Groundwater potential zone in Bachok District, Malaysia: Application of Remote Sensing and GIS Technique

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Abstract. The research aimed to identify probable groundwater zones by integrating GIS, remote sensing, and AHP techniques. Given the rising demand for water resources due to population growth and economic expansion, groundwater resources are vital. The paper presented a comprehensive approach to achieving this goal. Integrating geographic information systems with analytic hierarchy processes is demonstrated to obtain precise decision-making information through transforming geographical data and weightage ranking. The present study has identified seven principal criteria controlling parameters significantly impacting groundwater occurrence. These criteria have been derived from analysing satellite imagery, existing maps, and data sources. The abovementioned variables encompass drainage density, elevation, annual precipitation, slope gradient, land use and land cover. The overlay-weighted sum method maps the potential groundwater zones in the research area by incorporating all thematic criteria. The groundwater potential index map has identified various zones with differing levels of groundwater potential, ranging from very low (1.61%, low (1.81%), moderate (2.66%), high (22.59%) and very high (71.33%). Ultimately, the mean groundwater level information obtained from five wells in the study area is employed to authenticate the map depicting the potential groundwater zones. This research discusses the significant implications that need to be considered for sustainable groundwater exploration in the area.

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1 Introduction

Despite its rich hydrogeological resources and plentiful rainfall, Kelantan's water supply comes primarily from groundwater [1]. However, groundwater sustainability has recently emerged as a major issue because of rapid urbanisation, industrialisation, and population growth. This has prompted the development of a holistic and preventative plan for learning about, handling, and safeguarding these priceless artefacts. Because of this, GIS has emerged as a powerful tool that can significantly improve groundwater exploration studies in Malaysia [2,3].

Integrating GIS technology with hydrogeological investigations provides a systematic and efficient approach to analysing, visualising, and interpreting complex spatial data related to groundwater resources. Integrating geological, hydrological, and topographical data within a geospatial framework provides researchers, planners, and policymakers with valuable insights into groundwater reserves' distribution, quantity, quality, and vulnerability.

One of the biggest obstacles in groundwater exploration is pinpointing the location of possible aquifer zones and defining their boundaries. Aquifers have traditionally been mapped and identified using methods that rely on geological mapping [4] and extrapolation strategies using geophysical method [5,6]. However, these approaches often fall short because they fail to account for the multidimensional nature of groundwater systems and vital spatial relationships. To better understand groundwater's occurrence and flow dynamics, GIS technology enables the incorporation of diverse datasets, including geological formations, hydrological parameters, land use patterns, and climatic factors [7].

Researchers may also create groundwater prediction models using GIS-based modelling and simulation tools. Groundwater availability and vulnerability could be evaluated with the help of such models, considering factors like population growth, climate change, and changes in land use. By combining spatial and temporal information, GIS makes it possible to foresee changes in groundwater use, leading to better, more sustainable management and more educated decision-making. This paper aims to bring to light the pressing need for the application of GIS to groundwater exploration studies in Bachok, Kelantan, Malaysia. The Bachok area consists of a Quaternary deposit, which can be a good aquifer for the groundwater potential.

2 Methodology

2.1 Study Area

The study site is situated in Bachok, Malaysia (Figure 1). Bachok is a geographically located district within the northeastern region of Kelantan. The estimated land area of the Bachok district is approximately 195 square kilometres. The geographical features of Bachok encompass a diverse combination of low-lying regions, elevated hills, and expansive plateaus. The lowlands, primarily located near the coast and rivers, exhibit a flat topography and rich soil composition, rendering them highly conducive to engaging in agricultural pursuits.

