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# Mapping of Groundwater Potential Zones in a Crystalline Terrain Using Remote Sensing, GIS Techniques and Field Observations: A Case Study in Parts of Tanah Merah, Kelantan, Malaysia

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**Abstract.** Identification of potential groundwater exploration sites is a difficult activity in hard rock terrain. Groundwater occurs in hard rocks at secondary porosity developed due to weathering, fracturing, faulting, etc., and this is highly unpredictable and varies dramatically within very short distances, leading to the near-surface aquifer. Topographic, hydrogeological, and geomorphological features in these cases offer valuable clues for the identification of the appropriate location. The present investigation is confined to latitude 5° 45' 10.508'' N and 5° 47' 53.309'' N and longitude 101° 56' 29.001'' E and 101° 59' 12.249'' E. All across Telaga Bijih Area, Tanah Merah, Kelantan, this research focuses on the terrain investigation of groundwater potential zone by applying the geological mapping method and Geographical Information System (GIS) analyses. Briefly, derived from satellite imagery, topographic, geomorphological and hydrogeological observations, promising locations were delineated in hard rock areas of Telaga Bijih village and its surroundings. Several thematic layers including lineament density, lithology, drainage density, and slope density were created for this purpose using the Geographic Information System (GIS) application to generate groundwater potential zonation map. The final map of groundwater potential plays a key role while narrowing down the selection of potential zones in the study area. The present investigation is very significant in pinpointing the sites for the establishment of new groundwater wells. The areas in north-western and south-eastern parts around Kelisar, Gual and Air Chanal villages are very promising for groundwater exploration. The establishment of new wells will not only make sure the continuous supply of water to the local people but can also be exported to the other places in the vicinity, thus can prove pivotal in revenue generation.

## 1. Introduction

According to [1], the term of hard rock was initially used by the drillers to refer the poor drill ability across different types of rocks. Most of the hard rocks can be classified as crystalline igneous and metamorphic rock. This hard rock is characterized by insignificant primary porosity and primary



permeability. However, with the effect of deformation and weathering of consolidated rock leads to the development of fractures on the surface of the rock. These fractures significantly promote the percolation of water which enhances the groundwater potentiality of the aquifer in the area. On the other hand, these rocks hydraulic properties are primarily regulated by fracturing and are thus often referred to as fractured rocks. These fractured rocks will provide secondary porosity which enables groundwater transport in rocks. In the present investigation, tools such as the Geographical Information system (GIS) will be applied in conjunction with field inputs to get the basic information and data of groundwater aquifer potential. According to [3,8,13,15,16], This GIS method enables for the fast and cost-effective survey and management of natural resources. Additionally, it has been shown that remotely sensed data is an effective technique in groundwater prospecting surveys. From the last few decades, this GIS method and data have been increasingly used in groundwater targeting exercises [9]. In the earliest researching [2,12,13] all have applied this method for groundwater studies. So, in other words, it can save cost, time, energy and manpower in the research. In addition, this method is preferably adopted taking into account the use of data in fairly accurate hydrogeomorphological assessment and the identification and delineation of land characteristics [10].

