEPT.2025.v24i04.D1748

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 Sandakan Formation, Volcanic Breccia and Quaternary Alluvium. The ArcGIS 10.5 and Global Mapper software was 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 are 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.

1. INTRODUCTION

This research consists of two main aspects which is 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 aspect in 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 on the eastern part of Sabah. It consists of Sandakan Formation, Volcanic Breccia, and Quaternary Alluvium. Haile (1967) stated that Sandakan Formation (Late Miocene) overlap and having unconformity with mélange (Middle Miocene). The presence of melange 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 (Zulherry & Baba, 2022).[Z-1]

Sandakan town was located about 335 km from the Kota Kinabalu, the capital state of Sabah. The study area is consisting about 192 km^2. The longitude and latitude of the study area is $117^{o}99'$ E - $118^{o}08'$ E and $5^{o}49'$ N - $5^{o}55'$ N (Fig. 1).

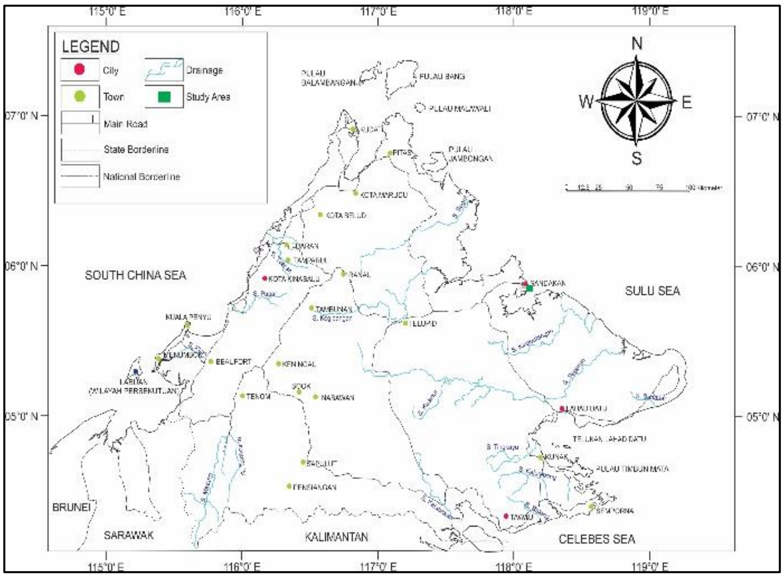

Fig. 1: Map showing the study area.

The AHP method were used during the analysis are based on the complex structure of decision making that is built on hierarchy structure, where the parameter used are being divided into sub-parameter (Saaty, 1980). Study was conducted based on 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 (Zulherry & Baba, 2022).

2. 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 (Zulherry & Hizratul, 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.[Z-2]

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

Weightage method in AHP analysis were combined with the GIS technique 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).

