



Integrated GIS Based Approach in Mapping Groundwater Potential Zones in Kota Kinabalu, Sabah, Malaysia

ZULHERRY ISNAIN¹ and JUHARI MAT AKHIR²

¹Faculty of Science and Natural Resources, Universiti Malaysia Sabah, Sabah, Malaysia
²Faculty of Science and Technology, Universiti Kebangsaan Malaysia, Selangor, Malaysia

Corresponding author: zulherry@gmail.com

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Abstract - The shortage of clean water occurs almost everywhere around the world. The demand for water supply increases from time to time due to various problems such as development, population growth, pollution, global warming, agricultural activities, logging, and so on. This study was conducted in the vicinity of Kota Kinabalu, Sabah, by using the Geographic Information System (GIS) for mapping the groundwater potential zones. The main objective of this study was to generate the predictive map of groundwater potential zones in the studied area through the integration of various thematic maps by using the GIS. This study includes five stages, namely collection and preparation of basic data, data analyses, development of space database, spatial analyses, and space integration. There are eleven parameters used in this study, namely rainfall, drainage, soil type, landuse, lithology, lineament density, topography, slope steepness, the ratio of sand and clay, major fault zones, and syncline zones. By using the Heuristic method, the final map of groundwater potential zones in the studied area is divided into five classes, which are very low, low, moderate, high, and very high.

Keywords: groundwater, GIS, Heuristic method

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INTRODUCTION

Groundwater is defined as water that fills the space, cavities, pores, and cracks in the soil, rock or regolitos below the earth surface (Abdullah and Mat Akhir, 1990). It has become an important and dependable source of water supplies in all climatic regions including both urban and rural areas of developed and developing countries (Todd and Mays, 2005). This was further supported by the nature of the groundwater itself (*i.e.* consistent temperatures, widespread, and continuous availability, excellent natural quality, limited vulnerability, low development cost, and

drought reliability). Therefore, the groundwater is the best alternative to replace the surface water as the main source of water supply for daily consumption.

The integration of GIS techniques followed by the observations in the field has known as a very effective method in groundwater mapping and exploration. Over the last decade, the international scientific community has shown great interest in this study, and many researchers have used this method in their studies (Sabin, 1987 and Sikdar *et al.*, 2004).

The Heuristic method is made by combining all thematic maps with the assumption any fac-

tors or parameters that have been studied for their position (ranking), based on its effect in augment of groundwater. Selection of the position (ranking) is based on a questionnaire that had been made to the experts involved or have experience in groundwater.

The studied area, Kota Kinabalu, is located on the west coast of Sabah, Malaysia. Geographically, the studied area is situated between the latitude 5°55' - 6°12' North and longitude 116°01' - 116°17' East (Figure 1). Geologically, the studied area consists of Crocker Formation and Quaternary sediments. The age of the Crocker Formation is estimated from Oligocene to Early Miocene. There are three main units of the Crocker Formation comprising sandstone, interbedding sandstone and shale, and shale.

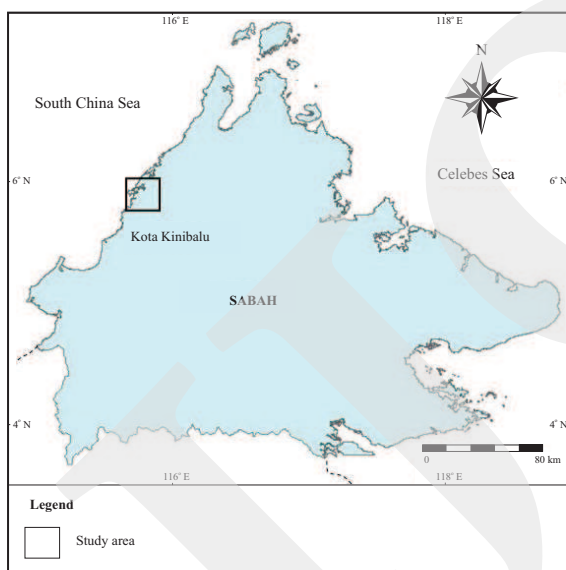


Figure 1. A map showing the studied area.

Among the main reasons, this study was conducted because this resource has not fully been explored in Malaysia, especially in Kota Kinabalu due to the surface water is sufficient enough for domestic consumption. However, Kota Kinabalu is a very fast developing area. Therefore, it is not impossible in the very near future it could suffer supply shortages due to the rapid development, urbanization, and increasing in population which can cause pollution to the surface water resources.

