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Determination of groundwater potential zone using geospatial and geophysical method for UPNM campus, Kuala Lumpur, Malaysia

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Abstract: Access to clean water is critical for various socio-economic purposes, particularly at Universiti Pertahanan Nasional Malaysia (UPNM). Groundwater has been elected as an alternative clean water resource to address the water scarcity issue at student residential colleges. The objective of this study is to develop a groundwater potential map for the UPNM campus by using the integration of geospatial and geophysical methods. This study adopted a weighted linear combination (WLC) model in ArcGIS software to integrate five major groundwater parameters: lithology, land use/land cover (LULC), slope, elevation, and lineament. The resulting groundwater potential zone map was classified into four zones, with 25.41%, 42.9%, 25.94%, and 5.73% of the study area falling under very low-potential, low-potential, high-potential zone, and very-high-potential zone, respectively. Electric resistivity tomography (ERT) traverses of 400 m and 800 m were conducted at two locations to validate the resulting groundwater potential map. Pole-dipole and dipole-dipole arrangements yielded resistivity and induced polarisation (IP) values with the 2D resistivity images, showing that the most probable groundwater potential zone was less than 50 m depth. The geospatial and geophysical results agreed well in prospecting the most probable area of groundwater. The application of integrated remote sensing, GIS, and geophysical survey in this study confirmed the groundwater potential zones in the UPNM campus, which are located in the northeast and southeast parts of the Bukit Gemilang stretch. The resulting groundwater potential map provides valuable information for future planning of water supply for the UPNM campus.

Keywords: groundwater, geospatial and geophysical method

1. Introduction

The availability of a clean water supply is essential for human survival and various socio-economic purposes. A continuous and reliable water supply is critical in accommodating population growth needs and supporting increasing water demand, particularly on the UPNM campus. Due to rapid development, there is a water shortage issue encountered at student residential colleges. The situation worsens during drought season, when those affected often face difficulties obtaining a clean water supply. The buildings located in terrain areas caused low reachability of water supply and consequently exacerbated the situation. This research was conducted to discover the availability of clean water resources nearby the affected area to overcome reoccurrence of the water shortage issue. Groundwater is seen as the most preferred option compared to surface water because it is a reliable source of clean water, less polluted, and has widespread availability. However, the occurrence needs to be identified through evaluation using the integration of techniques to resolve the hidden subsurface hydrogeological heterogeneity.

Geospatial and geophysical methods have been widely used in obtaining spatial information on surface and subsurface for searching potential groundwater zones because of their capability to identify features or parameters related to the groundwater phenomenon (Elbeih, 2015; Hasan & Shang, 2022). The geospatial method, which integrates geographic information system (GIS) and remote sensing (RS), is a powerful tool for managing multiple geo-environmental parameters derived from satellite images, tables, maps, and other institute data to provide a baseline for groundwater exploration (Manap et al., 2014). Such data, including land use, land cover, lineaments, slope, landform, rainfall, lithology, and other related data, will be integrated into GIS techniques using an empirical algorithm before visual interpretation. This method can cover a large and inaccessible area in a short time. Many researchers have employed geospatial methods to estimate groundwater potential

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worldwide (Arunbose et al., 2022; Lee et al., 2020; Wambui et al., 2022). In Malaysia, geospatial is primarily used to predict potential groundwater zones for various purposes (Isnain et al., 2017; Manap et al., 2013; Nampak et al., 2014; See et al., 2019).

Compared to the geospatial approach, the geophysical approach is a non-destructive method for remotely gathering the underlying geological properties without drilling a borehole. However, the high cost of installation, maintenance, and time-consuming data collection is not feasible for larger areas. Therefore, the geophysical method was conducted in the targeted region for extensive study (Gaber et al., 2020). Seismic refraction/reflection, surface wave, and electrical resistivity are just a few examples of geophysical methods. Because of its ability to identify groundwater signatures using the contrast in electrical resistivity of subsurface materials, the latter method has become one of the most commonly used geophysical approaches in groundwater investigations (Omolaiye et al., 2020). Many researchers have successfully employed the ERT method to locate groundwater resources in different geological terrain (Alshehri & Abdelrahman, 2021; Gyeltshena et al., 2019; Mahmud et al., 2022).