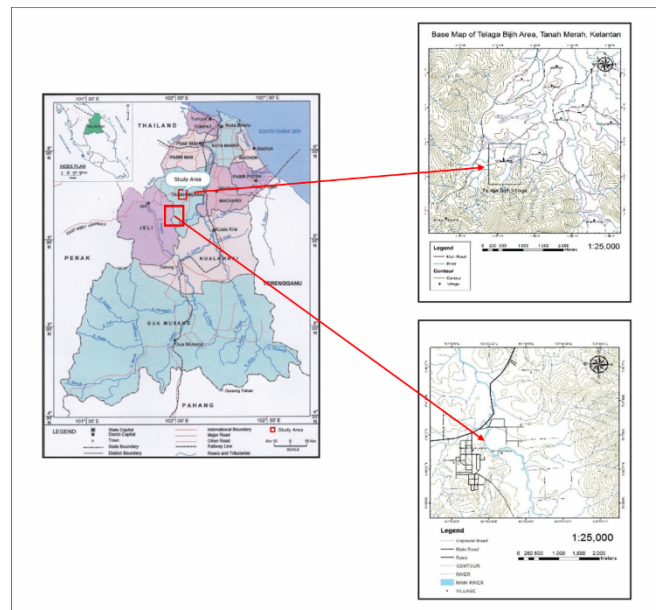
## 2. Objectives and study area

### 2.1 General

The primary purpose of the study is to come out with systematic groundwater exploration by utilising surface investigation and the Geographic Information System (GIS) in the delineation of potential groundwater areas. The main area of research located in side-by-side at Tanah Merah District. The study area lies between latitude  $5^{\circ} 45' 10.508''$  N and  $5^{\circ} 47' 53.309''$  N and longitude  $101^{\circ} 56' 29.001''$  E and  $101^{\circ} 59' 12.249''$  E in Telaga Bijih area side and lies between latitude  $5^{\circ} 45' 45''$  N and  $5^{\circ} 48' 15''$  N and longitude  $101^{\circ} 52' 45''$  E and  $101^{\circ} 56' 0''$  E in Ayer Lanas area side (Figure 1). The targeted research area is situated 70 km from Kelantan's main capital, Kota Bharu, which can be reached via East-West Highway. The area experiences moderate climatic conditions as it is situated in tropical zones climate, with temperature ranging between  $30^{\circ}\text{C}$  to  $35^{\circ}\text{C}$  as obtained from the Malaysian Meteorological Department. The main focus in this current research is on surface investigation specifically to identify structures such as joints, fractures and other minor structures. The research covers an area of  $25\text{ km}^2$  around Telaga Bijih village and Ayer Lanas village. The zone is surrounded by the mountainous hill known as the forest reserve Jedok and the Sator river is one of the rivers that flows from the west to the north part of the Telaga Bijih area.

### 2.2 Geology

Geologically the area consist of mainly similar to Kemahang granite rocks, which consists of irregular granite mass that eventually results in mountain range forms. The Kemahang Granite is typically made up of a coarse-grained to porphyritic biotite granodiorite where the feldspar phenocrysts frequently exceed 10 cm length. This mountainous range extends until to Sukhirin range that is located in Thailand. Towards the south of the Tanah Merah – Jeli Road the granite is easy to found along the road where Bukit Kemahang is the highest peak. According to [11], stated that the age of Kemahang granite is Triassic. According to field observation [5], the Sukhirin granite can be correlated with Tan Yong granite pluton, which resulted in the intrusion of Sukhirin granite occurred in the Triassic period. The Kemahang granite showing grey, medium- to coarse mega cristicbiotite-hornblende granite to granodiorite and this type of intrusive rocks are distributed around Bukit Jeli, Bukit Kemahang, Bukit Kusial and also some several smaller hills as obtained from the Mineral and Geoscience Department.



**Figure 1.** Location map of the study area

### 2.3 Hydrogeology

In the study area, groundwater occurs under the granitic basement. Lithological restrictions determine that the presence of groundwater is in the rock joint and fracture portions on the rock surface. Therefore, the groundwater formed in the study area is mainly confined in the secondary porosity zones in the hard rocks that formed due to fractures, joints and weathering. Based on a hydrological perspective, the intensity and degree of jointing, fracturing and flow contacts and weathering along the hard rock are the most important parameters that impart permeability and porosity for the creation of an effective groundwater aquifer in the granite.

### 3. Methodology

The research methodology includes various tasks such as preparations for base maps, map updating according to field observations, digitization and processing of images using map software and interpretation (see Figure 2). The initial stage is comprising the creation of a spatial database using a 1:50000 scale survey of Kelantan toposheet. GIS is applied to create various thematic maps regarding groundwater like drainage, lineament density, lithology, drainage density, and slope density. Besides that, the land use survey map, geological map and 3 dimension topography map are produced to describe the terrain of the area.

The second stage involved preparing the Digital Elevation Model (DEM) by inputting the contour map, which is digitized from the toposheet of Kelantan. DEM is applied to create slope order to prepare future runoff map for an engaged drainage basin. Digital image processing of the satellite data for geo-referencing and correction is performed in the third stage. Following this, various thematic layers are generated using a supervised classification approach. Then it will be continued by the producing of other important data that will be used at the later stage to determine the groundwater potential such as land use map, geological map, lineament map, geomorphological map and hydrogeomorphological map.