MATERIALS AND METHOD

All the necessary data for this study, such as topographic map, landuse map, soil map series, annual rainfall data, and satellite images have been collected. All data acquisition involved departments like the Mineral and Geoscience Department (JMG) Malaysia, Malaysian Remote Sensing Agency (ARSM), the State Department of Survey and Mapping (JUPEM), the Malaysian Meteorological Service Department, and related institutions. Random field inspections were also conducted at this stage to confirm the changes that occur in the studied area.

The ILWIS 3.3 (Integrated Land and Water Information System) software was applied to perform all the processes in GIS. Attribute analysis, classification of polygons, and weighting value have produced the thematic maps of rainfall, lithology, topographic elevation, slope steepness, drainage density, soil types, as well as sand and clay ratio. In theory, spatial analysis is used either to produce additional information using the existing information, or to increase the spatial structure or the relationship between the relevant geographic information (Murai, 1993).

For this study, the focus was on the technique or combination of overlapping raster data model in which all thematic maps that have been given the weights were combined to predict the groundwater potential zones. Each polygon for thematic map layers that have been given the weights was varied according to the characteristics of their remuneration like the annual rainfall (average annual rainfall in the studied area), lithology (permeability properties and porosity of rocks), lineament density (remuneration classes and features); drainage density (classes and attributes of permeability), land use (type and characteristics of remuneration), and the type of soils (properties of permeability and soil porosity). This stage was very fundamental, because the weight value assigned determined or influenced the accuracy of the final results that have been integrated later. DRASTIC method (Aller *et al.*, 1985) and the methods used by Krishnamurthy *et al.* (1996 and

1997) were used as references. In this method, Krishnamurthy used scales of 5 to 70 as the weight parameter. However, for this study, the researcher decided to use scales of 10 to 50 only. Weighting scale of 10 was used for the least contribute, while the scale of 50 was to indicate the highest influence or contribution to the availability of groundwater.

By using the Heuristic method, each thematic map has been given an index number or weight value, based on their position (ranking) on the groundwater augmentation process. The grant was based on the weightage of the questionnaires in Figure 2. This weight value or index number is given for the ranking based on the nature of these factors that influenced the availability of groundwater.

$$GWP = (LI) * 9 + (SC) * 8 + (RD) * 8 + (FZ) * 7 + (SZ) * 6 + (DD) * 5 + (LD) * 4 + (ST) * 3 + (TO) * 2 + (SS) * 2 + (LU) * 1 / 55$$

Table 1. Position (Ranking) and the Weight Value Given to Eleven Parameters in the Mapping of Groundwater Potential Zones

No.	Parameter	Position	Weight Value
1.	Lithology (LI)	1	9
2.	Sand and clay ratio (SC)	2	8
3.	Rainfall density (RD)	3	8
4.	Fault (FZ)	4	7
5.	Bedding (SZ)	5	6
6.	Drainage density (DD)	6	5
7.	Lineament density (LD)	7	4
8.	Soil type (ST)	8	3
9.	Topographic elevation (TO)	9	2
10.	Slope steepness (SS)	9	2
11.	Landuse (LU)	10	1
Total			55

QUESTIONNAIRE FORM FOR THE EXPERTS

The purpose of this survey was to obtain the opinion or view from the experts (in the groundwater study or related) regarding the factors that control the availability of groundwater in the state of Sabah.

Position :
 Organisation :
 Tel. No. :
 Email :
 Experience in groundwater study (years) :

Weightage 1-9 are used for the factors that control the availability of groundwater. Please circle the answer that was deemed the most appropriate.

** 1 – very less influence the groundwater availability
 ** 9 – very influence the groundwater availability

No.	Control Factor	Weightage								
		1	2	3	4	5	6	7	8	9
1.	Lithology									
2.	Lineament									
3.	Soil type									
4.	Rainfall									
5.	Drainage density									
6.	Contour									
7.	Landuse									
8.	Fault									
9.	Bedding									
10.	Sand and clay ratio									

Thank you for your cooperation and feedback.

Figure 2. Questionnaires that were used in this study.

The weight values that assigned to the thematic map layers were shown in Table 1.

Finally, the formula of the Heuristic method was developed as follows:

RESULTS AND DISCUSSION

All the thematic maps that have been produced are presented on Figures 3 through 13.