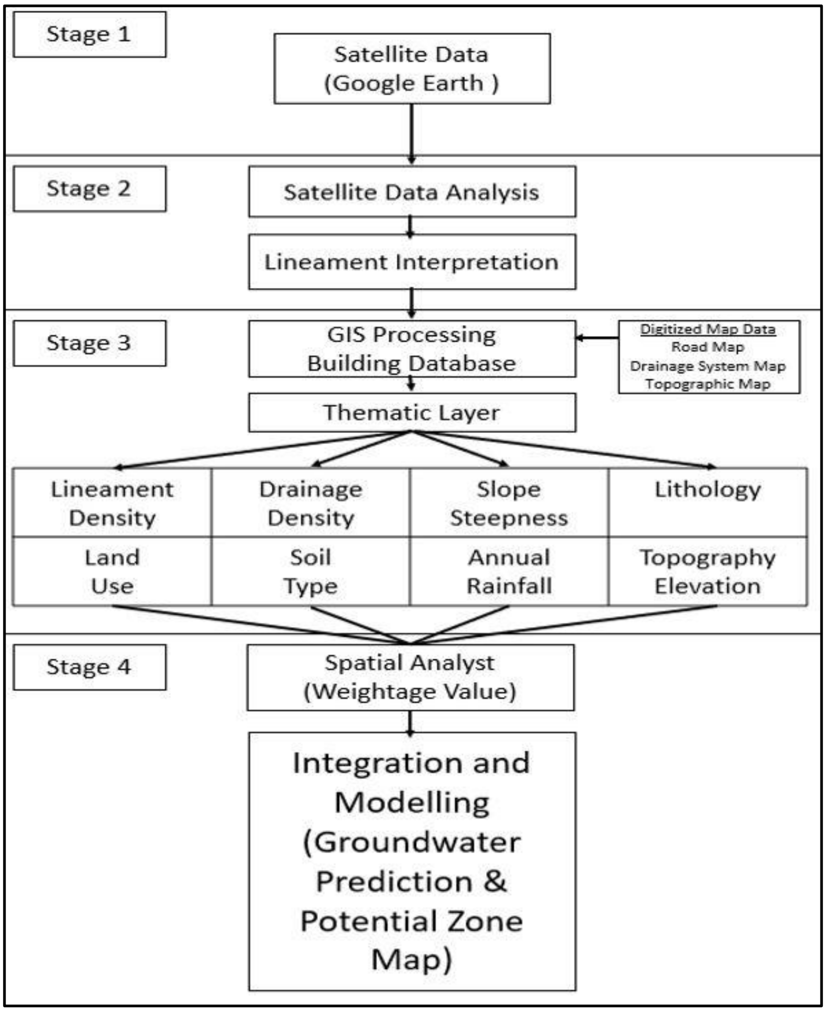

Fig. 2: Diagram shows the pathway of combining AHP and GIS in this study. (Edited from Khairul, A. M., Juhari, M. A. & Ibrahim, A. (2005)

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 Pairwise Comparison Method, and (3) put weightage on each criterion. Parameter chosen on multi-parameter approach was not the same between each other (Wan Yusryzal, 2008). To calculate the weightage on each parameter prepared, Saaty *et al.* (2012) has introduced a new method using Pairwise Comparison Method (PCM). PCM is to produce the calculation involving matrix ratio in AHP. This method was also connected with the procedure of decision making based on GIS (Wan Yusryzal, 2008).

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 scale 1 to 9 that 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 intermediate value. Table 1 shows the scale for pairwise comparison introduced by Saaty (1980).

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 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

In this process, every parameter will be given its value based on its importance from scale 1 to 9. Every parameter and its sub-parameter were considered as not equally importance to each other and lead to different ratio.

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 at first evolved by Saaty (1980). A few analysis have been done to ensure the groundwater potential zones by using the AHP method.

The AHP method can help manage the conflicting judgements. The Pairwise Comparison Matrices (PCMs) are a useful starting point for determining a ranking on a set of a 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 the estimation of 1 showing that the standards are similarly significant and an estimation of 9 demonstrates that the basis viable is critical contrasted with different parameters. PCM incorporates a consistency check where judgement errors have been differentiated and a consistency proportion is determined (Table 2).

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

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 with 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 parameter. Eight physical parameters were used in this study, which include the rainfall distribution, slope steepness, drainage and lineament density, topographic elevation, landuse, soil type, and lithology as shown in Table 3.

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

During preparation to determine the relative importance between each parameter, local experts have selected and subjected to a review of a parameters. Parameters that were used will be calculated based on its importance by using the Pairwise Comparison method, then every parameter will be subjected to score determination process (weightage) based on its comparison value (Eigen Vector). Finally, calculate the consistency value using Analytic Hierarchy Process (AHP) formula and examined onto 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 calculation the main vector; whether it is suitable and rational to prevent any unreasonable excuses. Every consistency value that is accepted will ascertain whether the data can be trusted towards decision maker to dictate the weight by each set of criteria used (Samsam, 2010). If the value of CR is less or equally to 10%, inconsistency can be accepted, but if the CR is more than 10%, subjective judgement will be revised (Saaty, 1980).

Every parameter will be arranged accordingly to its hierarchy. Every issue can be solved into some element that will divided into two that is alternative and criteria. Each parameter used for this research is to know which main factor will be the 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.

