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A HYBRID GIS AND KNOWLEDGE-DRIVEN APPROACH FOR WATER RESOURCES POTENTIAL ZONATION

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ABSTRACT: Assessing the potential zone of groundwater is extremely important in areas that are prone to climate-related hazards and have limited access to potable water supply such as Kuala Krai, Kelantan, Malaysia. The application of GIS and remote sensing allows for faster, cheaper, and more efficient groundwater management and exploration. In this work GIS and Knowledge-Driven approach are combined in an attempt to identify groundwater potential zones in Kuala Krai. The various thematic maps prepared for delineating groundwater potential zones are lineament, lithology, soil, land use, rainfall, slope, drainage density, and elevation. The knowledge-driven technique is used to assign weights for each factor and Weighted Linear Combination (WLC) approach is used to investigate several choice possibilities and evaluate suitability according to the associated weight of each factor. The results revealed that 31.64% and 15.10% of the area in Kuala Krai were categorized as high and very high groundwater potential zones which are mostly located in the central, western, and southern parts of Kuala Krai where interbedded sandstone, siltstone, and shale were the major geological unit. Furthermore, rainfall was also highly influential in determining groundwater potentiality. In terms of land use, forest, rubber, and oil palm were found to be suitable for high potential zones of groundwater. Moreover, the area located nearby the Kelantan River also exhibited high groundwater potentiality. The map can be used to develop and further expand groundwater utilization in Malaysia.

Keywords: Groundwater potential mapping, Geospatial analysis, Multicriteria decision making, Spatial prediction

1. INTRODUCTION

Groundwater is defined as water that occupies within an aquifer located in the saturated zone underground, in contrast to surface water bodies such as lakes, rivers, and reservoirs [1]. In groundwater exploration, an aquifer is a geologic formation that can provide a large amount of water to wells and springs. Groundwater is acknowledged as a valuable and important hydrological resource that is reliable in all climatic regions around the world. The usage of groundwater around the world has been increasing at an alarming rate over time as the results of improvement and rapid development of irrigation systems plus increases in energy development. For instance, groundwater is mainly utilized for industrial and domestic purposes in humid countries such as Japan and northern Europe [2]. Groundwater is also utilized extensively in agriculture for irrigation in countries like India, China, and United States [1]. In a tropical country like Malaysia, groundwater accounts for 90% of the freshwater resources in Malaysia and it is mainly used for domestic water supply, industrial use, and irrigation. The water demand is increasing over the years due to factors such as population growth, industrial and agricultural expansion & deteriorating surface water quality [3]. For instance, the dry season causes water scarcity in some states located in the northern part of Peninsular Malaysia such as Kedah and Perlis. In other states such as Perlis, Pahang and Sabah, groundwater is heavily exploited by private sectors for the production of commercial mineral water [4].

In Kelantan, surface water is the main water resource. However, water-related disasters and anthropogenic activities contribute to the depletion of surface water sources. Therefore, groundwater has become an important alternative of water supply in this region. There is abundance of groundwater alluvial basins in the northern part of Kelantan such as Kota Bharu, Pasir Mas, and Bachok. However, there is still a lack of exploration and development of groundwater in the southern parts of Kelantan such as Kuala Krai, Gua Musang, and Jeli due to insufficient evaluation of groundwater resource and local experts in groundwater management. Moreover, some remote areas in Kuala Krai have limited access to the potable water supply. Hence, finding and providing a potential water source is of utmost importance in Kuala Krai.

A review of the literature reveals that the usage of geospatial modelling in groundwater potential mapping is increasing and able to predict potential zonation accurately. Various methods are used for instance, frequency ratio (FR) model [5], catastrophe theory [6], evidential belief function (EBF) model [4], [7], statistical technique [8] and multi-criteria decision-making technique (MCDM) [9] – [14]. These methods are non-destructive as they don't require digging and cheaper compared to methods such as test drilling and geophysical technique that are more expensive and require more manpower.

In this study, a hybrid GIS and knowledge-driven approach were utilized to create a groundwater potential map in Kuala Krai, Kelantan.

