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RESEARCH ARTICLE

THE INTEGRATION OF GIS, AHP, AND REMOTE SENSING METHODS FOR POTENTIAL AREAS GROUNDWATER: CASE STUDY FOR PONTIAN DISTRICT, JOHOR, MALAYSIA

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ABSTRACT

In Malaysia, production and conservation of groundwater are essential to the ecosystem's climate and sustainability. The decline of groundwater level data is a related problem for managing water supplies in the Pontian District, Johor, particularly in rural areas. With demand for household water, agriculture and industrial use is still increasing. Studies-based Remote Sensing (RS) and Geographic Information System (GIS) have gained more advantages in groundwater exploration as it is rapid knowledge about the research and development tool. Therefore, the present study has conducted an example of mapping potential groundwater zones in the Pontian District, Johor, and assessing the factors leading to explore future groundwater opportunities. To identify possible groundwater areas, RS data and GIS are being used, and the data collected by the Department of Mineral and Geoscience Malaysia (JMG). The present study utilized integration between GIS through analytical hierarchy process techniques (AHP). Five different maps were prepared and studied for the potential groundwater area, such as Roughness, Topographic Wetness Index (TWI), Elevation, Curvature, and Slope. Weights in all the thematic maps assigned to each class using the AHP method on their characteristics and potential water capability. The production accuracy has checked using groundwater prospects information, and the process is approximately 87.5 percent accurate. The resulting map of groundwater capacity was graded into five groups-very good, good, moderate, low, and very low. The analysis shows that about 57.3 percent of the area occupies the low potential groundwater area. The potential zones of good and moderate groundwater are observed in 1.28 percent and 18.94 percent, respectively. Only in minimal areas is the area under perfect potential areas registered. The results from this study can be useful in the preparation and growth planning of related agencies in Malaysia, for possible groundwater exploration to provide a fast system and cost reduction and a shorter period.

KEYWORDS

Geographic Information System, Groundwater Potential, Remote Sensing, Analytical Hierarchical Process, Prediction, Mapping.

1. INTRODUCTION

1.1 Overview

The subsurface geological systems of the earth's crust provide groundwater, as one of the essential natural resources (Fitts, 2002; Al-Ruzouq, 2015; Arulbalaji et al., 2019). Groundwater is an essential role in Malaysia used for agriculture, domestic consumption, and industrial uses (Andualem and Demeke, 2019). Groundwater is an alternative resource to meet a demand for various purposes (Saaty, 2004). Precipitation and flow discharge into rivers and lakes, springs, pumping, and evaporation are the primary sources of recharge for groundwater. (Arivalagan et al., 2014). The issue of groundwater in developing countries were recorded to identify the potential development of extraction water resources in future. In the previous study, the conventional methods are based on ground surveys and field observation using a geophysical technique such as resistivity, ground penetrating-radar, geological and hydrogeological technique (Rao and Jugran, 2003; Adeyeye et al., 2019). The current study, geospatial technologies by GIS, and remote sensing are a helpful technique for the mapping of potential groundwater areas (Chowdhury et al., 2009). GIS and remote sensing applications are more comfortable, less expensive, and provides for efficiently handling spatial data for the planning of natural resources (Machiwal et al., 2011).

Groundwater potential zones are detected on controlling variables, namely slope, topographic wetness index (TWI), lineament density, drainage, rainfall, elevation, TPI, normalized difference vegetation index (NDVI), curvature and roughness. For groundwater management plans, the detection area of potential groundwater areas is preserved. For higher cognitive processes in groundwater fields, integration of the GIS and Analytical Hierarchy Process (AHP) methods were used in 1980 by Thomas Saaty. Consequently, the present study aims to map the future

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groundwater areas of the Pontian District, Johor, with efficient and effective using remote sensing and GIS applications (Badamasi et al., 2016). Hence, the results of groundwater potential areas were checked and approved by field identification data to accurate results.

1.2 Research background

Many researchers used remote sensing GIS to locate the possible area of groundwater. A group researcher investigated the delineation groundwater potential in Nekor Basin, Central Rif of Morocco using GIS, remote sensing, and AHP (Bourjila et al., 2020). The various thematic layers for variables potential groundwater included elevation, rainfall, land use, geology, drainage density, slope, lineament density, curvature, roughness, TWI, and TPI. The generated map shows that only 20.48 percent of the basin has a good and very good potential groundwater.