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

3. 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 compared in relation to its importance and weightage that has been given (Table 5). This method was an evaluation that been done to know the relative importance between two elements on every level and its relationship with the level above particular parameter (Table 6). Scale 1 to 9 is the scale of importance that used to expressed opinion (Saaty, 1980). These weightage value will be inserted into Pairwise Comparison Matrices (PCM) and then will be used to produce the Normalization Matrices (Table 7) on each of the eight parameters that has been the main factor.

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
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 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

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

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				

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

ArcGIS software generally used to help generate maps, data editing and presenting the result of an analysis. Thematic maps that have been produced for this study is 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 study area (Table 8). Then, detailed study and reading in related field was done to give a rational weightage value to each of the thematic map according to their contribution onto the formation of groundwater respectively. Therefore, weightage value given on this study was a modified comparison weightage value that was used by the previous researcher; Krishnamurthy *et al*. (1996 & 1997) and calculated by using the Analytical Hierarchy Process (AHP) method.

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

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

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

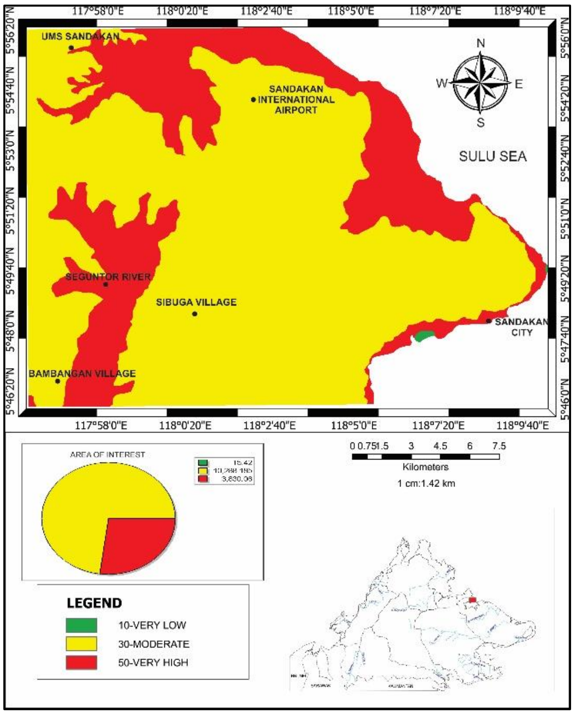

Fig. 3: A lithology weightage map in study area.

However, there is a vice versa for Volcanic Breccia. Volcanic Breccia consist of a mix rock and this type of rock is not potential to contribute any groundwater existence because it does not have any kind of geology structure that could contribute for those aspect. Rock formation that contains water will be known as aquifer.

If the lithology had high percentage of porosity and lower percentage of permeability so it is only suitable to be impermeable strata. However, 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 for soil, sediment, and rocks to accept and give way for water between unsaturated zone (ventilation zone) and saturated zone (Khairul Anam, 2001). Ibrahim Abdullah & Juhari Mat Akhir (1990) describe porosity as the ratio of void compared to total volume of the rock itself.

Water movement and groundwater placement affected by permeability and porosity factor. This type of nature for aquifer depends on composition and texture of the rock itself. High percentage of porosity could determine the rock formation can impound huge amount of groundwater.

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

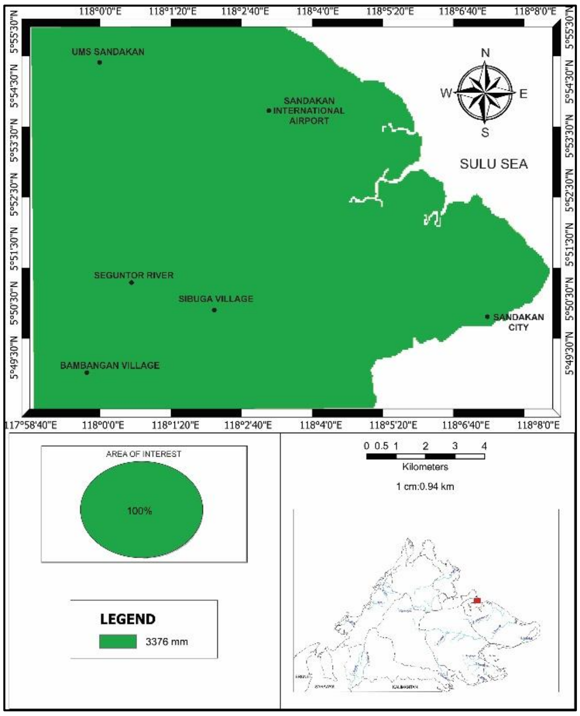

Fig. 4: A rainfall distribution weightage map in study area.