2.2 Establishment of groundwater potential zone-related factors

Previous literature is utilised to gather the elements determining groundwater potential zone and their relevance. After combining duplicate factors, only representative components were found. This study's five important parameters determining groundwater recharge capacity are rainfall, lithology, land use/cover, lineaments, elevation, drainage, and slope gradient. GIS technology was used to digitise the hydrologic and geographic data, creating a primary database. Scores were allocated to several variables. The allocation of appropriate weights was done to evaluate groundwater potential, with various parameters being considered (Table 1). The determination of weights for the thematic maps was conducted by weight normalisation using AHP analysis. This was followed by the establishment of a pair-wise comparison matrix using Saaty's analytical hierarchy process [8].

2.3 Satellite Data Analysis

This research involved multiple steps and software tools for analysing diverse types of geospatial data. The processing data for each thematic map is referred to [9]. The ALOS PALSAR Digital Elevation Model (DEM) was imported into ArcGIS, where preprocessing was performed to improve data quality and resolution. Hydrological analysis tools, such as Flow Direction and Flow Accumulation, were employed to identify drainage patterns, leading to the generation of a drainage network by delineating stream channels based on accumulated flow. The ALOS PALSAR DEM data was utilised in ArcGIS for slope gradient determination, explicitly using the Slope tool within the Spatial Analyst extension. This enabled the calculation of slope gradient values for each pixel, which could be customised according to specific requirements, including units and smoothing options.

Regarding elevation visualisation, the ALOS PALSAR DEM data was employed in ArcGIS. Basic visualisation techniques were applied to represent the elevation data as a digital terrain representation, while symbology and colour ramp adjustments were made to enhance visualisation and interpretation. As for the rainfall analysis, the data was accessed via the CHRS Data Portal to acquire the desired annual rainfall data, which was then downloaded and imported into ArcGIS. Additional processing, such as reprojecting or resampling, was undertaken to ensure compatibility with the desired coordinate system and resolution. Geospatial tools and techniques in ArcGIS were utilised to visualise and analyse the rainfall data.

Data from pertinent sources, such as the Geological map of Peninsular Malaysia at a scale of 1:750,000, was obtained for lithology analysis. If needed, the lithology dataset was imported into ArcGIS and preprocessed by reprojecting or aligning it with other spatial layers. Appropriate symbology and colour coding were assigned to represent different lithological classes, while spatial analysis and querying techniques were employed to extract specific lithological information or relationships.

In the context of land use and land cover analysis, Sentinel-2 satellite imagery data from USGS Glovis was accessed. This imagery was downloaded and imported into both ArcGIS and ENVI software. Preprocessing tasks, including atmospheric correction and image enhancement, were conducted using suitable tools available in ArcGIS and ENVI. The Support Vector Machine (SVM) supervised classification technique was then employed to derive land use and land cover information from the Sentinel-2 imagery. The classification results were subsequently validated and refined using ground truth data or additional spatial analysis techniques.

Lastly, lineament analysis used the ALOS PALSAR DEM data in ArcGIS, ENVI, and PCI Geomatics software. Edge detection algorithms, such as filters or gradients, were applied to highlight potential lineament features in the DEM data. This process generated lineament maps by extracting and visualising the identified lineament features. Moreover, additional analysis, such as lineament length or orientation measurements, could be performed using ArcGIS, ENVI, or PCI Geomatics software tools.