The groundwater potential zone can be spatially predicted using data from different sources and techniques. Integration of remote sensing, GIS, and geophysical techniques will improve understanding and yield more accurate results for determining potential groundwater zones, particularly for the UPNM campus. The objective of this study is to demarcate potential groundwater zones on the UPNM campus and determine the potential location for drilling a tube well near the affected water scarcity area.

1.1 Study area

Files must The UPNM campus is located in Sg Besi province, 12 km from the city center of the Federal Territory of Kuala Lumpur, between latitude E 101° 43' 15" and longitude N 3° 3' 38" and covers an area of approximately 1.84 km2 (Figure 1a). The study area is surrounded by hilly terrain, with the highest point being Bukit Gemilang (Jelani et al., 2018). The average elevation above sea level ranges from 50 to 190 m. The primary vegetation type in the study area is thick bushes, and secondary forest covers most of the hilly area, while buildings predominate on the flat land. There is also a small water body from the former tin mining pond located at the lowest elevation.

Sg Besi's bedrock is mainly composed of granite bedrock, as illustrated in Figure 1b (Jelani et al., 2021). Except for discontinuities in the rock mass caused by fractures, joints, faults, geological contacts, and shear zones, this geological formation is highly impervious to groundwater flow and storage. Sg Besi's alluvial deposits mainly consist of loose silty sand and gravel deposited during the quaternary period (Ayob, 1970).

The Southwest Monsoon has an impact on the weather condition. The highest rainfall occurs between October and January, with an intensity ranging from 2000 to 4000 mm per year and a mean annual temperature of 32°C.

As reported by previous authors, water table existence varies at depths ranging from 2 to 9 m on higher ground (Jelani et al., 2020). Spring waters have been observed seeping through exposed fractured granite rock slopes. The naturally occurring pond was filled with spring water that was constantly flowing (Figure 2). The spring water can be directed to potential groundwater and recharge sources, particularly on the UPNM campus's higher elevation and hard rock terrain.

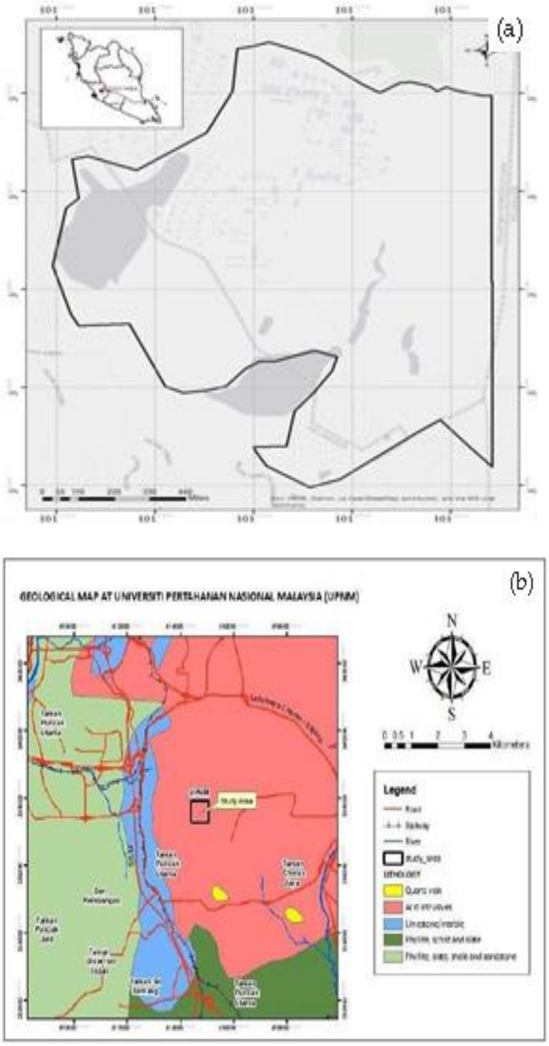

Figure 1. (a) Location of UPNM campus (b) Lithology of UPNM campus.