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

Table 10: Distribution of weightage value of the rain density in 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 [Z-3](Robinson & Ward, 1990). The water table was closed to the surface if that area has a high average of rainfall and vice versa. In other words, contribution from rainfall distribution were high for groundwater occurrence.

The existence of river and lake on the earth surface gives the preliminary description towards the existence of groundwater was nearby. This is because lake and river could illustrate the groundwater level. Groundwater level usually found on few meters depth, but for lake, swamp, the ocean and river, the groundwater level were near to the surface (Khairul Anam, 2001).

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

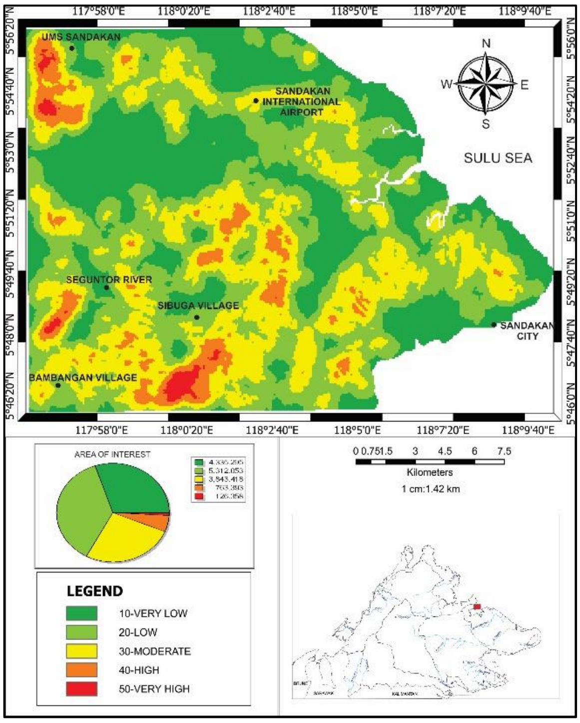

Fig. 5: Drainage density weightage map in study area.

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 Abdullah & Juhari Mat Akhir, 1990). In the high-density drainage zone, the water runoff on the surface is high so the rate of water to absorb into the catchment area is high and the weighting value given becomes high, but the opposite situation occurs in the low-density drainage zone.

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

Lineament density maps (Fig. 6) were generated through image reference Shuttle Radar Topography Mission (SRTM) 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. Lineament are interpreted as a straightforward, large-scale and clear feature found on the earth's surface. There are two type of lineaments namely positive and negative lineament. In this study, positive lineament is used and considered because negative lineament are drainage and river currents on the earth's surface.

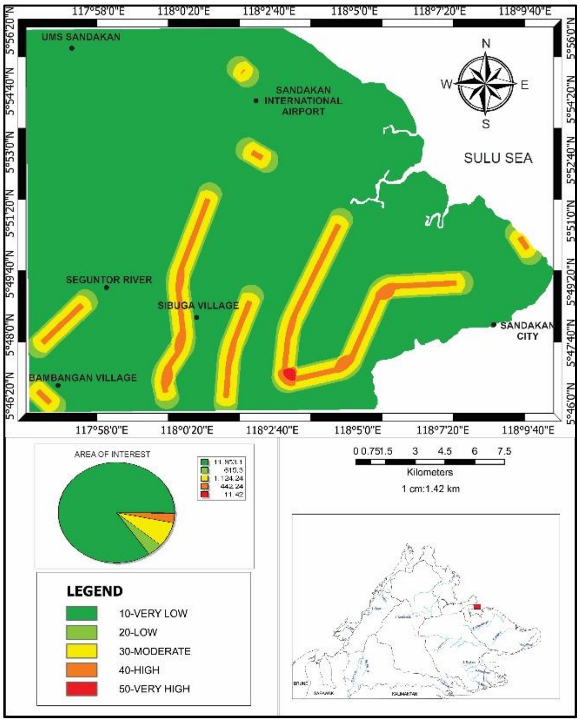

Fig. 6: Lineament density weightage map in study area.