In the fourth stage, all of the above maps are further analyzed in overlay and ranking is applied to determine viable groundwater potential areas. In the end, all the thematic layers including

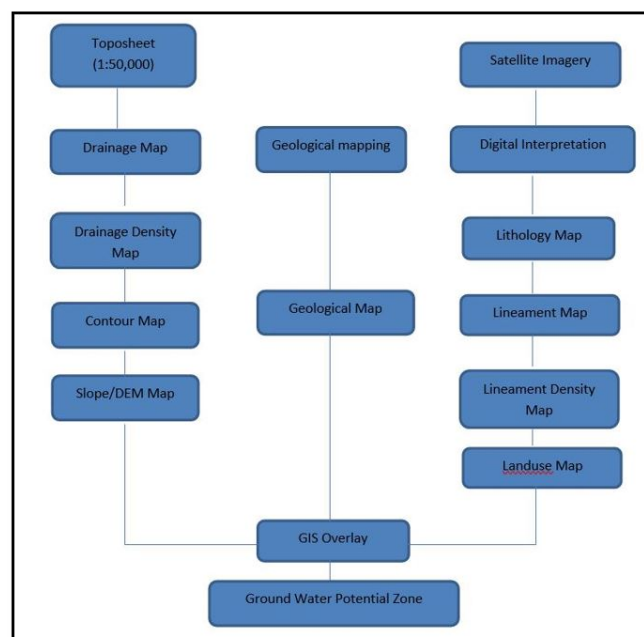
geomorphology, slope, drainage density, land use, geology, and lineament density will overlay using GIS to enhance the outcome of potential groundwater zones.

#### 4. The parameter used in producing a potential map

##### 4.1 Drainage and drainage density map

A drainage basin is a natural setting where the runoff water is drained to a central element. These maps are composed of water bodies, rivers, tributaries and streams. Network drainage helps to delineate watersheds. Drainage density and type of drainage give ripple, infiltration, and permeability related information. Dendritic drainage suggests homogenous rocks while structural and lithological controls are shown by the trellis, rectangular and parallel drainage patterns texture of the coarse drainage suggests extremely porous and permeable rock formations while the texture of the fine drainage is more typical in less pervious formations. Significant faults and lineaments often link two or more drainage basins and work as channel ways of connectivity. There is a proven fact that groundwater also flows in these weak zones of faults and lineaments area. The drainage pattern illustrates both surface morphology and also the formation of a subsurface [8].

The drainage density shows the closeness of the channel spacing and the quality of the surface material, thereby offering a quantitative indicator of the total stream channel length for the entire basin. From the measurement of the drainage density over a broad range of geological and climatic types, it has been observed that a low drainage density is much more likely to take place in highly permeable subsoil material under complex vegetative cover where relief is low. The effect of poor or impermeable subsurface soil, sparse vegetation and mountainous relief is believed due to the high drainage density. Low drainage density leads in coarse drainage texture, whereas high drainage density resulting in a fine texture of drainage. The density of drainage describes the runoff in an area, in other words, the quantity of relative rainwater that may have penetrated. Therefore, the lower the drainage level the higher the probability of restoration or potential groundwater environment.



**Figure 2.** Flow chart of the methodology

##### 4.2 Slope map

The slope is one of the essential terrain parameters that is clarified by contour horizontal spacing. In general, closely spaced contours reflect steeper slopes in the vector form and sparse contours show gentle slope, while each cell has a slope value in the elevation output raster. The lower slope values here reflect the flatter ground (gentle slope) and the higher slope values refer to the steeper slope of the ground. The slope is determined in the elevation raster by identifying the maximum rate of value shift from each cell to neighbouring cells.

#### *4.3 Lineament and lineament density*

Lineaments are straight linear components recognizable as important "lines of the landscape" on the Earth's surface [7]. Those are mainly a result of the discontinuities caused by geological or geomorphic processes on the Earth's surface [4]. Including faults, shear zones, cracks, dykes and veins as well as bedding planes and stratigraphic contacts, these are examples of geological structures that create lineaments. Geomorphic elements, which exist as lineaments on the maps, include streams, linear valleys and ridgelines, aerial photographs and satellite photos. In the present analysis, satellite image extracts area lineaments. All lineaments are related to the geomorphic lineaments. An area's lineament density has a direct influence on that area's groundwater prospectiveness. At present, the area of study with very high lineament density has good groundwater potential whereas an area with very low lineament density has poor groundwater potential.