Figure 2. Continuous water seepage through fractured igneous rock

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2. Methodology

All figures should Figure 3 illustrates the methodology of this study, which is divided into two main parts: geospatial and geophysical methods. Multi geo-environmental parameters such as lithology, LULC, surface elevation, slope, and lineament were used in the geospatial approach to develop a groundwater potential map. These data were used to generate thematic maps derived from various sources. Elevation and thematic slope maps were generated using the Shuttle Radar Topography Mission (SRTM) Digital Elevation Modem (DEM) with 30 resolutions. The LULC was prepared using Landsat 8 satellite imagery (freely accessibly from the United States Geological Survey (USGS) earth explorer) and processed using ERDAS Imagine software. The lithology map was obtained from the Department of Mineralogy and Geoscience Malaysia and the Department of Survey and Mapping Malaysia. The map was processed and analyzed using the ArcGIS 10.8 software. A lineament map was generated by extracting data from DEM in a TIN format.

The subsequent step involves integrating thematic maps to generate a groundwater potential map (GWPM). The vector format layer was transformed to a raster format using the ArcGIS platform conversion tools. The weightage of all factor layers was carried out using the WLC method that assigned a weight based on its importance. Table 1 shows the weightage and score adopted in this study based on previous research (Amin et al., 2011; Manap et al., 2013). Weighted overlay analysis is a simple method for analyzing multiclass maps based on the relative relevance of each thematic layer and class (Gyeltshena et al., 2019; Manap et al., 2013). The following factors were combined and summarized using Equation 1 to yield a GWPM:

$$GWPM = \sum W_i S_j$$

where Wi and Sj denote the weight for each theme and the score of individual features, respectively.

Table 1. Weightage and score assigned to thematic maps (Manap et al., 2013).

Theme	Weight percent	Classes	Score
Lineament Density	0.3	>0.0013	5
		0.0009-0.0013	4
		0.0006-0.0009	3
		0.0002-0.0006	2
		0-0.0002	1
Lithology	0.3	Acid intrusive	5
Slope	0.15	0-10°	8
		10-20°	5
		20-30 °	4
		30-40°	3
		40-50°	3
Elevation	0.15	50-64 m	7
		64-78 m	7
		78-106 m	7
		106-148 m	6
		148-190 m	6
Land Use Land Cover	0.1	Forest	7
		Vegetation	5
		Construction Land	1
		Building	4
		Water body	0

The 2D ERT approach was used in this study's geophysical survey to obtain a subsurface variation of lateral and vertical change in resistivity value, predicting lithology and hydrogeological structure underlay. An ABEM Lund Imaging System Terrameter LS2 was used to simultaneously acquire resistivity data and IP measurement. The instrument was equipped with a multi-core cable, jumper cable, stainless steel electrode, 12-volt battery, and remote cable. The equipment test setup is shown in Figure 4a. The ERT survey was performed at two different locations, namely survey lines UPNM1 and UPNM2, which are 400 m and 800 m, respectively (Figure 4b).

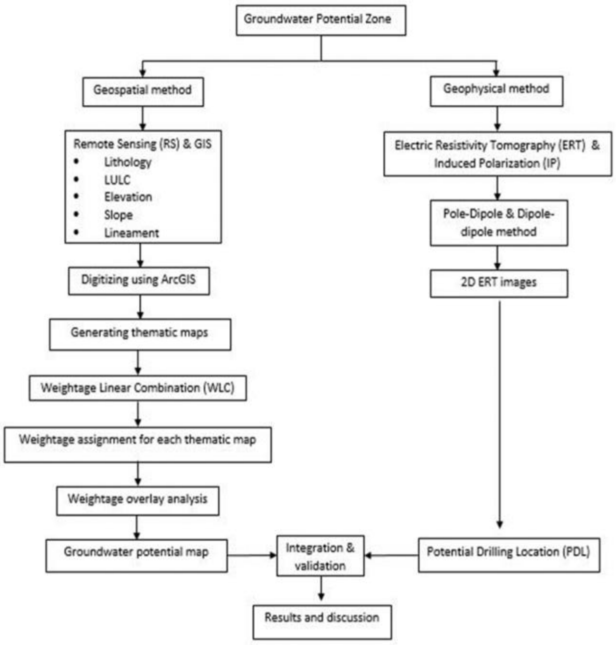

Figure 3. Flow chart of methodology employed in this study

Meanwhile, survey line UPNM1 was laid in the southwest-northeast direction, while survey line UPNM2 was laid in the north-south direction. The locations were chosen following the Department of Mineralogy and Geoscience Malaysia guidelines that emphasise on providing a sufficient buffer zone for groundwater quality assessment. A pole-dipole and dipole-dipole configurations were selected based on the resolution extension of lateral and vertical variations. The pole-dipole arrangement extends the vertical variation from moderate to high resolution, whereas the dipole-dipole arrangement extends the lateral variation significantly (Nur et al., 2020). Table 2 contains detailed information on the length, electrode spacing, and expected depth of subsurface data collection.

