

## Using the Arau Model to Locate Groundwater Potential Zones in the Northern Regions of Malaysia

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### Abstract

A major portion of water demand in most states in Malaysia is being supplied from surface water sources. These sources are deemed inadequate to fulfil the water demand for the future. Water supply for Perlis which is situated in northern Malaysia is mainly supplied from surface waters with groundwater supplementing this supply for localised use. In this study using an integration of remote sensing and Geographic Information System (GIS) techniques, groundwater potential zones were positively identified resulting in significant savings of resources. The Weighted Linear Combination (WLC) Method in GIS was used to predict potential groundwater zones in the study area based on a new mathematical model. This model called the Arau Equation for Groundwater Potential was applied where six parameters were identified based on Civil Engineering principles. This study investigated the analysis using GIS of landuse produced from a SPOT remote sensing image of Perlis, together with secondary data which consisted of geology, topography elevation, slope distribution, drainage distribution and rainfall distribution data. These data were analyzed to produce thematic maps. In the final analysis specific areas were identified as zones of very high, high, moderate or low in terms of groundwater yield. A reliability of 79% was achieved using the Reliability Analysis when compared to historical data on groundwater boreholes and tubewells in the study area.

Keywords: Groundwater potential, GIS Analysis, WLC, Arau Model, Perlis

### Introduction

In many parts of the world groundwater forms a major alternative source of clean water for domestic and industrial usage. A majority of areas contain groundwater, hence much research has been carried out to study its presence and to exploit it for various uses. Allah says to mankind, in the Quran in verse 22:63 and verse 39:21, that do we not see that He sends down rain from the skies and flows it through springs inside the earth. With this water He causes vegetation and plants to grow and the earth to green. And in verse 23:18 where He says that He sends down this rain in fixed measures and causes it to soak into the soil for storage (Malik, 1997).

Although groundwater forms an alternative source and is present in abundance, its development has been slow where in most parts of Malaysia, groundwater resources are still much underutilized (Jasni *et al*, 2006). Usage of groundwater in Malaysia is currently

less than 2%, where the use of groundwater is mostly for domestic purpose and mainly confined to the rural areas where there is still no piped water supply (Suratman, 2007). The extensive use of groundwater at present is mainly confined to the Malaysian states of Perlis and Kelantan. Water supply for irrigation and domestic use in Perlis is mainly supplied from surface waters from the Muda, Pedu (Kedah) and Timah Tasoh (Perlis) dams. Malaysia is water-stressed, and recent severe droughts have caused these dams' water levels to drop drastically. If groundwater can be a viable alternative source of supply for multi-purpose usage, it can be better exploited if potential areas with abundant groundwater can be identified. However existing methods of identifying potential groundwater areas are time consuming and costly, hence there is an urgent need to replace or complement these by devising a new improved approach such as one based on using relatively new technologies such as Remote Sensing and Geographic Information System (GIS).

In general this study aimed to determine areas deemed most potential to contain groundwater using the integrated approach of Geographic Information System (GIS) and Remote Sensing. To date no previous study to identify the potential areas which may contain large amounts of groundwater have been carried out in Perlis using this method of integration of Remote Sensing and GIS, although a previous researcher Khairul *et al* (2000) had employed a similar study technique in the Langat basin. The potential of groundwater availability in geological strata of the study area such as alluvium and other formations peculiar to Perlis (such as the Setul limestone and Chuping limestone hardrock, Bukit Arang coal beds and the Kubang Pasu -Singa formation) needed to be investigated. There are available groundwater resources in Perlis which can be utilized to supplement surface water sources to meet future demands of water.

The main objectives of this study were first to develop an integrated Remote Sensing and GIS technique as a new and reliable technique to establish a prediction model to identify groundwater prospective zones in Perlis. Next was to determine the most effective supporting parameters needed to be included in the groundwater prediction model of the study area based on the technique of integration of Remote Sensing and GIS. Finally the study validated the ability of the prediction model to identify groundwater potential zones for future exploration and hence the viability of the technique. It is foreseen that this study can contribute towards formulating a comprehensive and integrated approach for holistic groundwater exploration and also enhancing the regulation and management of water-deficient situations or water stressed areas in future.

