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GIS Aided Groundwater Potential Mapping of the Langat Basin

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Abstract

Groundwater constitutes an important source of water supply for various purposes, such as domestic industries and agriculture needs. In the hydrological cycle, groundwater occurs when surface water (rainfall) seeps to a greater depth filling the spaces between particles of soil or sediment or the fractures within rock. Groundwater flows very slowly in the subsurface toward points of discharge, including wells, springs, rivers, lakes and the ocean. In this study, the integration of remote sensing and geographic information system (GIS) methods were used to produce a map that classified the groundwater potential zone to either very high, high, moderate, low or very low in terms of groundwater yield. Almost all alluvial plains have a high potential of groundwater occurrence. Meanwhile, in the hard rock areas, groundwater potential is in the high density lineament zones.

Bantuan GIS Dalam Pemetaan Air Bawah Tanah di Lembangan Langat

Abstrak

Air bawah tanah merupakan punca utama sumber air untuk pelbagai keperluan seperti industri domestik dan pertanian. Dalam kitar hidrologi, air bawah tanah wujud apabila air permukaan (hujan) menyusup masuk ke kedalaman yang dalam dan mengisi ruang diantara butiran tanah atau sedimen atau rekahan diantara batuan. Air bawah tanah mengalir dengan sangat perlahan di subpermukaan sehingga kepunca pengeluarannya termasuk perigi, punca mata air, sungai, tasik dan lautan. Kajian ini merupakan integrasi kaedah penderiaan jauh dan sistem maklumat geografi (GIS) untuk membina peta pengelasan zon potensi air bawah tanah kepada sangat tinggi, tinggi, sederhana, rendah dan sangat rendah dalam aspek kewujudan air bawah tanah. Daripada hasil ini hampir keseluruhan aluvium rata mempunyai potensi tinggi kehadiran air bawah tanah. Manakala, dikawasan batuan keras, potensi air bawah tanah terdapat dibahagian ketumpatan zon lineamen yang tinggi.

INTRODUCTION

Groundwater forms the part of the natural water cycle, which is present within underground strata. The principle sources of groundwater recharge are precipitation and stream flow (influent seepage) and those of discharge include effluent seepage into the streams and lakes, springs, evaporation and pumping (Gupta, 1991). Ground water cannot be seen directly from the earth's surface, so a variety of techniques can provide information concerning its potential occurrence. Geological methods, involving interpretation of geologic data and field reconnaissance, represent an important first step in any ground water investigation. Remote sensing data from aircraft or satellite has become an increasingly valuable tool for understanding subsurface water condition (Todd, 1980). They are particularly useful, very detailed and also show up features which cannot be seen easily on the ground. The various surfacial parameters prepared from remotely sensed data and ancillary data can be integrated and analyzed through GIS to predict the potential of the ground water zone.

OBJECTIVES

The objectives of this study are as follows:

i. To collect the ancillary data and to analyze the remote sensing data for getting information that is related to groundwater occurrence.
ii. To prepare different thematic maps from the above information.
iii. To predict the groundwater potential zone through the various thematic maps using GIS technique.
iv. To develop a GIS model to identify groundwater potential zones.
v. To show the integration of remote sensing and GIS techniques for prediction of the groundwater potential zone in the study area.

STUDY AREA

Langat Basin is located in the south of Selangor and north of Negeri Sembilan within the latitude 2°40'U to 3°20'U and longitude 101°10'E to 102°00'E, with an area of around 2,394.38 km^2 (Figure 1).

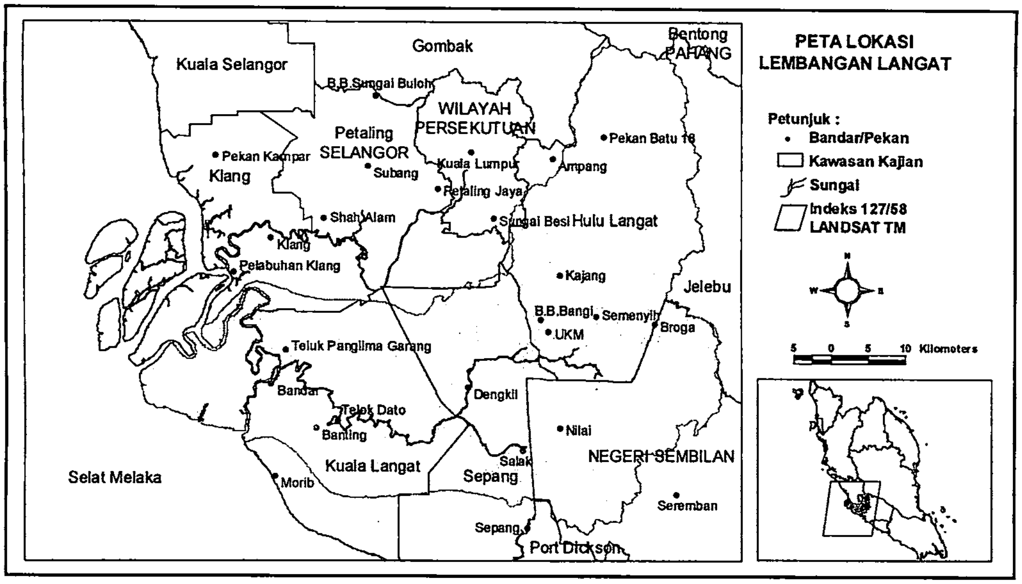

Figure 1: Map showing the location of the study area.