#### *4.4 Geomorphology*

Geomorphology is the study on how the earth is formed which included its origin and regeneration [6]. Geomorphology studies is a component of earth science that evolved after the introduction of aerial photographs or satellites images and data obtained from satellites. In addition, geomorphology has become one of the important inputs in preparing for various tasks along with data on soil, water, and vegetation. In general, structural evolution in a geological formation plays a role in determining the geomorphology of an area. Geomorphology represents various characteristics of land and structure and mostly many of the characteristics are suitable for groundwater occurrence and graded according to its potential for groundwater accumulation in the area.

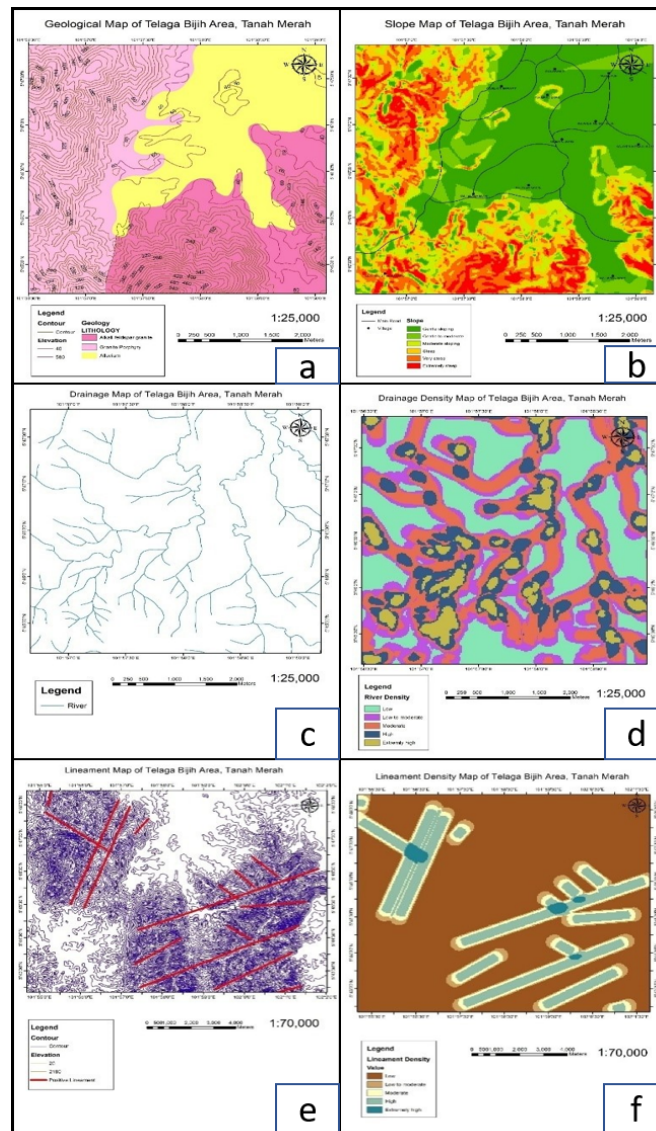
#### *4.5 Land use/ land cover*

Mapping of land use/ land cover is one of GIS's main applications. Land use plays a major role in groundwater resource development. In the water cycle, it regulates several hydrogeological processes such as water absorption, evapotranspiration, surface runoff etc. The surface cover gives surface roughness, thus minimizing the water discharge and increases the infiltration. The rate of infiltration will increase and runoff will decrease in the forest areas while in contrast the infiltration rate decrease in many major cities. Thus, GIS provides great information about the spatial distribution of vegetation type and land use in less time and low-cost relative to conventional data.