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 more prone to groundwater because there are various types of faults whether major or minor as well as cracks in various rocks.

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

Soil type maps are produced through land type trace maps from the Sabah Branch Agriculture Department (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 ground water, the nature of the porosity and permeability 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.

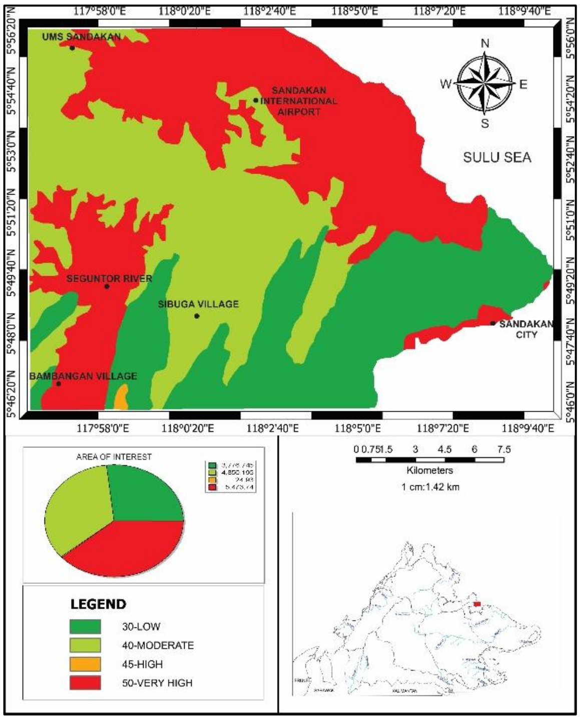

Fig. 7: Soil type weightage map in study area.

The weighting value based on the remuneration for the presence of groundwater can be determined through the determination of the forming material to the soil series. Soils with a high percentage of clay provide high remuneration to the presence of groundwater. However, sand is more porous and 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.

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

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.

Table 14: Group and soil type in 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

Khairul Anam (2001) states 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 presence of groundwater. Rainwater flowing from high areas to low areas makes these low areas more potential for groundwater.

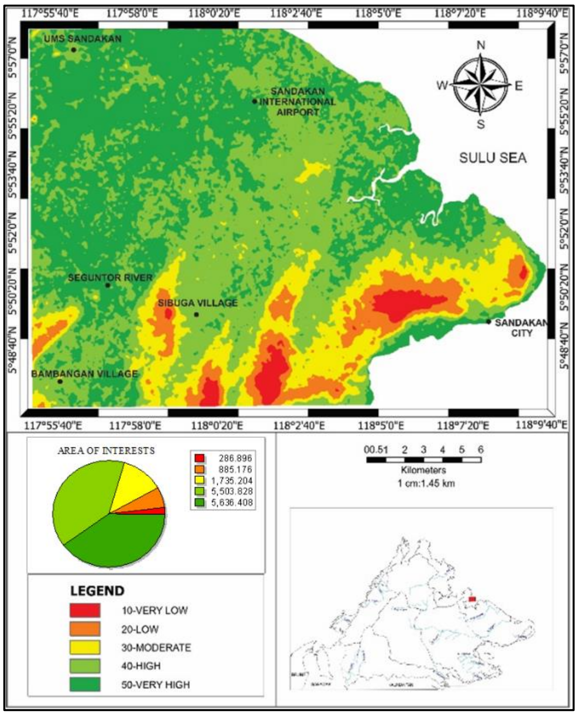

Fig. 8: Topography Elevation weightage map in study area.

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

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

Slope analysis using Slope Tools on ArcMap to classify slopes according to desired degree of slope can be done based on 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 sub-surface drainage. Slopes can have a dominant effect on rainfall overflow. Land flow period, infiltration as well as flow in the sub surface is controlled by slopes (Fig. 9).