2. RESEARCH SIGNIFICANCE

Groundwater exploration and development in the southern part of Kelantan has yet to be carried out. In fact, groundwater exploration hasn't been the main focus in other states in Malaysia. Therefore, this technique allows for faster and more efficient groundwater exploration in an area with limited data and resources. Groundwater potential zonation map produced from this study can be used as a basic information for groundwater management and exploration in an area that has an urgent demand for clean water supply such as Kuala Krai. This study also intends to prompt more groundwater exploration via a geospatial approach in other states of Malaysia.

3. METHODOLOGY

3.1 Study Area

Kuala Krai, Kelantan is in the southern part of Kelantan, Malaysia. The main town in Kuala Krai is nearby Kelantan River which comprises of the confluence of Lebir River and Galas River. The general topography of Kuala Krai consists of hills in the eastern, western, and southern parts of the area. Flatland is located in the northern part of Kuala Krai. The elevation in Kuala Krai ranges from 20 m to 1250 m and most of the areas in Kuala Krai have elevation levels from 0 to 160 m. Furthermore, the slope that ranges from 13º to 75º is prevalent throughout the study area due to the hilly landscape. The climate in Kuala Krai is tropical with high annual rainfall due to wind from the northeast monsoon. Additionally, the northeast monsoon can contribute to flooding due to high and prolonged rainfall which can be very extreme such as the 2014 Kelantan flood [15]. When it comes to land use and land cover, forest mainly covers Kuala Krai and rubber is the main land use that approximately covers 40% of Kuala Krai. Other land use such as oil palm, paddy, agriculture station, and mixed horticulture only cover small portions of Kuala Krai. Moreover, the soil type in the study area is mostly comprised of sandy clay. Finally, Kuala Krai has diverse lithology which is promising for groundwater availability. For instance, the main geological units that exist in Kuala Krai are acid intrusive (undifferentiated) rock, interbedded sandstone, volcanic rocks and schist.

3.2 Data Collection

Eight parameters used for this study were lineament, lithology, soil, land use, drainage density, rainfall, slope, and elevation. These parameters are groundwater storage controlling factors that are commonly utilized by researchers in groundwater potential mapping especially in Malaysia [4], [10], [11]. Landsat 8 OLI/TIRS C1 Level-1 imagery was downloaded from EarthExplorer website by United States Geological Survey (USGS). Furthermore, the geology map of Kuala Krai was acquired in digital format from the Department of Mineral and Geoscience Malaysia (JMG) and digital land use map was obtained from Department of Agriculture. Rainfall data were collected from the Department of Irrigation and Drainage Malaysia (DID) whereas the soil reconnaissance map of Peninsular Malaysia was obtained from European Soil Data Centre (ESDAC) website. Lastly, topography map of Kuala Krai was acquired from the Department of Survey and Mapping Malaysia. All data were assessed by the agencies to ensure high accuracy.

3.3 Integration of Thematic Layers

In this study, the thematic layers refer to the layers for all eight parameters. All thematic layers were converted to raster form with 20m cell size before integration was carried out. To create a groundwater potential map, all thematic layers were integrated in ArcGIS. Then, the groundwater potential index was calculated based on the weighted linear combination (WLC) model.

WLC is one of the MCDM tools based on a concept of weighted average in which multiple criteria are standardized to a common numeric range and then combined through weighted average [16]. In the context of GIS application, the decision-maker assigns weighted values according to their relative importance to the map layer. All parameters were given a weighted value using a knowledge driven approach. The weighted value ranges from 1 to 10 based on how each parameter influenced groundwater potentiality. The main reference for weighted/scoring for each parameter was referred from [11] as the environment of the study areas is similar and located in the same country. Other studies [17], [18], and [19] were also used as references because some attributes of the parameters like lithology were rarely evaluated in groundwater potential mapping because of its rare occurrence or absence in some environments.