A studied groundwater potential with GIS and AHP in a drought susceptible semi-arid region in eastern India (Mukherjee and Singh 2020). This assessment includes the 12 variables, including fault and lineament density, soil, roughness, land use, rainfall, slope, TPI, TWI, geology, drainage density geomorphology, and curvature. The outcome of this analysis was 80.49 percent, close to the tube well data observation.

Exploring the potential groundwater area for southern Banjarnegara, Central Java, Indonesia using GIS, AHP, and remote sensing techniques (Atmaja et al., 2019). Five factors are used to evaluate groundwater potential involving slope, rainfall, drainage, lithology, and lineament density. The result validation obtained via 52 springs and two bore wells data. The map generated and divided into five groups: very low, low, moderate, high, and very high. This study area has high potential groundwater, and it covered only 15.51 km^2 equally to 17.98 percent. This Groundwater potential area map can provide guidance and information on the desirable area in the prospective groundwater exploration for local authorities and planners.

The groundwater productivity spatial prediction model in the Langat Basin Area, Selangor using twelve groundwater variables includes stream power index (SPI), land use, lithology, elevation, slope, curvature, TPI, drainage capacity line density, NDVI, rainfall and soil (Nampak et al., 2014). Potential groundwater map findings from the map of beliefs have been tested using test data.

A study reported a statistical model and GIS for groundwater spring potential maps on the Taleghan Watershed, Alborz Province (Moghaddam et al., 2013). Factors such as slope, aspect, elevation, TPI, SPI, roads, failures, soil, lithology, land uses, and drainage density in the groundwater source. The statistical method has calculated, and ArcGIS software has reported the results.

The combination of numerical model and GIS was developed by a researcher in Banganga River, India (Gaur et al., 2011). In this study, the GIS was used to show different thematic from various variables like geology, slope, land use, geomorphology, soil, drainage, to identify the potential groundwater areas.

2. MATERIALS AND METHODS

2.1 Study aim and objectives

This study aims to classify possible areas of groundwater in the Pontian, Johor with GIS and remote sensing applications. The specific aims are to:

- Create thematic maps of variables that affect the capacity of groundwater in the region.
- Weighting by hierarchical analytical method (AHP) of each of thematic map.
- Map the possible areas of groundwater by overlaying the index weighted in GIS.

2.2 Study area

The study area falls in Pontian District, Johor, in Malaysia, located between 1.4869° N latitudes and 103.3890° E longitudes. The area covered by the research encompasses a total area of 1,017.2 km^2, with a population of approximately 164,400 peoples in 2016 (DOSM, 2017). Pontian consists of 11 Mukim's, namely Benut, Pontian, Ayer Masin, Serkat, Jeram Batu, Pengkalan Raja, Ayer Baloi, Rimba Terjun, Sungai Pinggan, Api-Api, and Sungai Karang. Pontian District, Johor has South China Sea monsoon rain from November to March. The annual average rainfall is 2355 mm, and the range of temperatures is from 25.5°C - 27.8°C. The area of study is elevated from 0 m to 177 m. Figure 1 shows the Johor state map and the Pontian map location of the study area shown in Figure 2.

Figure 1: Johor State map

Figure 2: Site map of the area of study

2.3 Application technology and data used

This paper used geospatial methods to detect the Pontian District; Johor is possible for groundwater areas using five layers that monitor variables. The application of GIS and remote sensing, namely Erdas Imagine 9.1 and ArcGIS 10.5, is a technique by combining spatial data and attributes from different sources. The different thematic maps, including boundary, drainage, contour, and road, were obtained. Satellite data were collected and mosaicked from ASTER image to determine the digital elevation model (DEM), curvature, elevation, TWI, roughness, and slope. Tube well was obtained from the Department of Mineral and Geoscience Malaysia Johor to overlay and locate with the GW map.