## Research Method

Remote Sensing is a technique of obtaining information about objects through the analysis of data collected by instruments not in physical contact with the objects of investigation. Advancements in satellite technology, sensor technology and computing have led to the creation of a new discipline affecting geomatic science and civil engineering. Remote Sensing with its advantages of spatial, spectral and temporal availability of data covering large and inaccessible areas within a short time, has become a very effective tool in assessing, monitoring and conserving groundwater resources. Digital image processing carried out with suitable computer software and hardware is a crucial stage in the effective use of satellite data. Image restoration processing usually consisted of geometric corrections before any image enhancement was carried out. Interpretation of the image may be done by a

classification process which may be either by method of supervised or unsupervised classification. In the unsupervised classification process used in this study computers were employed to analyze all pixels in the image and clustered them into several distinct classes where the researchers then had to determine the nature of each class.

Geographic Information Systems (GIS) is a tool for storing, manipulating, retrieving and presenting both spatial and non spatial data in a fast, efficient and organized manner. The term “geographic” or “geographical” in GIS refers to the locational attributes that define the spatial positioning of any piece of information on the face of the earth. GIS serves as a computer system capable of assembling, storing, manipulating and displaying geographically referenced information, i.e. data identified according to their locations. Maps and other data when stored as layers of information in GIS makes it possible to perform complex analyses such as information retrieval, topographical modelling, networks, overlay and data output. The main task for the GIS was to carry out the processing where the processing enabled building of the database, where all appropriate data had to be compiled together into a GIS database.

Digitizing of all existing data and relevant processing such as transformation and conversion between raster to vector format, gridding, buffer analysis and interpolation was conducted in this study. The output of this process was the production of a number of thematic layers which were used in the subsequent analysis. The satellite imagery, digitized geological maps and topography maps were analysed and used to generate the necessary data layers to satisfy various conditions within the established criteria. GIS was used to develop a computerized groundwater model, where this computer model represented a physical system that approximated or reflected specific behaviours of that system.

Remote Sensing and GIS were chosen as the tools to be used in this study because from the literature reviewed it was apparent that Remote Sensing and GIS did have the capability of providing the necessary data and the ability of processing and analyzing to achieve the study objectives. However previous studies by researchers who had used Remote Sensing and GIS as tools to identify groundwater were not based on relevant civil engineering principles. In this study Darcy's Law was identified as a relevant civil engineering principle related to groundwater. These principles were applied in the GIS analysis of the geology data.

Two main computer softwares were used for database building, i.e. Erdas Imagine 8.6 and ArcGIS 9.2. Both softwares were needed to support each other where Erdas Imagine 8.6 was used to process the Remote Sensing imagery while ArcGIS 9.2 was used to build the spatial geo-database and do spatial analysis. All spatial data used needed to be scanned using a scanner or digitized before using the Erdas Imagine software to register the spatial data into a local coordinate system to enable processing to be carried out. The satellite image was classified using the same software before the geospatial database was uploaded into the GIS system.

All data were processed and manipulated in line with the research objectives. Then GIS was used in the analysis of the spatial and attribute data to produce different digital thematic maps. In this study a total number of six digital maps were produced from the available spatial data and attribute data. These digital maps were known as thematic maps since each map was based on one specific theme. They were a Landuse map, Geology map, Rainfall distribution map, Topography (elevation) map, Slope steepness map and Drainage density map of the study area. The Landuse Map was produced from the analysis of a French SPOT (*Système Pour l'Observation de la Terre*) 3 band multi-spectral satellite image of the study area. The Rainfall Distribution Map was produced from the GIS analysis on rainfall gauge data collected by Department of Irrigation and Drainage (JPS) Malaysia between 2001 to 2004, while the other four thematic maps were digitized from printed (hardcopy) versions. All data were analyzed using the Overlay Method in GIS.