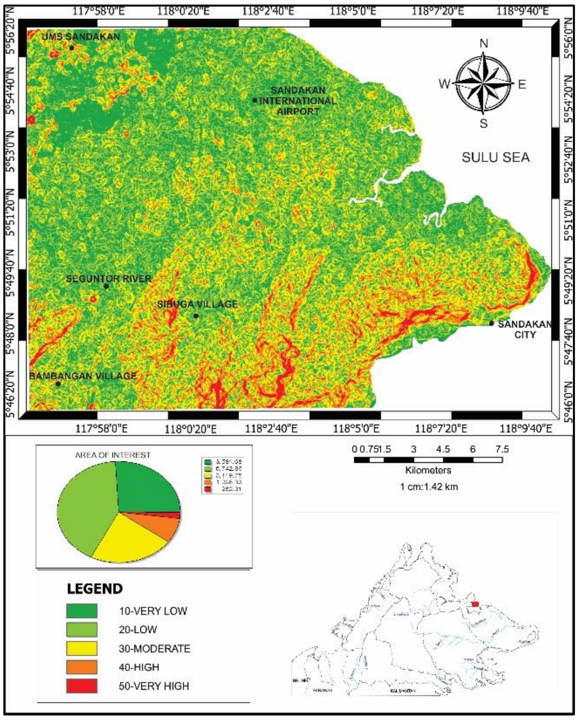

Fig. 9: Slope Steepness weightage map in study area.

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 are 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.

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

The type of landuse is important in producing 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.

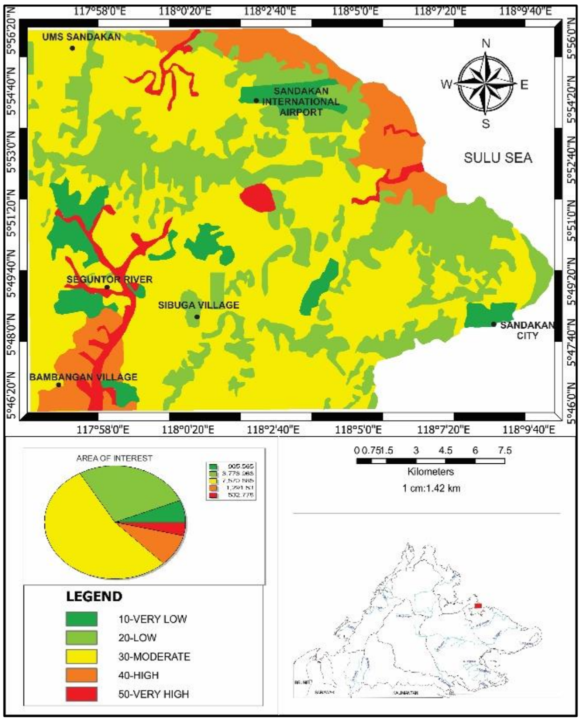

Fig. 10: Landuse weightage map in study area.

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 the area is high and not able to hold a lot of water due to various sloping structures compared to forestry and agricultural areas.

Table 17: Classification of weightage for landuse thematic map.

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

The water present on the surface indicates 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. Landuse near the sea will be prone to saltwater injections or groundwater pollution. The settlement also has 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 landuse, 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 area 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 18: Summary of the results from the Final Groundwater Potential Map of 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	$0 – 3^0$ $3 – 8^0$ $8 – 14^0$ $14 - 23^0$ $23 - 66^0$	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 is to convert the traced map to raster in GIS format. All eight analyzes 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 Zulherry Isnain and Juhari Mat Akhir (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 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 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 clear understanding on 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 parameter based on its contribution to the presence of groundwater.