A lithology map of the studied area is shown in Figure 3. Alluvium was given the highest weight-age value of 50 (Table 2) due to the characteristics

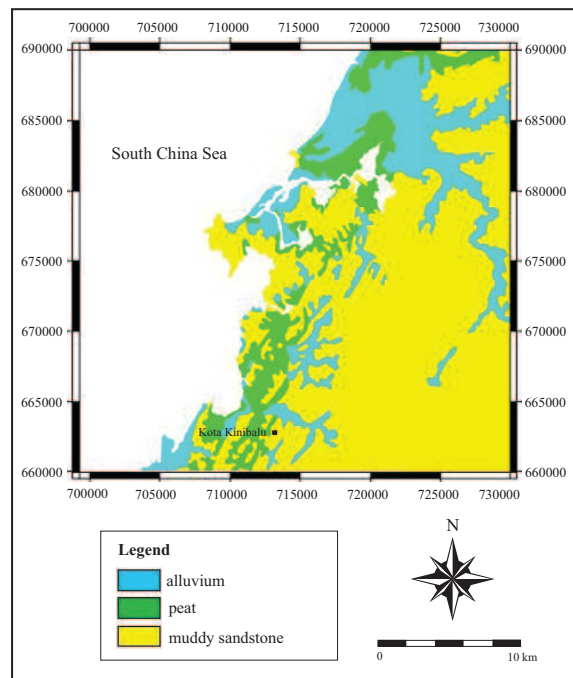


Figure 3. A lithology map of the studied area.

Table 2. Distribution of the Weights for Lithology Type at the Studied Area

Lithology	Weight
Alluvium	50
Peat	40
Muddy sandstone	30

of high porosity and permeability. Alluvium which is consisting of unconsolidated sediments mainly gravels and sand that mostly deposited by moving water. It usually developed in a floodplain, river, and estuary. It is always defined as the youngest sediment in the geological time scale. The nature of its porosity allows surface water to seep easily between grains, and makes it a good supplement for the groundwater. Muddy sandstone which is a mixture of sand and mud is given the lowest weightage value of 30. This is because when compared to the alluvial nature of the porosity and permeability it is not very good due to the presence of mud. This makes it difficult for water to seep through the surface, and causes surface water flow into water bodies such as rivers and lakes compared to seep into them. Whereas, peat is given a weightage value of 40 due to surface water seeping between the grains easier than muddy sandstone. This is due to its characteristics of porosity and permeability is better than muddy sandstone.

Figure 4 is a sand and clay ratio map of the studied area. The soil sample that contained the highest percentage of sand to clay ratio was given the highest weightage value of 50 (Table 3). This is due to the nature of the sand that has a high porosity. Instead, if the percentage of sand to clay ratio is low, the weightage value will also be low, due to the nature of the nonporous clay that contains less air pores in comparison with sand.

A rainfall density map of the studied area (based on three rainfall observation station) presented in Figure 5 reveals that the average value of the rainfall in each station is interpolated by the 'moving average' function of the ILWIS 3.3 software. The map of rainfall density generated is classified into five classes and was given the appropriate weightage for its contribution to groundwater (Table 4). Areas that received the highest amount of rainfall are given the highest

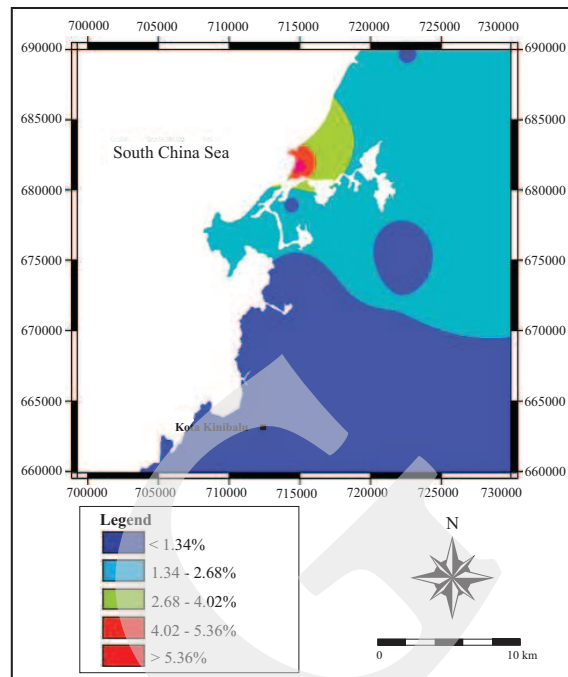


Figure 4. A sand and clay ratio map of the studied area.