In this study a new mathematical model (called the Arau Model for Groundwater Potential) was proposed by the researchers. Further GIS analysis was then employed based on this model to predict the groundwater prospective zones in the study area. The output of this model was a digital map of Perlis indicating the most potential areas to contain groundwater. The Arau Model for Groundwater Potential can be stated below:

$$GP = (1)Lu + (2.1)Ge + (1)Rf + (1)Te + (1)Ss + (1)Dd$$

- Where GP= Groundwater Potential
- Lu = land use
- Ge = geology
- Rf = rainfall
- Te = topography elevation
- Ss = slope steepness
- Dd= drainage density

Finally data on actual locations of available boreholes

and tubewells in the study area were sourced from the National Water Resources Study, Malaysia 2000-2050 (EPU, 2000) which were used in the Reliability Analysis. To determine the reliability of the new Arau Model, the Perlis map of groundwater potential areas was overlaid with the digital map of the actual locations of boreholes and tubewells to determine whether there was a significant match between the actual data and the result of the analysis.

### Study Area

The study area encompassed the entire state of Perlis, Malaysia where Perlis is bounded between latitudes 5° 05' and 6° 35' and between longitudes 99° 35' and 100° 50'. The state of Perlis lays in the driest part of Malaysia, hence water resources availability remains a problem. It is the smallest state that lies at the north-western tip of Peninsular Malaysia and covers a small area of 795 sq. km with a population of 190,000 (as per census conducted in 1991) and is expected to reach 490,000 in 2050. The physical makeup of Perlis, which is mountainous and undulating in the north and gradually levels in the central and southern regions, is considered a potential area for groundwater catchment. Figure 1 below shows a location map of the study area.

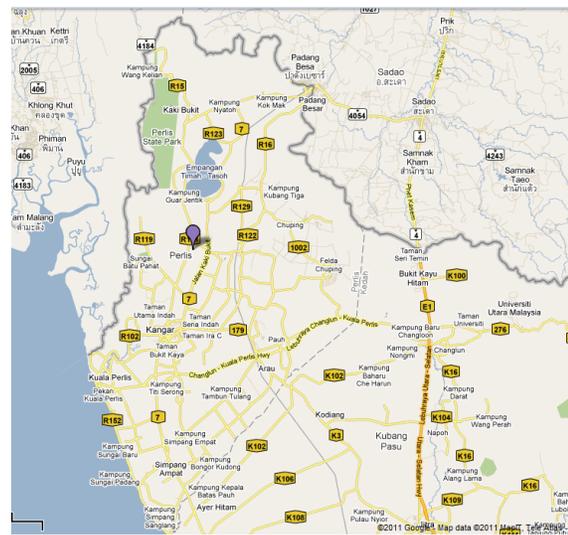


Figure 1: Location Map of the Study Area –Perlis (source: Google Maps, 2011)

### GIS Database

Two main types of data were involved in the GIS database development. First was the spatial (space) data which involved data on the shape, elevation and ground surface of the state of Perlis. Here the relevant spatial data chosen were Topography Map, Geology Map, a SPOT (*Système Pour l'Observation de la Terre*) 3 band

multi -spectral satellite image of Perlis, Road Map of Perlis and Location Map of boreholes and tubewells in Perlis. While attribute data, which was data giving more information on the phenomena stated in the spatial data selected for this study were rainfall data, data on groundwater yield of boreholes and tubewells and also geological data. Some of the data needed in this study were only available in the form of printed or hardcopy maps. These maps first had to be scanned with a digital scanner and saved into the GIS system together with all other spatial and attribute data.