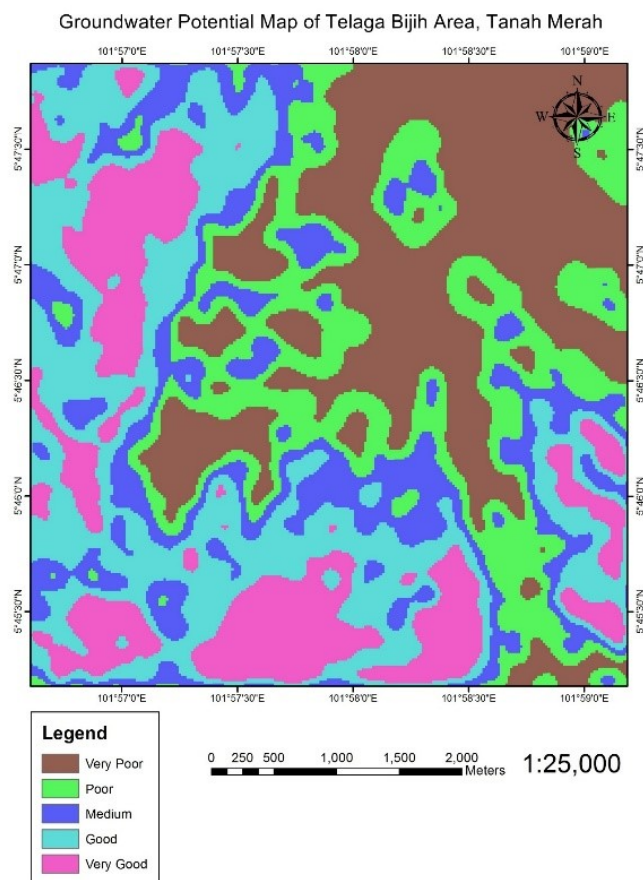
### **5. Groundwater potential map**

The data of groundwater potential zones are acquired by overlaying all the thematic maps using the spatial analysis tool in ArcGIS 10.1 in terms of the weighted overlay method. All the thematic maps are converted into raster format and superimposed by the overlay method. The optimum rating is provided to the attribute with the highest groundwater potential as well as the minimum presented to the least potential feature. The groundwater potential map has been classified into five main classes which are very poor, poor, medium, good and very good. This class was classified according to the most potential area for groundwater occurrence. This map was built by referring a parameter such as a lineament density, slope, lithology, and drainage density of the study area. According to Figure 4, the most potential groundwater occurrence was located at the North-West, South-West, South, and South-

East area. These groundwater potential areas were located at the hill environment areas where most of the elements for the occurrence of groundwater can be found, such as lineament, crack and fracture, while the low potential area which is located at the North-East area showing very poor too poor classes of groundwater potential. This type of potential map plays a very important role in locating domestic well for the villagers. This study is believed to provide very vital information to the decision-makers and will meet the groundwater demands in the entire area to a great extent, and this study will be used as references as far as the future investigations are concerned.



**Figure 3.** Reclassified map, a) Geological map, b) Slope map, c) Drainage map, d) Drainage density map, e) Lineament map, f) Lineament density map.



**Figure 4.** The groundwater potential map of the study area.

## 6. Conclusion

The results of this analysis indicate a discontinuous hydrogeological network, which is exposed by conditions of low water levels. Through emphasizing on the integration of the fracture network, we were able to highlight the system's compartmentalisation. Firstly, we demonstrated that the granite is laterally well connected as a permeable zone. Besides that, this research has investigated the relation of structural elements, especially lineaments to potential zones of groundwater development. The present studies show that potential zones are well correlated with the zones having a high density of lineaments in the study area. The outcome of the lineament and fracture studied suggested that the region that has various long and short features which most of the structural patterns are primarily in the direction of N-S and E-S. The lineaments are relatively more across the western and eastern parts but less than in the central, northern, and southern parts. The high lineament density areas are ideal areas within the study area for groundwater prospecting. Most of the main lineament orientation in the area was observed effectively from the aerial photographs and modified in the GIS software. The study findings show that GIS software application could even extract lineament trends in an inaccessible area. Therefore, it is suggested that the detection of high lineament density using GIS approach should also be integrated with the application of remote sensing technique to obtain a more precise assessment of the study area's groundwater potential. Also, to delineate the study area's groundwater availability, multiple thematic maps such as a base map, lithological map, geological structural map, geomorphology map and hydrological map were designed using Arc GIS



software from the topographic maps, geology maps and hydrogeomorphology maps, and these maps are combined to create a groundwater prospects map. Finally, in the end, the groundwater prospect map is a suitable way which shows hydrogeomorphological aspects that are important as its foundation for groundwater exploration planning and execution.

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