Table 3. Distribution of the Weights for the Sand and Clay Ratio at the Studied Area

Sand and Clay Ratio (%)	Weight
< 1.34	10
1.34 - 2.68	20
2.68 - 4.02	30
4.02 - 5.3	40
> 5.36	50

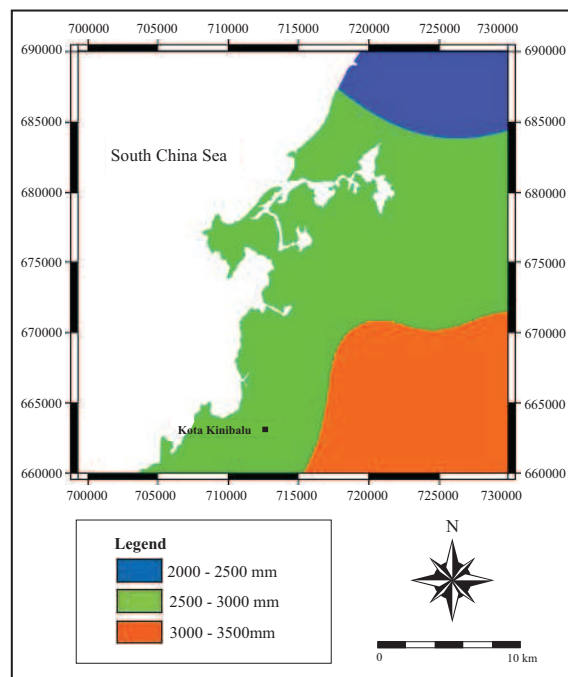


Figure 5. A rainfall density map of the studied area.

Table 4. Distribution of the Weights for Annual Rainfall Density Zone at the Studied Area

Rainfall Density Zone (mm)	Weight
> 3500	50
3000 - 3500	40
2500 - 3000	30
2000 - 2500	20
< 2000	10

weightage value, and vice versa in areas that received the lowest amount of rain.

Lineament density map of the studied area shown on Figure 6 tends to indicate that the areas with a high lineament density indicate the presence of numerous faults and fractures in the area. Therefore, the characteristics of secondary porosity and permeability were high in the areas with a high lineament density. Distribution of the weightage was also given a high value in the areas of high lineament density (Table 5).

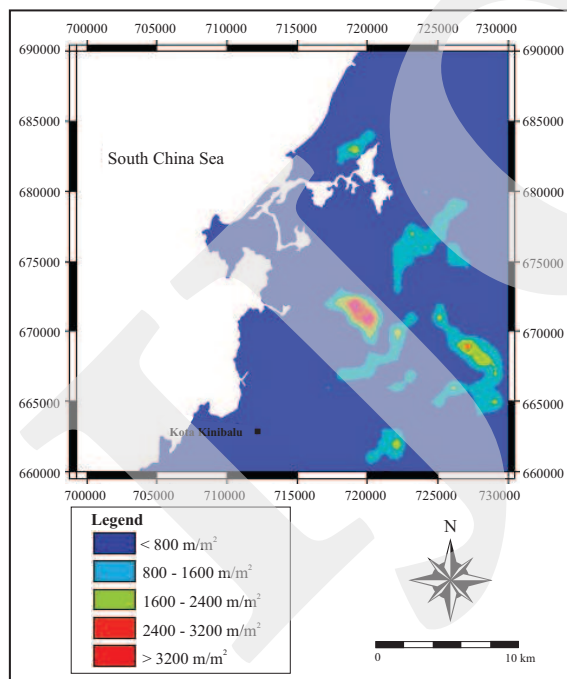


Figure 6. A lineament density map of the studied area.

Table 5. Distribution of the Weights for Each Lineament Density Zone at the Studied Area

Lineament Density Zone (m/m ²)	Weight
> 3200	50
2400 - 3200	40
1600 - 2400	30
800 - 1600	20
< 800	10

Figure 7 presents a drainage density map of the studied area. The weightage values that are given were the inverse of the lineament density map. This is because the streams that abound in the areas of high drainage density cause surface runoff rush toward the main river. This causes the absorption of water into the soil be low. Whereas, in areas with a low drainage density, the rate of absorption of water into the soil is high due to the velocity of surface runoff that has become weak. Therefore, the high weightage value was given to the areas with a low drainage density. Table 6 shows the distribution of the weightage value for drainage density zones of the studied area.