A landuse map of Perlis was produced resulting from the unsupervised classification process carried out on the satellite image. Figure 2 below shows the SPOT multi -spectral satellite image of the study area used. In this study the unsupervised classification process had been chosen where essentially this classification was fully carried out by the computer software. However before the classification process could begin the user must first determine the required number of classes. Here six classes were selected to represent the major landuse of Perlis namely Water bodies, Human settlement areas, Forested areas, Paddy planted areas, Sugar cane plantations and Rubber plantations.

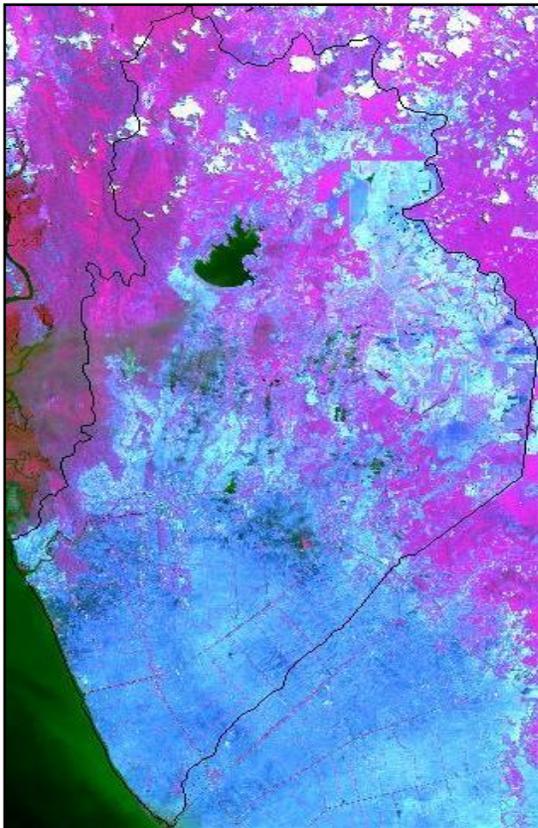


Figure 2: Satellite image of Perlis (source: SPOT, 2005)

Using the Multi Criteria Evaluation (MCE) technique, a weightage value between 1 to 9 was assigned to the data layers to reflect their relative importance. MCEs are numerical algorithms that define the suitability of a particular solution on the basis of the input criteria and weight together with some mathematical or logical means of determining tradeoffs when conflict arises. In the GIS analysis carried out in this study, the weight age value for each layer was based on the 'k-value' or the Hydraulic Conductivity (k) as included in Darcy's Law of each geological formation. Hydraulic Conductivity is also known as Coefficient of Permeability and is defined as the volume of groundwater flow per unit time through a unit cross-sectional area normal to the direction of flow under a unit hydraulic gradient.

The 'k-value' is used as a measure of the resistance to flow offered by the soil and is affected by several factors: porosity, particle size distribution, shape and orientation of soil particles, degree of saturation of water, thickness of absorbed layers associated with clay minerals if present and viscosity of soil water (Whitlow, 2001). An example of weightage values used in the GIS analysis of geology layers as tabulated in Table 1 below were based on representative values sourced from Whitlow (2001).

#### *GIS Analysis using Weighted Linear Combination (WLC) Method*

Using a Weighted Linear Combination (WLC) Method of the Arau Model, a higher influence was assigned to one parameter over the others. Here the geology parameter was chosen to be given an increased weightage of 30%, which translated into a weightage factor of 2.1, compared to the other 5 parameters which were given a weightage factor of 1 as shown in Table 2 below. In this method the total sum of the weightage must be 100%. Geology was chosen over other parameters based on previous literature which stated that geology, in terms of rock and soil properties had a fundamental influence on the presence of groundwater. All the relevant data were uploaded into the GIS system before analysis was carried out using the 6 thematic maps: landuse, geology, rainfall distribution, topography (elevation), slope steepness and drainage density.