2.4 Stage of data processing

2.4.1 Stage 1 - Identify the Variables

The processing of data starts with the digitization, merging, and converting all thematic maps into grid maps. The factors of groundwater potential were developed from satellite images using QGIS and ArcGIS. The drainage and slope maps are obtained using the spatial analyst tool in the ArcGIS application. All data have been overlaid and geographically referenced by the World Geodetic System (WGS 84). AHP model was conducted to determine the thematic maps' weighting based on the considerable influence on groundwater accumulation within a scale of 1 to 9. The weighted index overlay technique did the mapping of groundwater potentials in ArcGIS 10.5 after the reclassification process. Figure 3 summarizes the methodology charts for this analysis.

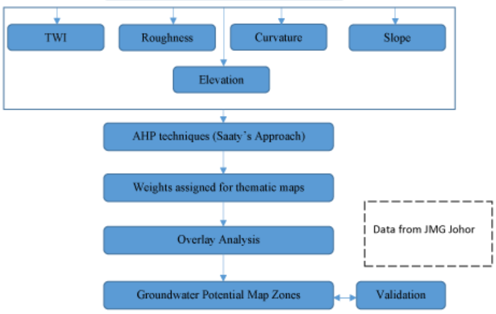

Figure 3: Methodology chart used for mapping potential of groundwater.

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2.4.2 Stage 2 - Analysis of Multi criteria decision Approach (MCDA)

MCDA derived as the weighting of each controlling variable based on the Saaty AHP technique. The result shows that the highest possible value is given to the indicator with the highest ground-water potential and the lowest possible minimum value. Based on a study, scale 1–9, where scale 1 is the same score between the two controls and scale nine, implies that one controlling variable is highly significant relative to the other (Saaty, 1980; 1992). The following equation (1) is referenced as a consistency measure by Saaty called Consistency Index (CI):

$$CI = \frac{\lambda max - n}{n-1}$$

$$CI = \frac{5-5}{5-1} = 0 \qquad \text{(Equ.1)}$$

$\lambda_{\max}$ is the peer-wise matrix's largest self-value, and n is the number of groups or characteristics.

Consistency Ratio (CR) is a pairwise comparison matrix consistency measure given by equation (2):

$$CR = \frac{CI}{RI} \qquad \text{(Equ.2)}$$

The index of the ratio is RI and CR is also defined as CR = CI / RCJ = Random Consistency Index Value (RCIV) derived from the norm of Saaty (Table 1).

$$CR = \frac{0}{1.12} = 0$$

Table 1: Index Saaty ratio for N various values.

The consistency of mutual matrices randomly generated					
Matrix series					
N	**1**	**2**	**3**	**4**	**5**
RCI value	0.00	0.00	0.58	0.90	1.12

2.4.3 Stage 3 – Weights assigned for thematic maps and overlay analysis

The weights of the various themes are qualitatively assigned by scale 1 to 9 based on their groundwater effect. Each topic's different characteristics were given weights on a scale from 1 to 9 according to its relative impact on groundwater production. The different thematic characteristics were evaluated accordingly in a qualitative manner: poor (1-2); moderately poor (2-4); fair-moderate (4-6); fair (6-8); excellent (8-9) (Table 2).

Table 2: Qualitative weightage of different themes

Theme	**Weight**
Elevation	9
Slope	7
Roughness	3
TWI	5
Curvature	1

At the last procedure, the weightage and scores were obtained from a weighted linear combination in a raster format using the spatial analyst in ArcGIS 10.5 software. Finally, all thematic layers are incorporated using overlay analysis and created groundwater areas Polygons weighted to achieve a reasonable amount of groundwater in the following equation (3) (Rao and Briz-Kishore, 1991):

2.4.4 Stage 4 – Calculation of GWPAI

$$GWPAI = \{(SLw)(SLwi) + (\mathrm{CTw})(\mathrm{CTwi}) + (\mathrm{RNw})(\mathrm{RNwi}) + (TWIw)(TWIwi) + (EVw)(EVwi) \qquad \text{(Equ.3)}$$

GWPAI = Groundwater Potential area Study area indices SL=slope, CT=curvature, RN=roughness, TWI=topographic wetness index. Moreover, subscription 'w' and 'wi' indicates the normalized and normalized weight of each issue.
Other methods of generating Pontian District groundwater potential area map using equation (4).

$$GWPAI = \sum_{i}^{n}(X_{\mathrm{a}} \times Y_{\beta}) \qquad \text{(Equ. 4)}$$

GWPAI = Groundwater Potential Area Index, X- represents the thematic layer weight; Y-represent the thematic layers of the sub-class category. The thematic maps are represented by the 'a' term (a=1, 2, 3 ......, X). Furthermore, a set of thematic maps defined by 'β' (β = 1, 2, 3 ..., Y).