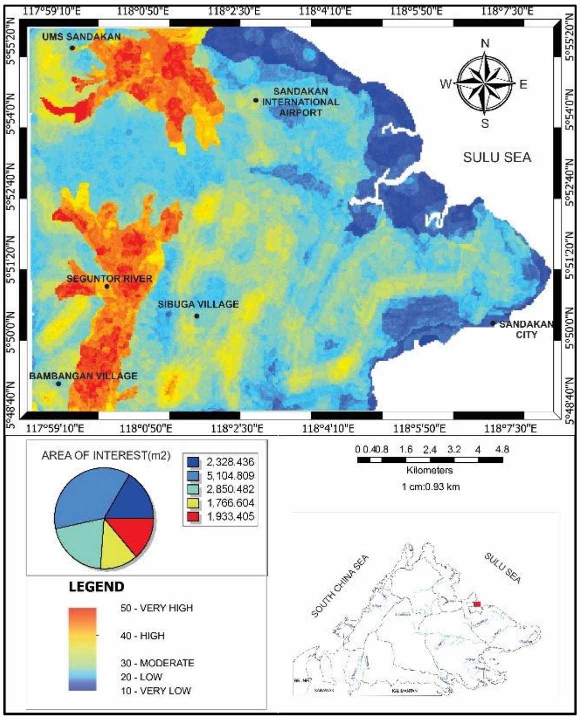

Fig. 11: A groundwater potential zone map of study area.

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 have a very high potential and 13% have a high potential of groundwater. 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 is in the area around Bambangan village and other settlements adjacent to this river.

It is found that most areas of very high potential zones are located at 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 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 adequate clean water supply probably due to the growing human population and the 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 m³/h.[Z-4]

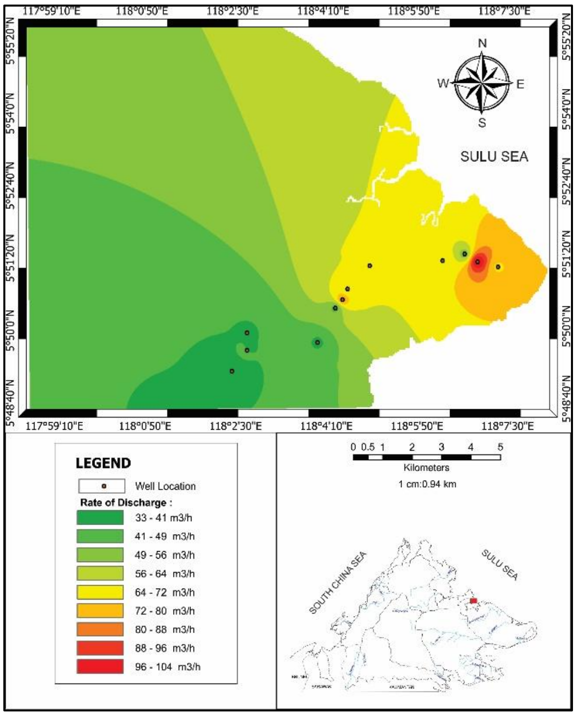

Fig. 12: Well-location map and rate of discharge in study area.

(Source: Mineral and Geoscience Department)

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

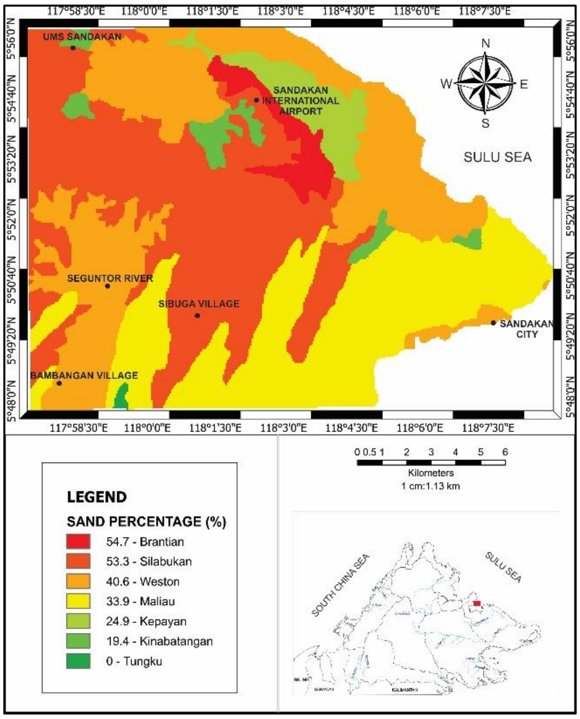

Fig. 13: Sand Percentage Map according to soil type in study area.

The classification that has been produced according to the distribution of grain size shows that 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 from the formation of alluvial deposits.

4. 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/method can serve as a reference for other locations, provided that the parameters are adjusted to fit the local geology.[Z-5]

Acknowledgment
The authors express appreciation to Universiti Malaysia Sabah, for all their support in this research.

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