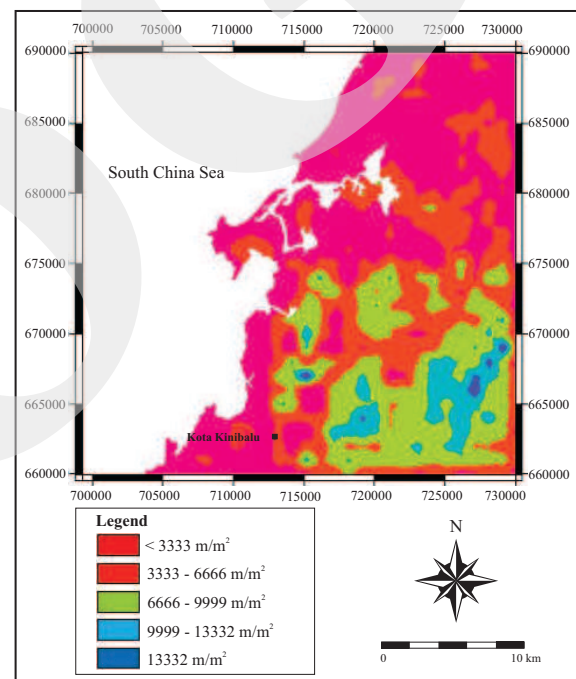


Figure 7. A drainage density map of the studied area.

Table 6. Distribution of the Weights for Drainage Density Zone at the Studied Area

Drainage Density Zone (m/m ²)	Weight
< 3333	50
3333 - 6666	40
6666 - 9999	30
9999 - 13332	20
> 13332	10

A soil type map of the studied area (Figure 8) explains that the weightage value that was given to each soil types depends on their percentage contents of sand, silt, and clay. For soil that con-

tained a high percentage of sand, the weightage value is high due to the nature of high porosity. Next, it depends on the percentages of silt and clay contents. The weightage value for each soil type is shown in Table 7.

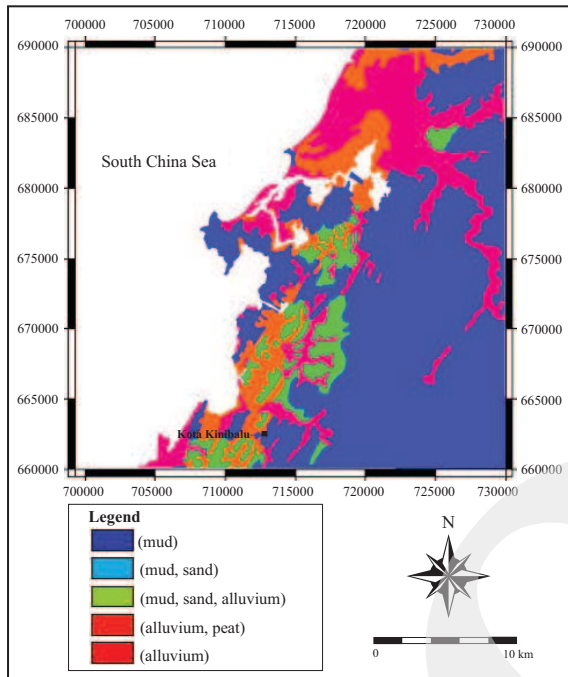


Figure 8. A soil types map of the studied area.

Table 7. Distribution of the Weights for the Soil Type at the Studied Area

No.	Soil Series	Soil Type	Weight
1	Weston	alluvium and peat	40
2	Tanjong Aru	alluvium	50
3	Tuaran	alluvium	50
4	Kinabatangan	alluvium	50
5	Sapi	Alluvium and peat	40
6	Klias	Alluvium and peat	40
7	Brantian	alluvium	50
8	Dalit	Sand, mud, alluvium	30
9	Lokan	Sand, mud	20
10	Crocker	Sand, mud	20

Highland that can be seen on a topographic elevation map of the studied area (Figure 9) is found in the southeast and east part of the studied area. Meanwhile, low-lying areas occupy the northeastern and southwestern parts of the studied area. In this highland, rainfall and surface water will continue running down through valleys and rivers to lowlands and on to the sea. Thus, the low weightage value will be given in these areas, be-