3. RESULTS AND DISCUSSIONS

All different thematic maps of slope, elevation, curvature, roughness, and TWI in the study area are generated by GIS and RS data in the following section to present the groundwater potential map.

3.1 Slope

The slope is an indication of the ground surface's steepness. The more extensive slopes produce fewer recharges because the water received from precipitation flows down rapidly during rainfall. These variables can be viewed as one possible accessibility measure for groundwater (Al Saud, 2018; Machireddy, 2019). Therefore, this condition does not provide enough time to penetrate and regenerate (Reu et al., 2013; Arulbalaji et al., 2019). Figure 4 shows the Pontian District slope diagram. The study area slope ranges were carried from 0^{o} to 64^{o}. The slope values have been categorized and reclassified into five groups: flat (0-3.27), gentle (3.27-6.55), medium (6.55-12.09), steep (12.09-24.44), and very steep (24.44-64.27).

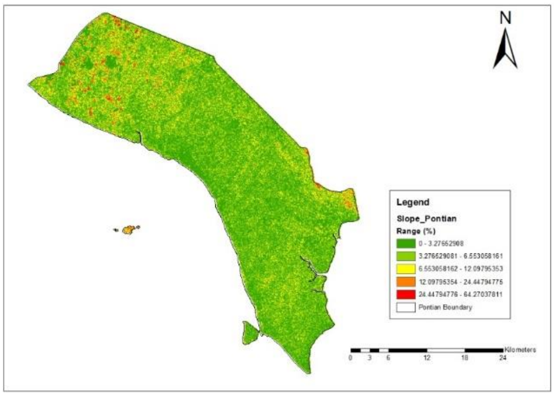


Figure 4: Slope map

3.2 Elevation

An area elevation has a pronounced impact on an area's GWP. Water appears to be collected at lower topography, rather than at higher topographies. Higher elevation reduces groundwater potential and vice versa (Ramu et al., 2015; Hamid et al., 2018). The elevation of the study area varies from 0 meters to 177 meters from the meantime sea level. The research field is fragmented into five classes by height (Figure 5): 0-11, 11-19, 19-35, 35-71, and 71-177.

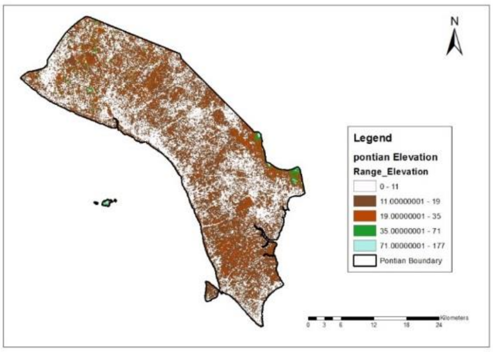


Figure 5: Elevation map

3.3 TWI

Commonly, the Topographic Wetness Index (TWI) is used to measure the topographical influence of hydrological processes and represent groundwater's possible intrusion due to the topographical impact (Mokarram, 2015). The TWI was developed using 'TOPMODEL' – a model that stimulates hydrological flows in the watershed. For the estimation of TWI, the equation (5) given below was used.

$$TWI = \mathrm{In}\frac{\alpha}{\tan\beta} \qquad (5)$$

$$\alpha = Uslope\ contributing\ area;\ \beta = Topographic\ Gradient\ (slope)$$

The study area of the TWI ranged from 2.71 to 15.43. Five ranges, such as 2.71-6.00, 6.00-6.95, 6.95-8.05, 8.05-9.54, and 9.54-15.43, reclassified the values. For lower TWI, the lower weights were allocated, and vice versa. Figure 6 displays The Pontian Johor's TWI map.