#### **Discussion on proposed Arau Model for Groundwater Potential**

Figure 3 showed the results of the GIS analysis where the areas marked in dark blue formed the very high potential (VH) and high potential (H) areas for

groundwater, while the light blue coloured areas indicated the moderate (M) and low (L) potential areas.

To determine the reliability of the proposed model, the analysis output from this study i.e. the Map of Potential Groundwater Zones, was digitally overlaid with the location data of all available boreholes and tubewells in Perlis using GIS. Over the years a large number of boreholes and tubewells have been drilled in Perlis by various government agencies. Of these only a total of 8 boreholes and 25 tubewells are currently producing and could be located. Figure 4 shows the

location of all identified boreholes and tubewells in the study area.

The result of reliability analysis carried out by overlaying these locations with the Weighted Linear Combination model was as shown in Figure 5 below. It was shown that the Weighted Linear Combination (WLC) method based on the Arau Model had managed to achieve 79% reliability, as evident from Table 3 below.

Table 1: Example of Weightage Values used for GIS layers in Geology

Features	Materials	Hydraulic Conductivity, k (m/day)	Weightage (1-9)
Alluvium	Sand-Clay-Mud	45	8
Chuping Limestone	Limestone	0.94	7
Granite	Granite	1.4	1
Kubang Pasu and Singa Formations	Mudstone-Siltstone	0.08	2
Setul Formation	Limestone	0.94	7
Bukit Arang Beds	Gravel-Sand-Clay	150	9

Table 2: Weightage assigned to parameters according to WLC

Parameter		Weightage (%)	Weightage Factor
Landuse	Lu	14	1
Geology	Ge	30	2.1
Rainfall	Rf	14	1
Elevation	Te	14	1
Slope Steepness	Ss	14	1
Drainage Density	Dd	14	1

Table 3: Reliability Analysis by Comparison of Result from the GIS analysis

Total No. Of Boreholes and Wells in study area	No. Of Boreholes and Wells included in VH and H zones	No. Of Boreholes and Wells not included in VH and H zones	Percentage of Boreholes and Wells included in VH and H zones	Reliability of Method
33	26	7	79%	79%