Table 1 Weighted values of parameters and rating scores

Parameter	Weighted value	Classes	Score
Lineament density(km/km^2)	9	0.8175 - 1.1980 (very high)	10
		0.6156 - 0.8175 (high)	8
		0.4418 - 0.6156 (moderate)	6
		0.2398 - 0.4418 (low)	4
		0.0002 - 0.2398 (very low)	2
Lithology	8	Schist, phyllite, slate	9
		Limestone/marble	8
		Interbedded sandstone	8
		Acid to intermediate	7
		Sandstone	7
		Ignimbrite	7
		Intermediate to basic volcanic (mainly pyroclastics)	7
		Schist	6
		Phyllite, schist	6
		Acid intrusive	5
		Ultrabasic intrusive	3
Rainfall (mm)	8	2750 - 3000	10
		2500 - 2750	8
		2250 - 2500	7
		2000 - 2250	5
Slope (°)	4	0 - 5	8
		5 - 15	7
		15 - 25	5
		25 - 35	4
		35 - 60	3
		60 - 90	2
Elevation (m)	4	<20	9
		20 - 100	7
		100 - 500	6
		500 - 1000	4
		>1000	3
Drainage density (km/km^2)	3	<0.75	10
		0.75 - 1.49	9
		1.5 - 2.24	7
		2.25 - 3.0	6
		3.0 - 3.74	4

Table 2 Weighted values of parameters and rating scores

Parameter	Weighted value	Classes	Score
Soil	3	Sand	10
		Coarse sandy clay	8
		Sandy clay	7
		Coarse sandy clay - clay	7
		Sandy loam - sandy clay	5
		Fine sandy loam - clay	4
		Fine sandy clay	4
		Silty clay - Clay - Fine sandy clay	4
		Clay	2
Land use	2	Forest	7
		Rubber	6
		Paddy	6
		Coconut	6
		Other crops	6
		Oil palm	6
		Agricultural station	4
		Mixed horticulture	4
		Pasture/Ruminant	4
		Orchard	4
		Clear land/Unwanted	4
		Scrub	3