The RES2DINV version 4.4.16 software package was used for data acquisition and imaging to obtain 2D electrical resistivity and induce polarisation images. The inversion process converts the resistance measurements of earth materials to apparent resistivity values. In contrast, ground resistivity is affected by geological factors such as mineral and fluid content, porosity, and degree of water saturation. Since sedimentary rocks are porous and have a higher water content, they have lower resistivity values than igneous and metamorphic rocks. The resistivity contour value is adjusted based on geological information corresponding to the different colour's resistivity ranges.

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Table 2. Parameters of ERT survey lines

Survey Line	Electrode Protocol	Length (m)	Electrode Spacing (m)		Expected Depth of Subsurface (m)
			Min	Max	
UPNM1	Pole-Dipole	400	5	10	100
UPNM2	Dipole-Dipole	800	10	20	170

Resistivity value (Ωm)	Colour range	Interpretation
1 - 100	0.00 80.0	Water containing zone associated with weathered granite
101 - 1700	170 340 820 1700	Weathered granite
> 1700	1700 4000 7400	Fresh granite / Residual soils (presence at upper layer of subsurface)
Chargeability value (ms)	**Colour range**	**Interpretation**
0 - 7.5	0.00 3.00 4.50 7.50	Water containing zone associated with residual soils or weathered granite
> 7.5	7.50 12.0 20.0 30.0 40.0	Weathered - fresh granite

A resistivity value of 10 to 100 Ωm indicates the presence of a potentially water-containing zone. However, ERT resistivity is limited in distinguishing distinguish between water and clay. Therefore, such ambiguity can be resolved using the IP value (Hasan & Shang, 2022). Figure 5 shows the resistivity and chargeability values used in this study for interpretation. The geological formation is considered a weathered granite rock associated with a water-containing zone when the resistivity value is less than 100 Ωm. If the value is greater than 100 Ωm, the rock is considered very dense bedrock or fresh granite rock.

There are two types of chargeability values obtained from IP tomography. Granite rock is indicated by a chargeability value greater than 7.5 ms due to its ability to retain electrical charge longer than other subsurface materials. Meanwhile, a chargeability value of 0 to 7.5 ms is expected in a water-containing zone because water disables the electrical charges. The potential of a water-containing zone can be accurately predicted by combining resistivity and IP tomography profile results.

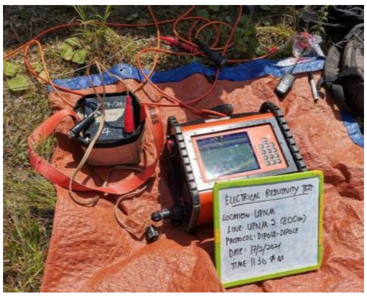

Figure 4. (a) ERT tools employed in this study. (b) Plan view of two ERT traverse lines conducted at site with 400m and 800m length.

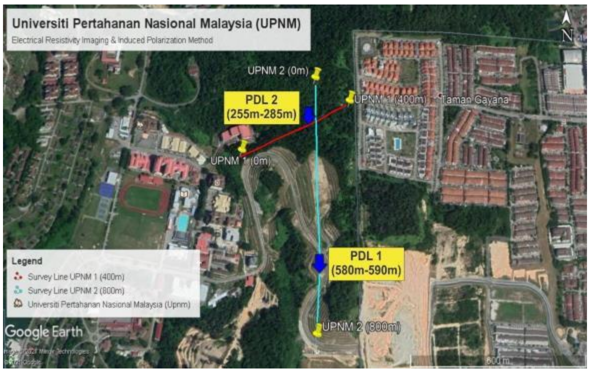

Figure 5. The resistivity and chargeability interpretation based on color range

3. Results and discussion

Based on Figure 6a, the study area is entirely dominated by acid intrusive igneous rock. Igneous rocks are generally rigid and impermeable. Groundwater occurrence in hard rock terrain depends on secondary porosity associated with joints, faults, lineaments, and weathering status (Kaliraj et al., 2017). The geological discontinuities play a vital role as a source of groundwater recharge.