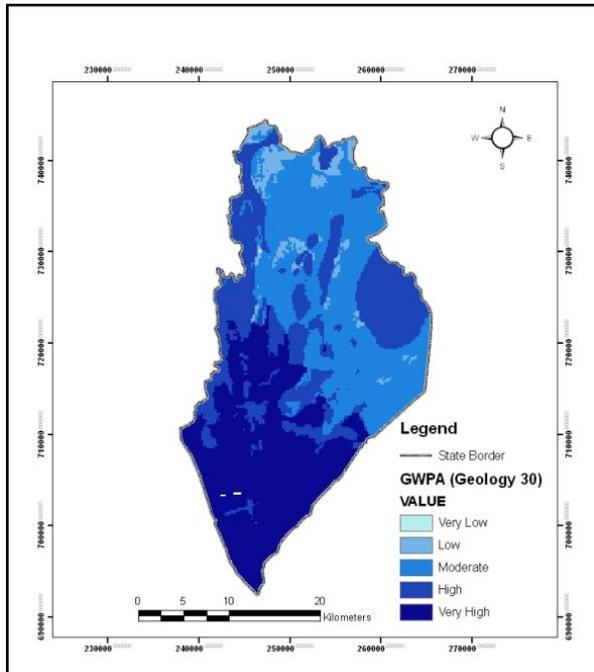


Figure 3: Groundwater Map based on WLC Method produced in this study

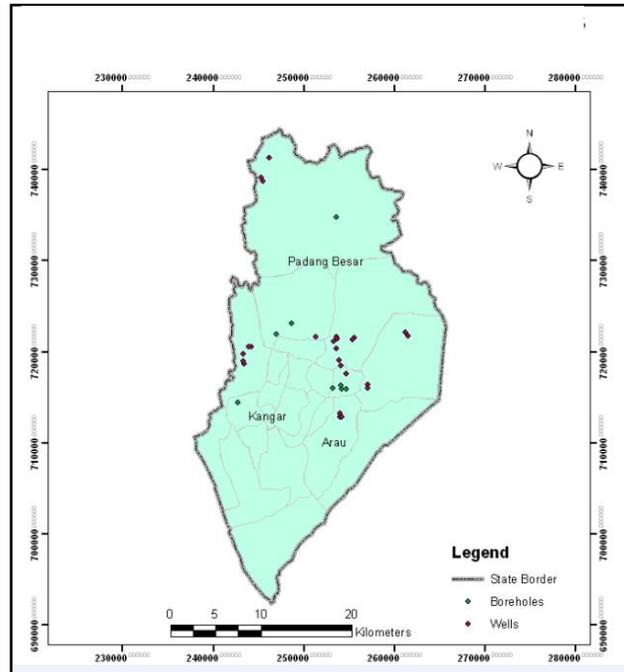


Figure 4: Map of Boreholes and Tubewells in Perlis

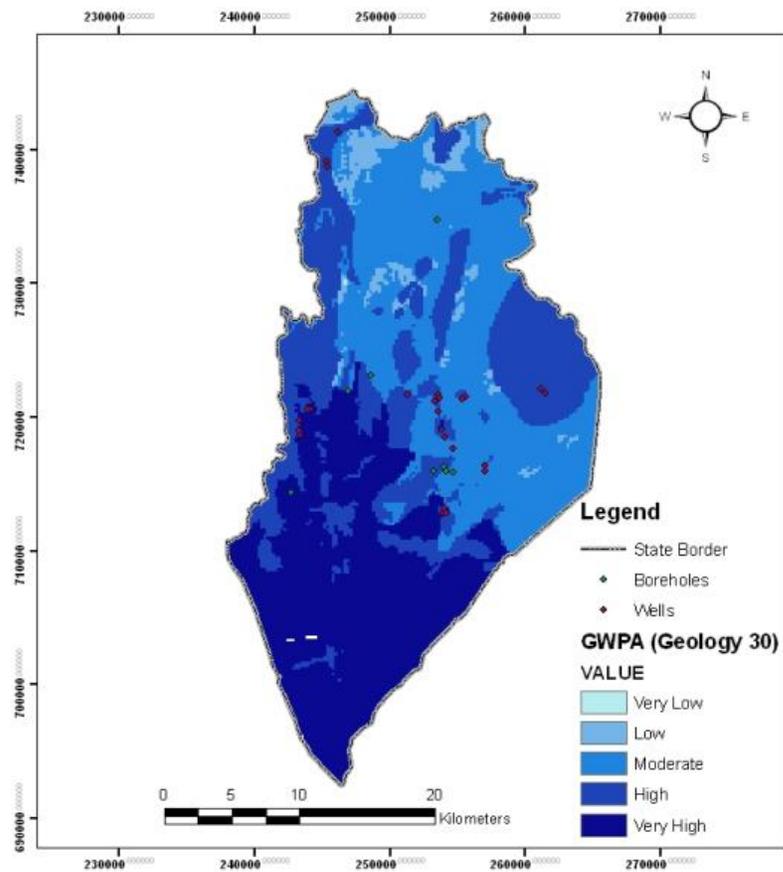


Figure 5: Reliability Analysis showing Most Potential Groundwater Zone in Perlis based on WLC overlaid with Location of Boreholes and Wells

## Conclusion

In conclusion this study showed that the Weighted Linear Combination (WLC) method based on the Arau Model had managed to achieve 79% reliability. This achievement was deemed sufficient to imply that the method employed in this study was successful. The study indicated that potential areas were located mainly within the alluvium, Setul limestone and Chuping limestone formations and the Bukit Arang semi-consolidated formation, where previous studies (EPU, 2000) had indicated these geological formations were expected to be capable of providing an estimated total groundwater yield of about 44 million litres per day.

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