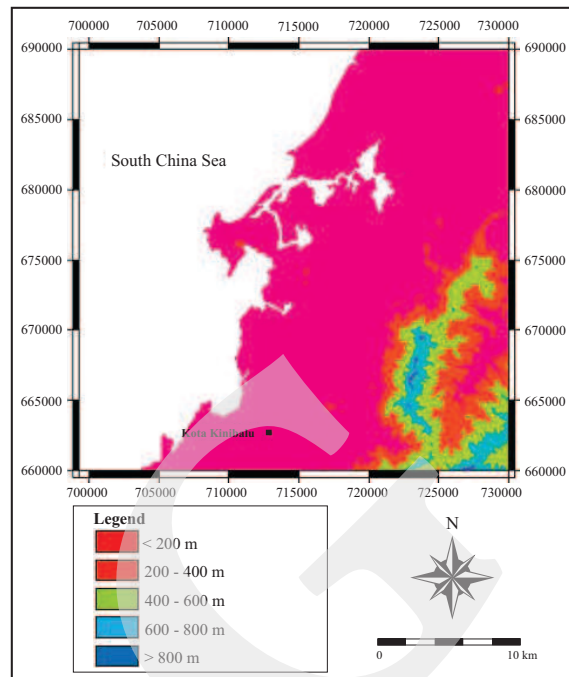


Figure 9. A topographic elevation map of the studied area.

cause it does not augment the groundwater well as in low-lying areas. Weightage values for this topographic elevation zones were shown in Table 8.

Table 8. Distribution of the Weights for Each Topography Elevation Zone at the Studied Area.

Height (m)	Topography Zone	Weight
< 200	Low lying area	50
200-400	Undulating hills	40
400- 600	Steep hills	30
600 - 800	Steep mountain	20
>800	Mountain area	10

Furthermore, a slope steepness map of the studied area is presented in Figure 10. This map also shows the same characteristics as the topographic elevation map. For this studied area, mostly the steep zones are located in the southeastern and eastern parts of the area. Meanwhile, the flatlands were at the northeastern and southwestern parts of the studied area. The weightage values were given based on the rate of runoff on steep zone which is higher than in the flatlands. Therefore, higher weightage value is in the steep zone and low weightage value is in flat-land areas (Table 9).

Figure 11 displaying a landuse map of the studied area, shows that the southeastern and

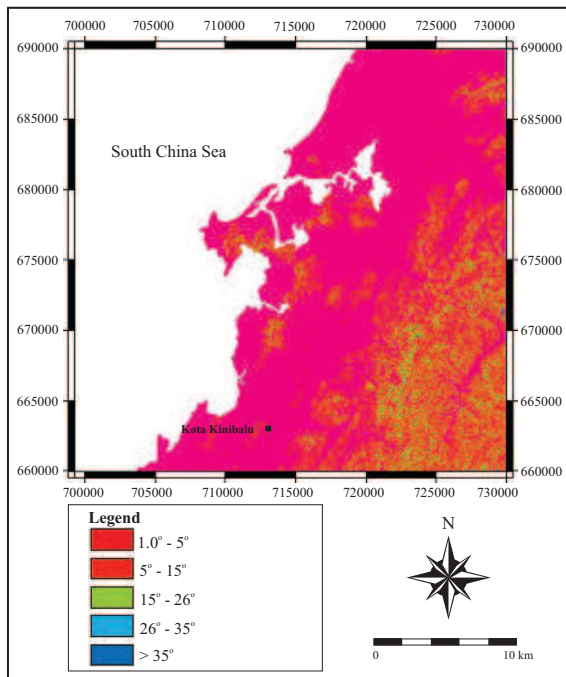


Figure 10. A slope steepness map of the studied area.

Table 9. Distribution of the Weights for the Slope Steepness Zone at the Studied Area

Slope Steepness (°)	Slope Steepness Zone	Weight
0 - 5	Low lying area	50
5 - 15	Undulating hills	40
15 - 26	Steep hills	30
26 - 35	Steep mountain	20
> 35	Mountain area	10

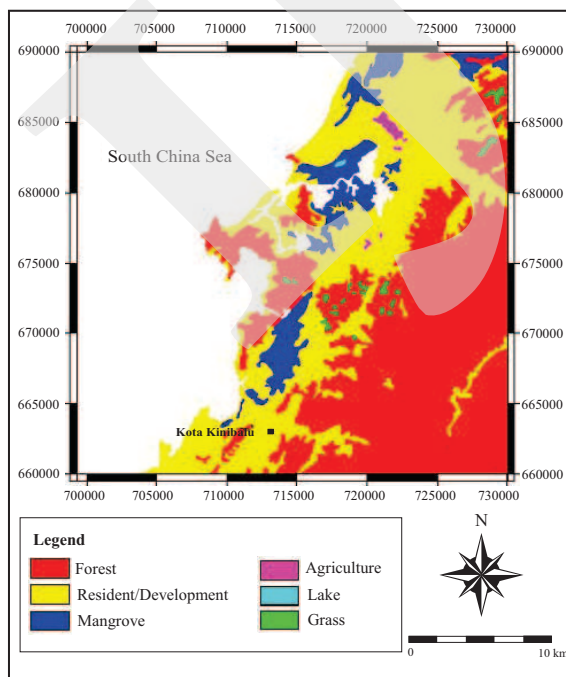


Figure 11. A landuse map of the studied area.

eastern parts of the studied area are covered by forests and highlands. In determining the weightage of each category of landuse, the zone of higher humidity rated high. Thus, an aqueous zone rated high while the dry zone rated low. Weightage value for each category of landuse was given depended on its contribution in appending groundwater (Table 10).