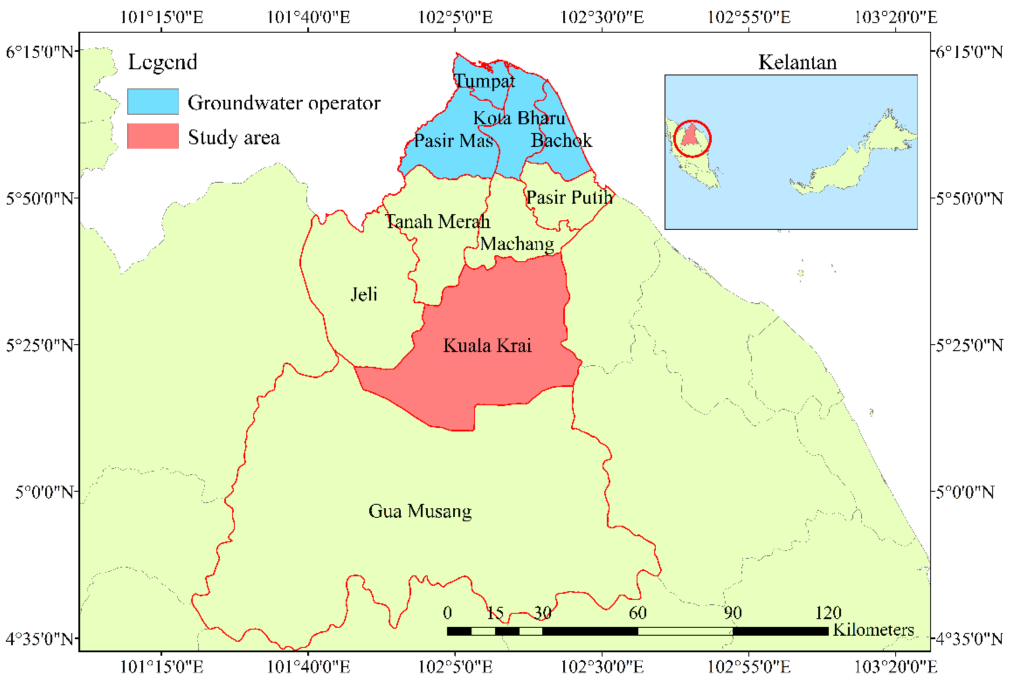

Fig. 1 Study area map

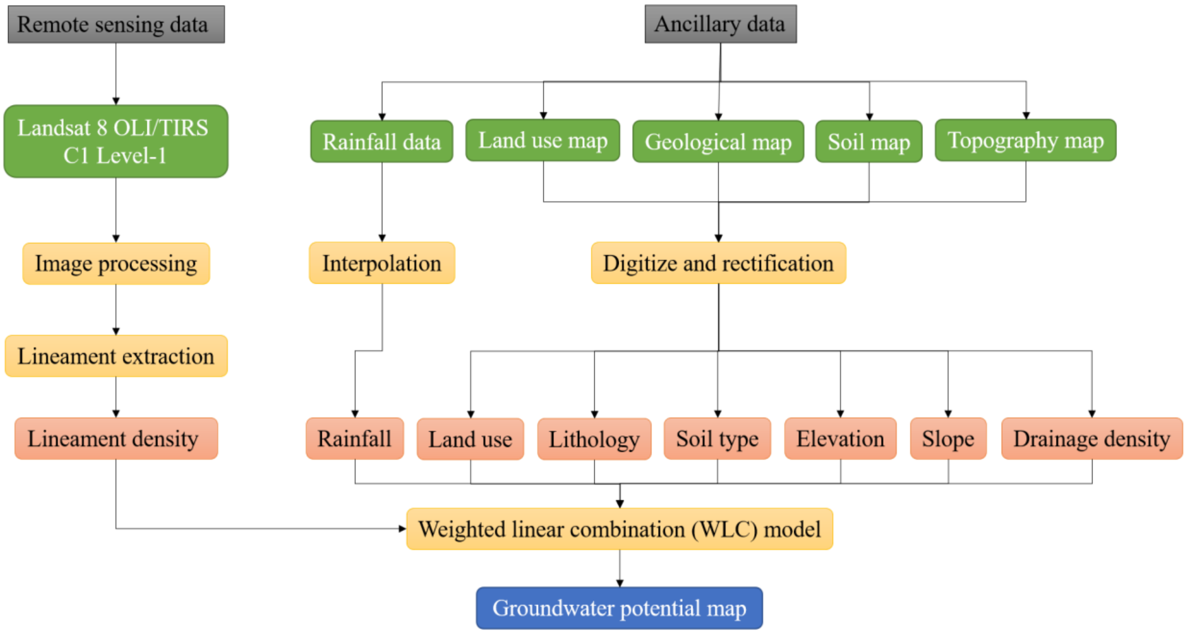

Fig. 2 Flow chart of the methodology

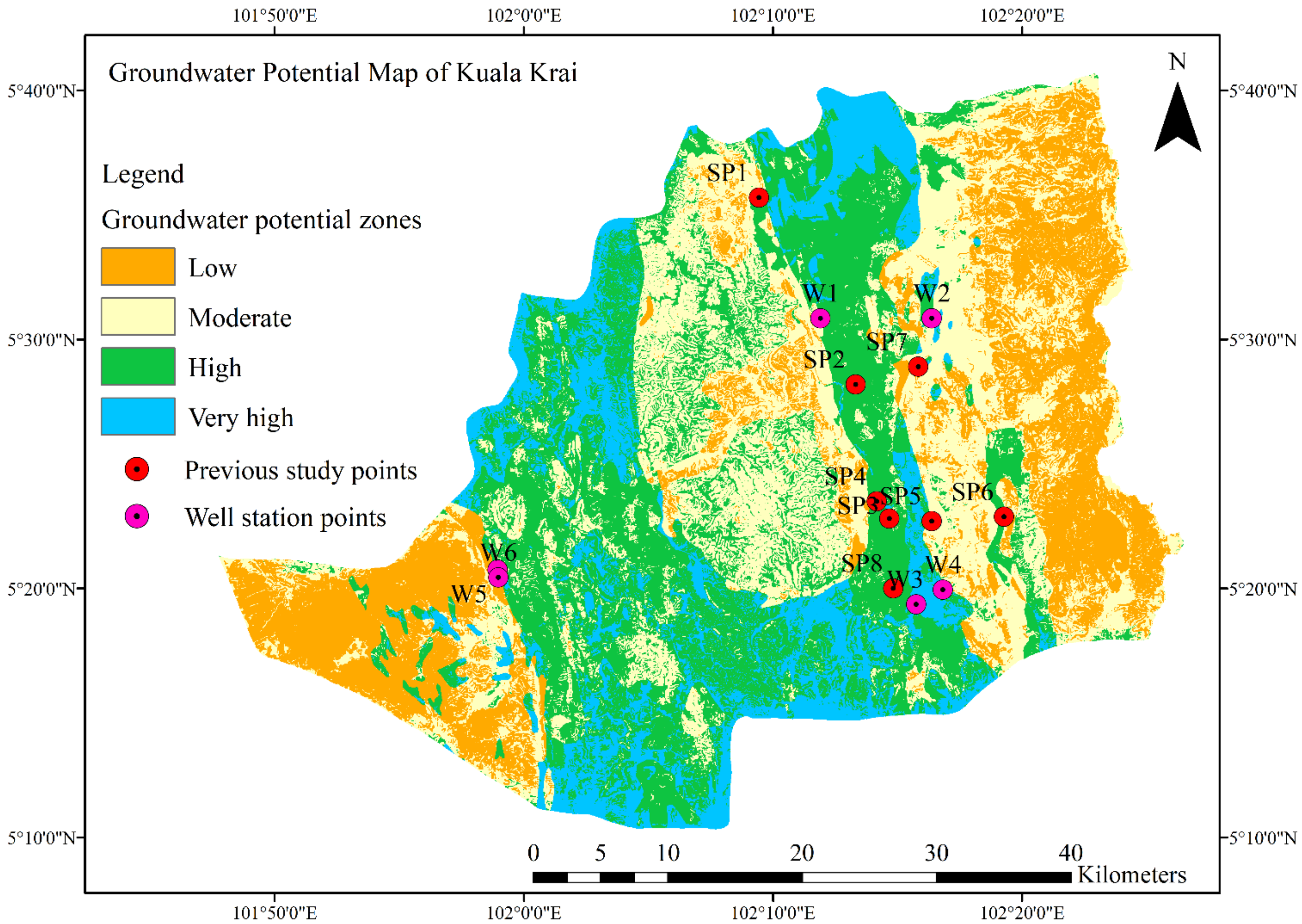

Fig. 3 Groundwater potential map of Kuala Krai

All weighted values gathered from these studies were conducted based on a knowledge-driven approach such as experts' opinions and field experience. The accuracy of the map produced from [11], [17], [18], and [19] have accuracy range from of 76% to 86%.

A low weighted value indicates that the parameter is less significant or influential in determining groundwater potentiality whereas a high weighted value indicates high importance. Every parameter has its own attributes and the same range of values (1 to 10) was given to each attribute. Tables 1 and 2 showed the list of parameters and attributes/classes with respective weighted values and rating scores. Then, the weighted value of the parameter was multiplied by the scaled value given to the attributes of the parameter. Next, the products were summed to obtain a suitability map. The formula of the WLC model is shown in Eq. (1):

$$S = \sum WiXi \quad (1)$$

where "*S*" is the suitability, "*Wi*" the weight of the parameter, and "*Xi*" is the criterion/rating score of the features of the parameter [16]. Therefore, the groundwater potential index is calculated by using the formula below:

$$GWPI = E_wE_r + LD_wLD_r + R_wR_r + S_wS_r + LT_wLT_r + ST_wST_r + LU_wLU_r + DD_wDD_r \quad (2)$$

where *w* is defined as the weight of the parameter and *r* represents the criterion/rating score of the features of the parameter (refer to Table 1 and 2); "*E*" represents elevation and "*LD*" represents lineament density; "*R*" represents rainfall data and "*S*" is the slope; "*LT*" represents lithology and "*ST*" represents soil type; "*LU*" represents land use; "*DD*" finally represents drainage density.