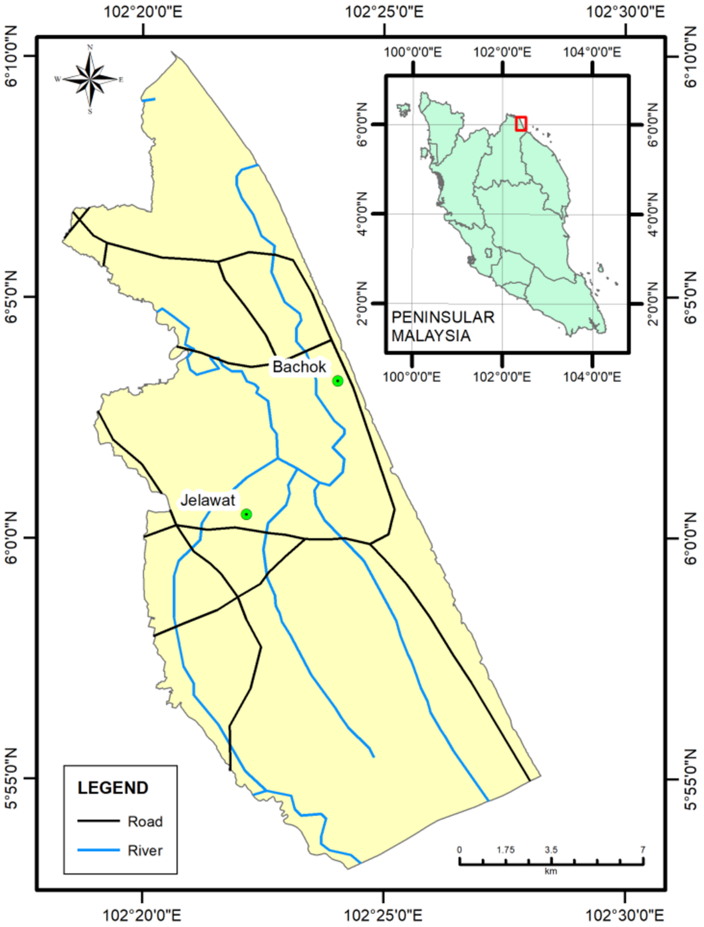

Fig. 1. The location of study area at Bachok, located at northern part of Peninsula Malaysia.

Table 1. The weightage for each parameter used in the analysis.

Parameters		Weightage
Annual rainfall (mm)	1,921.63-1,997.64	30
	1,997.64-2,084.02	40
	2,084.02-2,160.04	50
	2,160.04-2,239.51	60
	2,239.51-2,346.62	70
Lithology	Alluvium	70
	Granite	10
Lineament density (km/km^2)	0 - 0.75	30
	2.02 - 3.57	50
	0.75 - 2.02	40
	3.57 - 5.91	60
	5.91 - 10.11	70

Land use/ land cover	Agriculture	40
	Built-up/ Urban	10
	Forest	20
	water body	60
Topography elevation (m)	< 8	50
	8 - 20'	40
	20 - 60	30
	70 - 100	20
	200	10
Slope gradient	0° - 3°	50
	4° - 9°	40
	10° - 24°	30
	25° - 44°	20
Drainage density (km/km^2)	0 - 0.7	10
	0.7 - 1.2	20
	1.2 - 1.9	30
	1.9 - 2.8	40
	2.8 - 5.1	50

3 Result and Discussion

3.1 Thematic Map

Seven thematic maps were generated from the analysis: a geological map, lineament density map, drainage density map, topography elevation map, slope map, landuse map and rainfall map.

3.1.1 Geology

The lithology plays a vital role in controlling potential groundwater resources. Aquifer properties, groundwater storage, groundwater flow, aquifer recharge and groundwater quality are among the factors the lithology controls [10]. The geology of Bachok (Figure 2a) consists of two primary geological materials: alluvium and granite. The alluvium dominated the Bachok area, 96.8%, while the granitic rock covered 3.2%.

3.1.2 Lineament Density

Groundwater recharge, storage, flow, surface water-groundwater interaction, and locating suitable sites for well installation are just some of the many things the density of lineaments in alluvial regions can affect [11,12]. The analysis shows that the highest lineament density is at the southern part of Bachok, associated with granitic rock, representing 7.08%. Other parts of the study area can be classified as low and medium dense. The detailed lineament density map at the Bachok area can be referred to in Figure 2b.

3.1.3 Drainage Density

The drainage density plays a significant role in evaluating zones with groundwater potential. The phenomenon above influences the subsurface environment's water infiltration and recharge processes. A greater drainage density, characterised by more streams and channels, can increase surface water discharge, thereby diminishing groundwater replenishment and its associated potential [13].