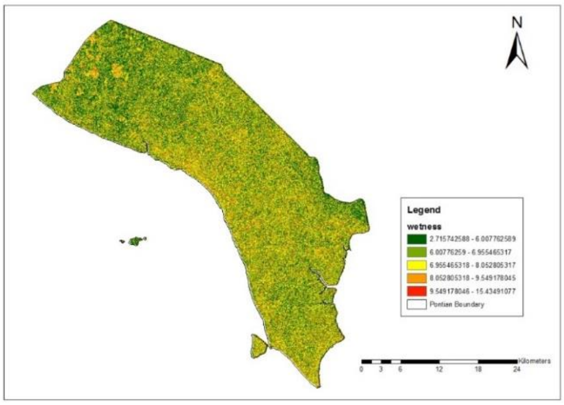


Figure 6: Topographic Wetness Index map

3.4 Curvature

Curvature is used to see concave or convex upward profiles as a quantitative representation of the surface profile character (Nair et al., 2017). Water continues to slow down and is susceptible to accumulation by profile. Curvature variables in the study area ranged from 22.05 to-22.76. The ranges are divided into five groups such as -22.76 to -1.49, -1.49 to -0.44, -0.44 to 0.43, 0.43 to 1.66 and 1.66 to 22.05. For optimum curvature value, assigned high weight, and minimal curvature value, assigned low weight. Figure 7 shows the Pontian Johor's curvature map.

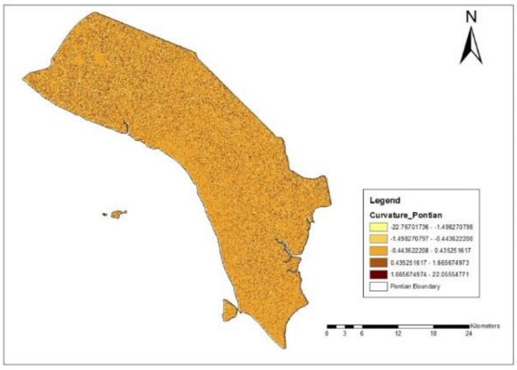


Figure 7: Curvature map

3.5 Roughness

The roughness index indicates the difference in height between the neighbouring DEM cells (Riley, 1999). The index of roughness typically reflects the undulation of the topography. The roughness increased, the undulation increased and the roughness decreased, and the undulation decreased. Undulated topography is typical of a mountainous area where weathering and erosion processes constantly alter a rough and smooth surface landscape on a long-term basis (Nair, 2017). Figure 8 shows the Pontian roughness map and the values ranged from 0.02 to 0.88. Reclassified the values into five classes: 0.02-0.32, 0.32-0.39, 0.39-0.45, 0.45-0.52 and 0.52-0.88. For low roughness value, the high weights are given, and vice versa.

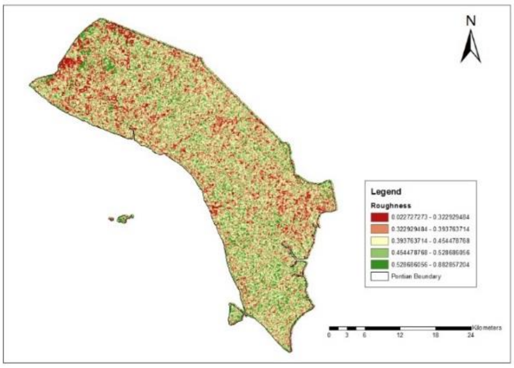
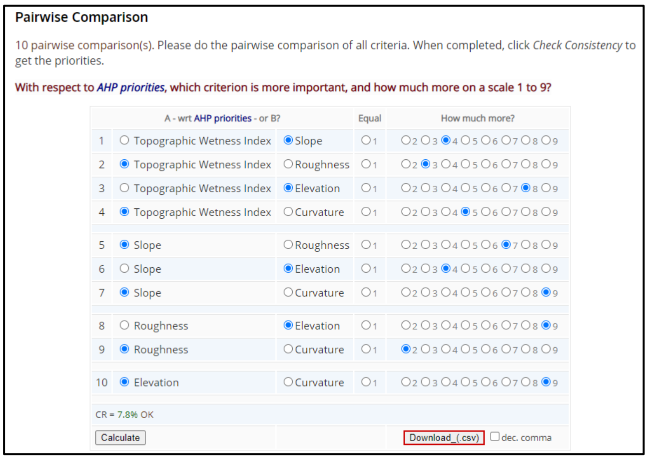