Table 10. Distribution of the Weights for the Landuse Type at the Studied Area

Landuse Type	Weight
Forest	20
Residen/Development	10
Mangrove	20
Agriculture	40
Lake	50
Grass	30

Geologically, the main faults in the studied area are presented in Figure 12. From this map the buffer zones were made by using the ILWIS 3.3 software for five categories (based on how far the buffer zone from the main fault) which is less than 500 m, 500 - 1,000 m, 1,000 - 1,500 m, 1,500 - 2,000 m, and over 2,000 m. The high weightage values were given to the zones closest to the main fault because the closer a major fault

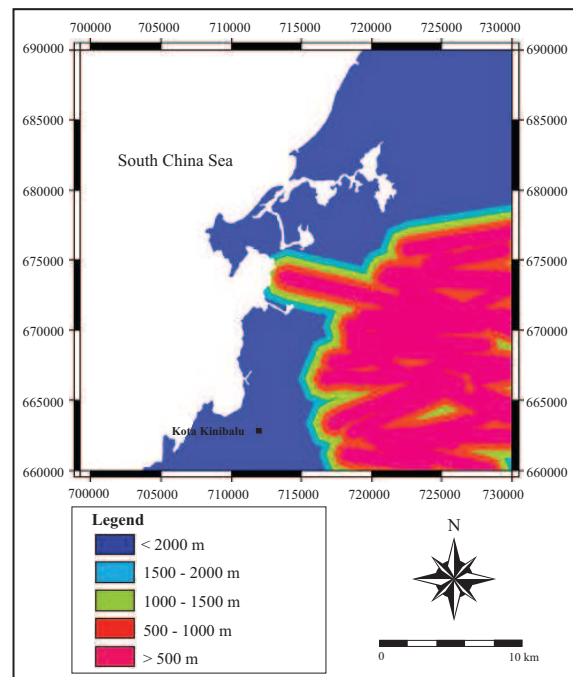


Figure 12. Major fault zones map of the studied area.

zone with the higher, the more potential the availability of groundwater. Zero weightage value was given for an area that over 2,000 m away from the main fault zone, and is considered as not affecting the main fault factor. The weightage values were given in Table 11.

Table 11. Distribution of the Weights for the Major Fault Zones at the Studied Area

Major Fault Zone	Weight
<500 m	40
500-1000 m	30
1000-1500 m	20
1500-2000 m	10
>2000 m	0

Moreover, a syncline zone map of the studied area can be seen in Figure 13. Each polygon for syncline zone was given its weightage value based on how far the zone from the syncline structure. Zones are divided into five categories which are less than 500 m, 500 -1,000 m, 1,000 - 1,500 m, 1,500 - 2,000 m, and over 2,000 m. Zone 5 is given a value of zero, because it is located outside of the area that is not affected by the syncline structure. The weightage values were shown in the Table 12.

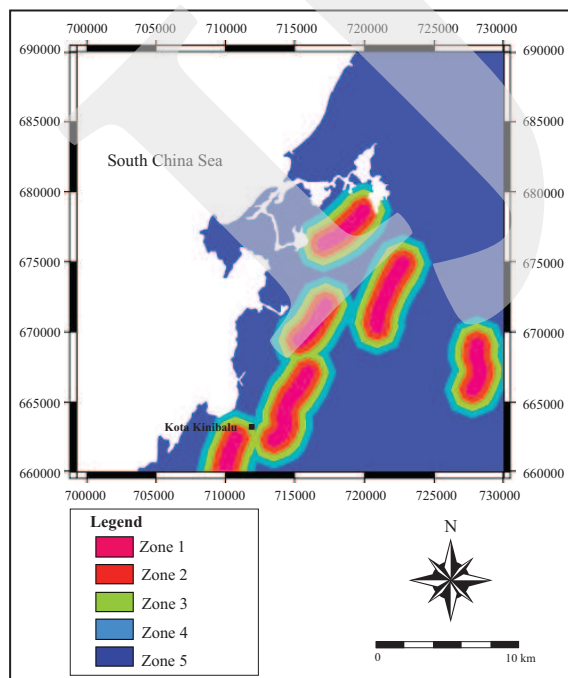


Figure 13. A syncline zones map of the studied area.