The highest drainage density at the Bachok ranges between 4.5-5.1 km/km2. The drainage pattern at the site area can be classified as a dendritic pattern. The drainage system is well distributed at the site area. Figure 2c shows the drainage density map for the Bachok district.

3.1.4 Topography Elevation

Variations in altitude can exert an influence on the properties of the underlying aquifer substrates [14]. Elevated regions often exhibit sediments with a more granular composition and higher permeability, facilitating fluid flow. This characteristic can potentially enhance groundwater retention, increasing volume and efficiency. Figure 2d shows the topography of the study area.

3.1.5 Slope

The slope could change the way the groundwater materials in sediment layers behave. The places with modest or gentle slopes will have more good aquifer characteristics and a bigger chance of having groundwater supplies. The Bachok area is dominated by a flat area, which a slope degree is less than 15°.

The total area located in a flat zone is 99.19%. The remaining area, 0.81%, is located in a sloping area, ranging between 15°-44°. The area with a steep slope is located at the granitic hill. Figure 2g shows the distribution for slope in the Bachok area.

3.1.6 Landuse

The ease with which groundwater supplies may be accessed can be influenced by how land is managed. Some land uses, such as irrigated farms or areas with many people who consume much water, may put much pressure on groundwater sources, resulting in too much water being taken out of the ground and the groundwater being used up.

The Bachok area is dominated by agriculture and built-up area, which covers 73.36% of the total area. The rest were filled with forest and water bodies, with 18.56% and 8.08%, respectively. The detail of landuse cover distribution at Bachok can be referred to in Figure 2e.

3.1.7 Rainfall

Rainfall is one of the most essential ways groundwater is replenished in alluvium areas. Infiltration of rainwater into the ground helps to fill the aquifer and increase the amount of water that could be used from the ground. Rain's amount and distribution directly affect the groundwater recharge rate. Groundwater tends to be refilled more in places where it rains a lot, and rain falls evenly.

This means there is a higher chance of groundwater being available in these places. The rainfall intensity is higher in the southern part of Bachok, with precipitation ranging from 2.239-2.346.6 mm per year. Figure 2f shows the rainfall distribution intensity for the Bachok area.