Figure 8: Roughness map

3.6 Groundwater potential area

Then, a matrix of comparison in pairs was built using Saaty's AHP to determine all parameters (Das et al., 2019). AHP scale: Figure 9 indicates that the CR is 7.8 percent equal to 0.078, suggesting that this value was agreed and reasonably consistent. Saaty assumed that a CR of 0.10 or less would be sufficient for the study to proceed. When the consistency value reaches 0.10, then the decision must be updated to find and correct the causes of the inconsistency. When the CR value is 0, it implies that the pair-wise relation has a perfect consistency. The essential factor is elevation, followed by slope, TWI, roughness, and curvature.



Pairwise Comparison

10 pairwise comparison(s). Please do the pairwise comparison of all criteria. When completed, click *Check Consistency* to get the priorities.

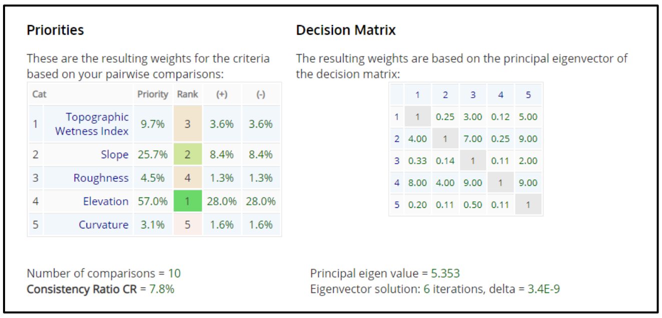
With respect to *AHP priorities*, which criterion is more important, and how much more on a scale 1 to 9?

	A - wrt AHP priorities - or B?		Equal	How much more?
1	○ Topographic Wetness Index	● Slope	○ 1	○2 ○3 ●4 ○5 ○6 ○7 ○8 ○9
2	● Topographic Wetness Index	○ Roughness	○ 1	○2 ●3 ○4 ○5 ○6 ○7 ○8 ○9
3	○ Topographic Wetness Index	● Elevation	○ 1	○2 ○3 ○4 ○5 ○6 ○7 ●8 ○9
4	● Topographic Wetness Index	○ Curvature	○ 1	○2 ○3 ○4 ●5 ○6 ○7 ○8 ○9
5	● Slope	○ Roughness	○ 1	○2 ○3 ○4 ○5 ○6 ●7 ○8 ○9
6	○ Slope	● Elevation	○ 1	○2 ○3 ●4 ○5 ○6 ○7 ○8 ○9
7	● Slope	○ Curvature	○ 1	○2 ○3 ○4 ○5 ○6 ○7 ○8 ●9
8	○ Roughness	● Elevation	○ 1	○2 ○3 ○4 ○5 ○6 ○7 ○8 ●9
9	● Roughness	○ Curvature	○ 1	●2 ○3 ○4 ○5 ○6 ○7 ○8 ○9
10	● Elevation	○ Curvature	○ 1	○2 ○3 ○4 ○5 ○6 ○7 ○8 ●9

CR = 7.8% OK

Figure 9: 10 Pairwise using AHP Priorities scale 1 to 9 for all criteria

Figure 10 shows that the criteria resulting weights are based on pair comparison and decision matrix to get a fundamental value of their own (eigenvalue). The elevation is the highest percentage for all variables. The value of its eigenvalue is 5.353.