Meanwhile, LULC refers to land coverage and natural characteristics that have been influenced by human activities and are primarily related to groundwater occurrence. As shown in Figure 6b, LULC is classified into five categories: building, vegetation, construction land, water body, and forest. Forest and vegetation areas are given a high weightage due to their high capacity in holding water compared to other categories (Amin et al., 2011).

Figure 6c shows the elevation map divided into low, moderate, high, very high, and most high. The UPNM campus is predominantly covered in high to primarily high ground. The higher the elevation,

the lower the potential to retain water and the lower the infiltration rate. Similarly, slope angle influences groundwater occurrence. A high slope angle has an inverse relationship with infiltration rate, implying a low likelihood of groundwater occurrence (Rahman et al., 2012). Subsequently, Figure 6c depicts the study area's slope classes, divided into five categories, i.e., low, moderate, high, very high, and extremely high.

Lineament is a vital aspect of groundwater research. Surface runoff infiltration is consistently influenced by high lineament density. It acts as a conduit for runoff to enter a subsurface aquifer (Arulbalaji et al., 2019). The lineament density of the study area is classified into five categories, as shown in Figure 6e, while Figure 6f demonstrates the GWPM of the UPNM campus.

Based on previous research, each zone was divided into four distinct categories: very low, low, high, and very high. The findings showed that very high groundwater potential zones account for 5.73% of the total area. The hilly terrain along Bukit Gemilang has a high groundwater potential zone, accounting for approximately 25.94% of the total. Most of the land, approximately 42.9%, is covered by a low groundwater potential zone. Meanwhile, very low groundwater potential zones covered the remaining 25.41% of the area. The area with very high groundwater potential had a moderate slope, high elevation, high lineament density, and forest area. In contrast, a very low groundwater potential zone falls under building-covered areas, moderate elevation, low slope class, and low lineament density. Based on the results of this study, high lineament density and forest-covered land are essential parameters that contribute to high groundwater potential compared to other parameters such as elevation and slope angle.

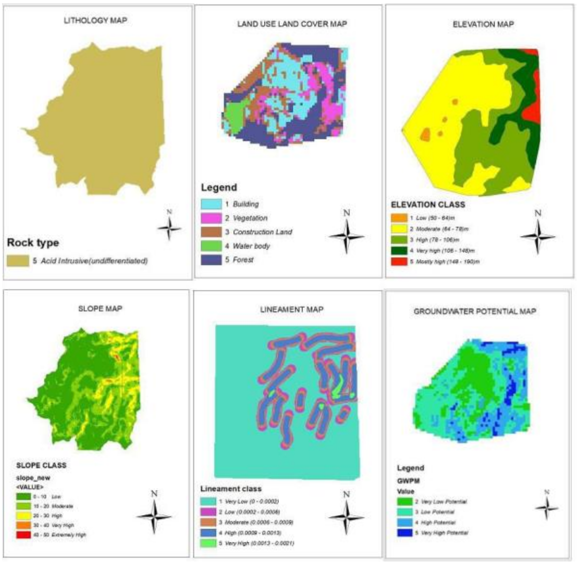

Figure 6. Thematic maps of (a) Lithology; (b) LULC; (c) Elevation; (d) Slope; (e) Lineament density; and (f) GWPM for UPNM campus

Figures 7a and 7b show the 2D tomography of resistivity and the IP profile for survey lines UPNM1 and UPNM2. Both profiles are colour-coded, and each colour is represented by a logarithmic colour scale bar. The vertical and horizontal scales represent the depth investigated and the distance on the ground, respectively. High resistivity values (> 4000 Ωm) were observed at a depth of more than 60 m for survey line UPNM1, indicating fresh granite bedrock. Meanwhile, a small pocket of water was observed at three different locations, i.e., 100 m, 170 m, and 270 m. PDL2, located at a distance of 270 m and a depth of 25 m to 50 m, was the most likely groundwater potential zone. There is no evidence of a fracture zone in the granite formations. However, the water potential zone is probably associated with weathered granite. When the results were compared to the IP profile, low chargeability values (<7.5 ms) were observed, supporting the interpretation that a water-containing zone exists in this area.