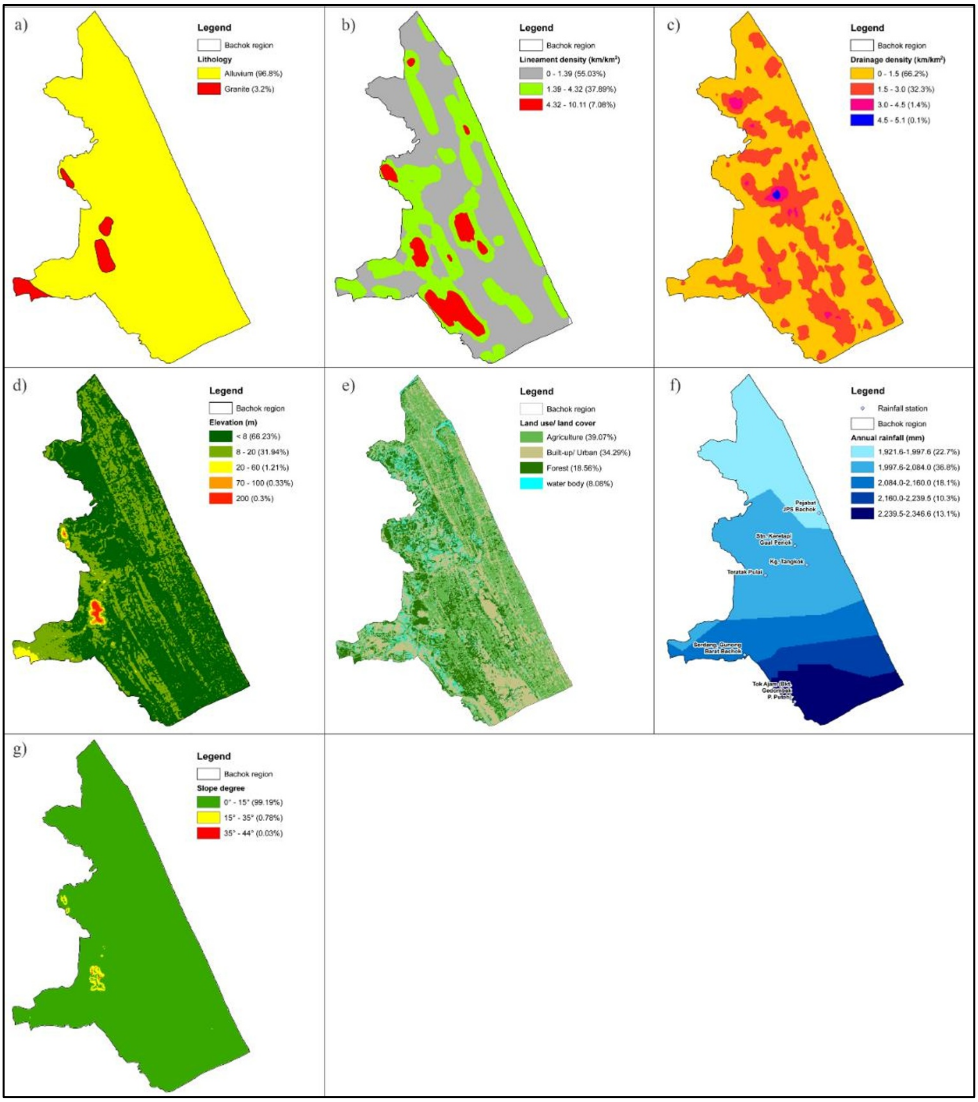

Fig. 2. The thematic map generated from the analysis, a) geological map, b) lineament density map, c) drainage density map, d) Topography elevation map, e) landuse map, f) rainfall map, and g) slope map.

3.2 Spatial Analysis for Groundwater Potential Zone

Figure 3 depicts the projected distribution of groundwater zones in the Bachok area. Several thematic maps were assembled using Geographic Information Technology (GIS) technology to create the map. The numerous topic layers could be linked together by applying the groundwater potential model, which resulted in the production of the final derived layers. The findings were then classified into five categories based on their groundwater capacity (see Table 2): very high, high, intermediate, low, and low. According to a review of the data in Table 2 and Figure 3, about 93.92% of the Bachok area possesses traits indicating substantial groundwater resource potential. The majority of the materials in the Bachok region are Quaternary in age.

The Quaternary layer is primarily composed of alluvial material, which the presence of sandy and silty particles may distinguish. As a result, coarse-grained materials such as sand or grit improve porosity and drainage significantly. These materials have a more excellent permeability, allowing them to function effectively as pools for storing and retrieving water from the ground. It can also be shown that it rained all year in the Bachok region, keeping the subsurface system full of water. Rainwater flows through the Earth's shell and into the layer's underneath, replenishing the subterranean pool known as the aquifer. This has a significant impact on the quantity of groundwater accessible. The replenishment rate is determined by how much, how powerful, and where in space waterfalls. The water table typically rises when it rains heavily and continuously. As mentioned earlier, this suggests that the places are more likely to have groundwater resources.