Table 12. Distribution of the Weights for the Syncline Zones at the Studied Area

No.	Syncline Zone	Weight
1	Zone 1	40
2	Zone 2	30
3	Zone 3	20
4	Zone 4	10
5	Zone 5	0

The final map after the integration process was shown in Figure 14. The result (Table 13) revealed that the groundwater potential can be divided into five classes or zones (based on their recharge rate) which are:

- very low (less than 1,000 l/hour/well)
- low (1,000 - 2,000 l/hour/well)
- moderate (2,000 - 3,000 l/hour/well)
- high (3,000 - 4,000 l/hour/well)
- very high (more than 4,000 l/hour/well)

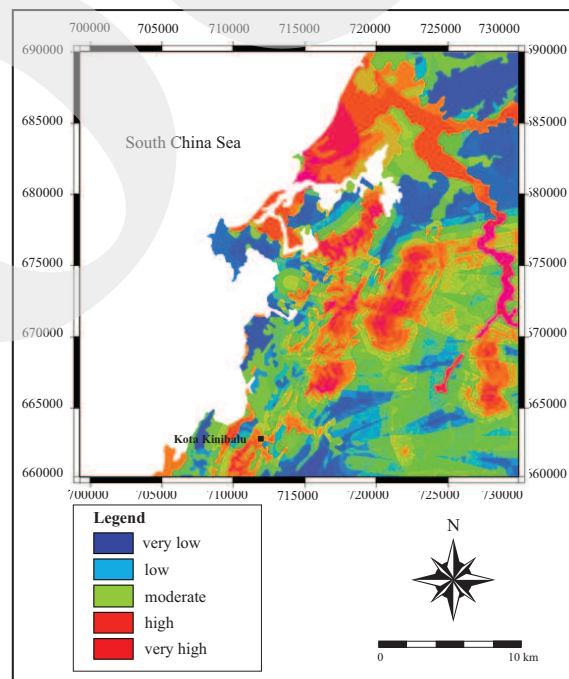


Figure 14. A groundwater potential zone map of the studied area.

Table 13. Groundwater Potential Zone Based on Weights of their Recharge Rate

No.	Groundwater Zone	Weight	Groundwater Recharge
1	Very low	10	Less than 1000 liter/hour/well
2	Low	20	1000-2000 liter/hour/well
3	Moderate	30	2000-3000 liter/hour/well
4	High	40	3000-4000 liter/hour/well
5	Very high	50	More than 4000 liter/hour/well

Finally, the relationship between the parameters studied and groundwater potential zone is presented in Table 14 (only the high and very high potential zones presented)

Table 14. A summary of the Results from the Final Groundwater Potential Map of the Studied Area

Maps	High Potential Zones	Very High Potential Zones
Lithology	Alluvium, peat, muddy sandstone	Alluvium, muddy sandstone
Sand and Clay Ratio	Very low - very high (< 1.34 - > 5.36%)	Very low - very high (< 1.34 - > 5.36%)
Rainfall Density	Low - moderate (< 2,400 - 3,200 mm)	Low - moderate (< 2,400 - 3,200 mm)
Drainage Density	Very low - moderate (< 3,333 - 9,999 m/m ²)	Very low - moderate (< 3333 - 9999 m/m ²)
Lineament Density	Very low - very high (< 1,000 - > 4,000 m/m ²)	Very low - very high (< 1,000 - > 4,000 m/m ²)
Topographic Elevation	Very low (< 200 m)	Very low (< 200 m)
Slope Steepness	Very low (0°)	Very low (0°)
Soil Types	Weston, Tanjung Aru, Tuaran, Lokan, Dalit, Kinabatangan, Crocker	Tanjung Aru, Tuaran, Brantian, Lokan
Landuse	Forest, Resident/ Development, Mangrove	Forest, Resident/ Development, Mangrove, Agriculture
Major Fault Zones	500 - 1,000 m	< 500 m
Syncline Zones	500 - 1,000 m	< 500 m

CONCLUSION

From the results obtained, there are three main factors that influence the availability of groundwater potential in the studied area which are lithology, topographic elevation, and syncline zones. This study concludes that five potential groundwater zones are recognized, where the higher groundwater potential ones are located at the northern part of the studied area. The area is a low-lying area consisting of mostly alluvium with peat and muddy sandstone which are also found in some of the areas.

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