Water-containing zone is less evidence for survey line UPNM2 than for UPNM1. This pattern is due to the water-containing zone having a lower volume than UPNM1. The low volume could be a less weathered rock formation in this area, as a high resistivity value (> 4000 Ωm) was observed at a depth near the ground surface. PDL1, located at 590 m at approximately 20 to 30 m depth, is the most probable groundwater potential zone. A low chargeability value (< 7.5 ms) indicated the presence of a water-containing zone. Similarly, weathered granite rock is associated with the water-containing zone at this survey line.

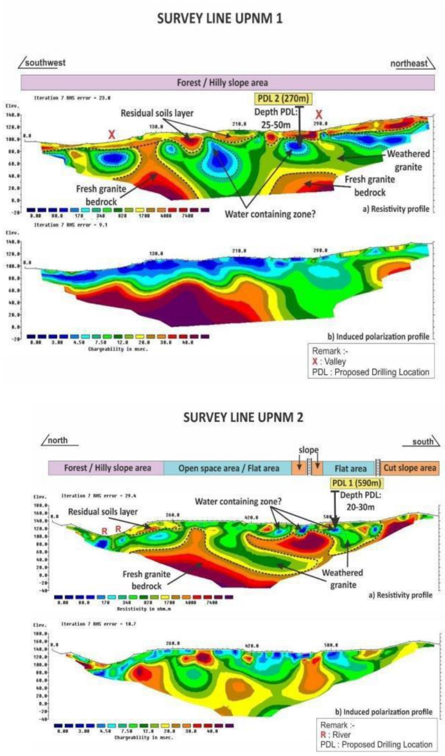

Figure 7. Survey lines UPNM1 and UPNM2 resistivity and IP profile

Data verification is essential to accurately predict the groundwater potential zone on the UPNM campus to locate a possible location for drilling tube wells successfully. The geophysical survey results were used to cross-validate the groundwater potential zone map. As illustrated in Figure 8, the GWPM agreed well with the electrical resistivity and IP results. Both methods reported the existence of groundwater in the northeast and southeast parts of the Bukit Gemilang stretch. Several shallow aquifers were identified and located at less than 50 m depth. It is recommended that a detailed investigation be conducted using a conventional method, such as drilling a tube well at PDL 1 and PDL2, to determine its capacity and recharge rate.

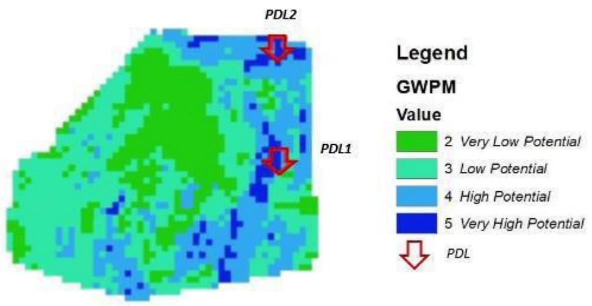

Figure 8. Comparison of geospatial and geophysical survey results for potential groundwater zones on the UPNM campus

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4. Conclusion

In this study, the integration of remote sensing, GIS, and geophysical survey was implemented to determine the groundwater potential zone on the UPNM campus. Five predominant groundwater parameters delineated the resulting GWPM: lithology, land use land cover, slope, elevation, and lineament. Next, the groundwater prospect zones were categorized into four distinct regimes: very low, low, high, and very high. Based on the findings, 5.73% of the groundwater potential was classified as very high, followed by 25.94%, 42.9%, and 25.41% for high, low, and very low potential, respectively.Meanwhile, the geophysical survey was conducted at two traverse lines, UPNM1 and UPNM2, using pole-dipole and dipole-dipole arrays. Both lines had a high resistivity value of more than 4000 Ωm at different depths, interpreted as fresh granite rock. The 2D resistivity images showed a water-containing zone at a shallow depth of fewer than 50 m within the study area. Additionally, IP results were used to support the interpretation. Therefore, this study revealed good agreement between geospatial and geophysical results. Both methods demonstrated that the northeast and southeast parts of the Bukit Gemilang stretch have a high potential for groundwater existence.

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