4. RESULTS AND DISCUSSION

4.1 Identification of Groundwater Potential Zones

Groundwater potential zones were classified based on JMG's classification which generalized groundwater potential classes into low, moderate, high, and very high. Based on Figure 3, the groundwater potential map showed that the high groundwater potential zone had the largest area coverage (765.35 km^2) and was mainly located in the central part of Kuala Krai. Zone with very high groundwater potentiality covered around 319.29 km^2 of the area and mainly located in the southern and western part of Kuala Krai. Areas categorized as very high potential zone which located in the southern and western part of Kuala Krai consisted of all favourable features attributed to very high groundwater potential class such as sandstone, siltstone shale, schist, phyllite, slate (for lithology factor), course sandy clay (soil media factor), high rainfall, low slope, low elevation and forest, rubber, and oil palm as landcover. Figure 4 presented a graph of the area coverage for each class of groundwater potential zone.

The results revealed that lithology was the most significant factor in groundwater potentiality, and it was evident in high groundwater potential zone such as the central part of Kuala Krai which consisted of interbedded sandstone, siltstone, and shale (covered 37.85% of the study area) as its geological unit. Sandstone is a sedimentary rock that consists of a structure of grains, interstitial detrital silt and clay, chemical cement, and an interconnecting pore system that give sandstone its ability to store and transport groundwater [20]. Therefore, sandstone is a very favourable rock type for groundwater occurrence. High groundwater potential zone could also be in places with phyllite, slate, and shale which also consists of sandstone and limestone that are locally prominent [11]. In this study, phyllite, slate, and shale are located in southern, southwestern, and northern parts of Kuala Krai (3.36%) which explain why this area is indicated as high potential zone.

Furthermore, zones with low groundwater potentiality were located in areas with igneous rock and acid intrusive (undifferentiated) rock which were mostly located in the eastern region of Kuala Krai. Igneous rock is classified as hard rock which exhibits negligible primary porosity and primary permeability [21] thus serve as a poor aquifer.

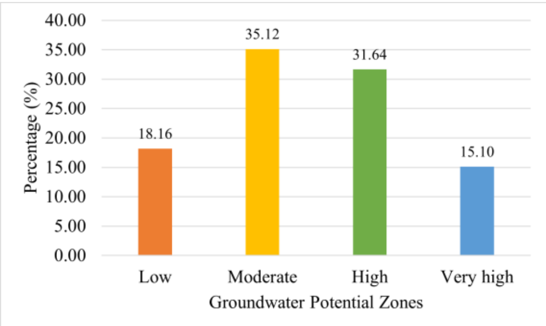

Fig. 4 Groundwater potential zones area coverage

Next, the lineament density factor which was supposed to be the most influential parameter in groundwater potentiality didn't influence much because of low lineament density throughout Kuala Krai. The main reason why lineament density is low throughout the study area is due to few fault lines. Areas with high lineament density were located in the southwestern and southern regions of Kuala Krai. As a matter of fact, lineament occurrence in the Kelantan river basin is mainly related to the N-S trending of the Bentong-Raub Suture Zone (BRSZ) in the west and Lebir Fault Zone in the eastern part of Kelantan [22]. Low lineament density limits groundwater movement because the rock is very unlikely to have fracture or joint to allow water movement.

Besides, rainfall was also proven to be a very effective parameter in providing favourable condition for the groundwater potential zone. The annual rainfall in Kuala Krai ranges from 2800mm to 3461mm. Consequently, the high annual rainfall is very good for high groundwater recharge. Additionally, the fact that Kuala Krai is mostly covered with coarse sandy clay soil (64.96% of the study area) makes groundwater recharge easier due to high permeability of the soil which leads to better infiltration. Coarse sandy clay soil is mainly located in the central, western, and eastern parts of Kuala Krai.