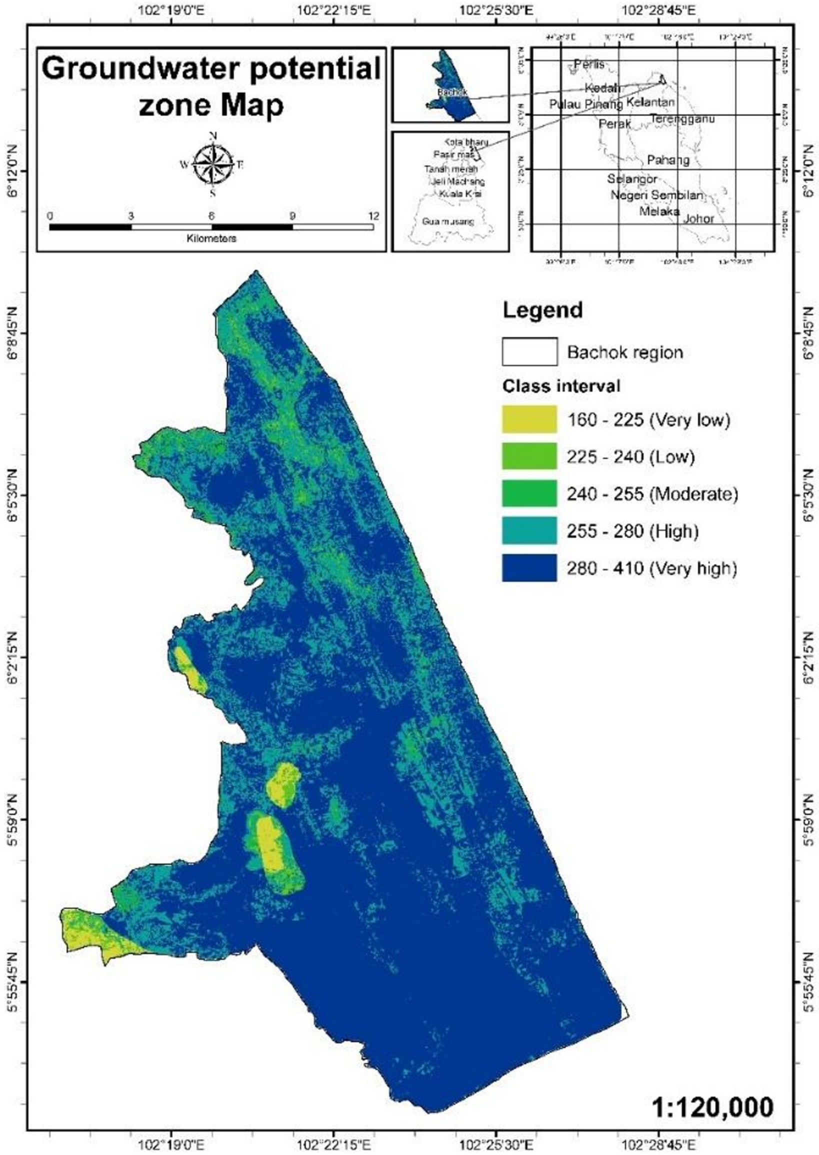

Fig. 3. Groundwater potential map for the Bachok area.

Table 2. The percentage of groundwater potential area at Bachok, Malaysia.

Class Interval	Groundwater potential zone	Area (km^2)	Area (%)
160 - 225	Very low	4.35	1.61
225 - 240	Low	4.90	1.81
240 - 255	Moderate	7.20	2.66
255 - 280	High	61.18	22.59
280 - 410	Very high	193.14	71.33

4 Conclusion

Using satellite data has proved highly beneficial in surface analysis, particularly for identifying and examining various surface attributes and properties, such as lineaments and geological formations. In order to improve the ability to foresee areas with high groundwater potential, a collection of thematic maps was developed.

This study examines the spatial distribution of annual precipitation, land use patterns, geological characteristics, density of lineaments, topographic elevation, slope, and drainage density. Applying a Geographic Information System (GIS) model for conducting an integrated assessment of thematic maps has proven its accuracy in predicting groundwater potential. However, the finding from the GIS study need to follow up with the ground study, using other methods such as geophysical survey and follow up with the drilling technique.

Acknowledgements

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