Priorities

These are the resulting weights for the criteria based on your pairwise comparisons:

Cat		Priority	Rank	(+)	(-)
1	Topographic Wetness Index	9.7%	3	3.6%	3.6%
2	Slope	25.7%	2	8.4%	8.4%
3	Roughness	4.5%	4	1.3%	1.3%
4	Elevation	57.0%	1	28.0%	28.0%
5	Curvature	3.1%	5	1.6%	1.6%

Number of comparisons = 10
Consistency Ratio CR = 7.8%

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix:

	1	2	3	4	5
1	1	0.25	3.00	0.12	5.00
2	4.00	1	7.00	0.25	9.00
3	0.33	0.14	1	0.11	2.00
4	8.00	4.00	9.00	1	9.00
5	0.20	0.11	0.50	0.11	1

Principal eigen value = 5.353
Eigenvector solution: 6 iterations, delta = 3.4E-9

Figure 10: The priorities and decision matrix for the different criteria

After combining all previous layers, the groundwater area map was graded, as shown in Figure 11, beginning from very poor to very strong. The suitability map with the different spectra of colors may identify the groundwater level is.

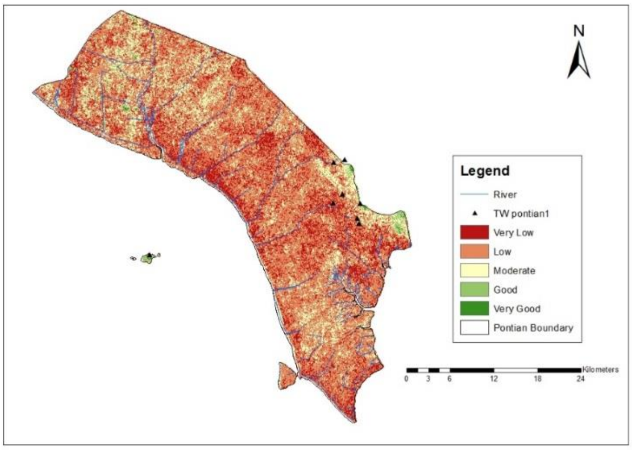


Figure 11: Groundwater Potential map

Table 3: Potential groundwater areas with coverage area and percentage

Groundwater Areas	Area Covered (KM^2)	Percentage Covered (%)
Very Low	226.3818	22.26
Low	583.2978	57.34
Moderate	192.7016	18.94
Good	13.00787	1.28
Very Good	1.815258	0.18

The weighted overlay technique showed that 57.34 percent of the study area was occupied by the low zone, equivalent to 583.29 km^2. The following are very low, moderate, good, and very good areas with 22.26 percent, 18.94 percent, 1.28 percent and 0.18 percent equivalent to 226.38km^2, 192.70km^2, 13.00km^2 and 1.81km^2 respectively (Table 3). It indicates that only 1.46 percent of the study area has a secure capacity to supply water. In the research area, elevation plays the most vital position in groundwater developments, followed by slope, TWI, curvature, and roughness. For validation, on the groundwater potential map, the position for groundwater or tube well was overlaid from JMG data. From the JMG tube well database, eight tube well exploration is valid, and the seven only are located in the right zone. The only one tube well-considered as a moderate and low category.

4. CONCLUSION

The conclusion of this analysis carried out with the five possible groundwater areas includes very good, good, moderate, low, and very low. Five different thematic layers, namely, slope, elevation, curvature, roughness, and TWI, are prepared using satellite images. These layers are implemented in GIS with a weighted overlay to create possible maps of groundwater. This study's finding was validated using some existing tube well from the JMG database in Pontian Johor. Hence, potential groundwater mapping area using RS and GIS methods are inexpensive, fast, accurate, and covers a large area. This method will reduce unnecessary work labor, save time and cost (Okoli, & Marcellinus, 2019). This data finding from this study using the AHP technique from GIS device is an excellent tool to make a policy, evaluating, and decision making for sustainable water resources plan (Zeinolabedini & Esmaiely, 2015; Patle, 2019). The groundwater potential map shows that about 57.3 percent of the area occupies the low potential groundwater area, good and moderate groundwater are observed in 1.28 percent and 18.94 percent, respectively. Future research must concentrate on identifying more complex factors that may lead to shifting potential groundwater to ensure the final map's accuracy and validity.

RECOMMENDATIONS

Future research will concentrate on checking and enhancing the findings by implementing more checked weight values and exploring other factors that can lead to possible groundwater areas changes. To ensure the end map's accuracy and authenticity, the digital maps' reliability and the full range needs to examine. It should be noted that the maps produced need to be verified and improved before they are adopted for future research.

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