As for land use, a large portion of areas in Kuala Krai is covered by forest (63.35%) and rubber (12.57%) which have high groundwater potentiality. Forest and rubber are mainly located in the central, eastern, and western regions of Kuala Krai. Forest is the most effective land use for groundwater potential zone because the abundance of trees and vegetation maintain groundwater and streams during the dry period by storing rainwater and slowly releasing it [23]. Other land use types like oil palm and rubber plantation are shown to have high groundwater potential. This is because moderate tree cover can increase groundwater recharge [23]. On the contrary, the urban area is unsuitable for groundwater occurrence because rainwater can't infiltrate impervious surfaces such as road and concrete and the lack of vegetation induces the limitation of water movement. Hence, the village and town areas in the eastern part of Kuala Krai had low groundwater potentiality. The high groundwater zone was also located along the Kelantan River because groundwater provides water to the river in the hydrologic cycle and the river simultaneously recharges the aquifer.

The reasons why groundwater exploration and development in Kuala Krai have not been carried out because the lithology (acid intrusive rock covers 30.47% of the study area) and topography are seemingly unfavourable for groundwater occurrence. However, the results from the study showed that quite a large portion of area (46.74% of the study area) in Kuala Krai exhibited suitable conditions for groundwater occurrence in areas with high rainfall, forest and rubber cover, porous soil, and rocks, and flat topography. Groundwater supply can be developed in the areas which are located near the river (also nearby towns and villages), central and western parts of the study area. Eastern and southwestern regions however are not favourable for groundwater occurrence mainly due to high elevation, high drainage density, steep slope, and acid intrusive rock.

4.2 Map Validation

Map validation was executed by overlaying the groundwater potential map with groundwater wells points and locations of potential tube wells in Kuala Krai. These data were extracted from a previous study [24] on groundwater exploration in Kuala Krai. A study from [24] used a geophysical method to explore potential groundwater locations to build tube wells. The locations of groundwater wells and points from the previous study were provided in Table 3 and Table 4.

Table 3 Location of groundwater wells in Kuala Krai

Well station	Latitude	Longitude	District
1	5.51425	102.1985	Batu Mengkebang
2	5.51425	102.273	
3	5.322806	102.2625	Olak Jeram
4	5.332639	102.2804	
5	5.346014	101.9825	Dabong
6	5.3408	101.9829	

Table 4 Location of previous study points in Kuala Krai

Point	Latitude	Longitude	District
1	5.595111	102.1574	Batu Mengkebang
2	5.470039	102.222	
3	5.380158	102.2446	Olak Jeram
4	5.391694	102.2361	
5	5.378517	102.273	
6	5.381444	102.3213	
7	5.481883	102.2639	Batu Mengkebang
8	5.3335	102.2471	Olak Jeram

Overlaying groundwater potential map and groundwater well points showed that 5 out of 6 well stations in Kuala Krai were located in high and very high groundwater potential zones. Accordingly, a deduction could be made that groundwater could exist in interbedded sandstone, siltstone, and shale in the central, western, and southern part of Kuala Krai. The results from the previous study [24] successfully found the potential location at the study points with groundwater occurred at a depth ranging from 5 to 40m. Furthermore, the results also found that groundwater also could exist in pyroclastics. Hence, the results coincided with the groundwater potential zones. 5 out of 8 previous study points were located in high and very high groundwater potential zones.

5. CONCLUSION

The results from the groundwater potential map showed that groundwater could be utilized in Kuala Krai as the main water source because 31.64% and 15.10% of the study area had high and very high groundwater potentiality which were mostly located in the central, western, and southern regions. Therefore, more development on groundwater should be encouraged. The advantage of this method is it can be used with limited data and calibration and validation aren't mandatory. However, the user should be aware of the subjectivity in this assignment of the weighted and rating score as different experts might have different opinions on how certain parameter influences groundwater occurrence. Therefore, a proper survey by experts and a thorough literature review is important. Additionally, groundwater potential mapping could also be integrated with other methods like geophysical method or numerical model to produce better results and accuracy. However, the main reason why these methods were used in this study is to provide a simple and quick insight of areas that have potential groundwater occurrence. Hence, any modification should be made while keeping the simplicity of the methods. Lastly, GIS and remote sensing methods in groundwater exploration proved to be fast, efficient, and cost-effective. The results from the groundwater potential map also could be a guide for future groundwater exploration and research.

6. ACKNOWLEDGMENTS

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