MATERIALS AND METHODS

The data used for the study are Landsat TM data acquired on 6 March 1996, topographic map sheets 3858, 3657, 3757, 3857, 3656, 3756, 3856, 3755 and 3855 on 1:50,000 scale; geological map sheets 93, 94, 95, 101, 102 and 103 on 1:63,360 scale; soil series map of the study area on 1:150,000 scale, prepared by the Agriculture Department of Malaysia; and rainfall data from 1982 to 1996 collected by the Meteorology Department of Malaysia, Drainage and Irrigation Department (JPS) and Universiti Kebangsaan Malaysia (UKM). In addition, hydrogeological maps of Peninsular Malaysia on a scale of 1:500,000 and borehole data collected by the Minerals and Geoscience Department were also utilised.

The methodology used in this project is outlined in Figure 2 and summarised in five stages, as shown below:

Stage 1		Stage 2		Stage 3		Stage 4		Stage 5
Source Data Collection	→	Image Processing	→	Building Database	→	Data Processing	→	Integration & Modelling

The Landsat TM data was collected together with the Geological maps, topography maps, rainfall data, soil series map and hydrological map of Peninsular Malaysia.

Satellite Data Analysis

The main task in this stage is to do an analysis and interpretation of satellite data, in order to produce basic maps such as structural and land use maps in digital form. Basically, satellite data registration, correction and other image processing (such as enhancement, filtering, classification and other GIS proceses), together with field checking of the relevant area will be applied in this stage.

Spatial Database Building

The main task is to bring all the appropriate data (from stage 2 and existing relevant data) together into a GIS database. Basically, all the available spatial data will be assembled in digital form, and properly registered to make sure the spatial component will overlap correctly. Digitizing of existing data and relevant processing such as transformation and conversion between raster to vector, griding, buffer analysis, box calculating, interpolation and other format will also be conducted. This stage produces derived layers such as annual rainfall, lithology, lineament density, topography elevation, slope steepness, drainage density, land use and soil type.

Spatial Data Analysis

This stage will process all the input layer from stage 2 and 3 in order to extract spatial features which are relevant to the groundwater zone. This phase includes various analysis such as table analysis and classification, polygon classification and weight calculation. Polygons in each of the thematic layers were categorised depending on the recharge characteristics and suitable weightages were assigned (Tables 1-8).

Table 1: Landuse.

Landuse	Weight
Forest	20
Agriculture	40
Scrub	30
Wetland	50
Urban	10
Cleared Land	10
Water Body	60

Table 2: Lineament density.

Lineament Density (km/km^2)	Weight
> 0.0075	60
0.0055 – 0.0075	50
0.0035 – 0.0055	40
0.0015 – 0.0035	30
< 0.0015	20

Table 3 : Annual rainfall.

Annual Rainfall (mm)	Weight
2500 – 2750	70
2250 – 2500	60
2000 – 2250	50
1750 – 2000	40
1500 – 1750	30

Table 4: Lithology.

Lithology	Weight
Alluvium	70
Limestone	40
Phylite-Schist-Quarzit	20
Quartz vein	5
Volcanic	30
Granite	10

Table 5: Topography Elevation

Elevation (m)	Elevation Zone	Weight
< 20	Almost Flat Topography	50
20 – 100	Undulating Rolling Hilly	40
100 – 500	Hilly Steeply Disserted	35
500 – 1000	Steeply Dissected Mountainous	25
> 1000	Mountainous	10

Table 6: Slope steepness.

% Slope	Slope	Slope Zone Gradient	Weight
0 – 7	0° - 3°	Almost Flat Topography	50
8 – 20	4° - 9°	Undulating Rolling Hilly	40
21 – 55	10° - 24°	Hilly Steeply Disserted	30
56 – 140	25° - 63°	Steeply Dissected Mountainous	20
> 140	> 63°	Mountainous	10

Table 7: Drainage density.

Drainage Density (km/km^2)	Weight
> 0.0055	10
0.0040 – 0.0055	20
0.0025 – 0.0040	30
0.0010 – 0.0025	40
< 0.0010	50

Data Integration & Modelling

The final stage involves combining all the thematic layers using the method that is modified from the DRASTIC model, which is used to assess ground water pollution vulnerability by the Environmental Protection Agency of the United State of America (Aller, 1985). The output is then reclassed into five groups such as very high, high, moderate, low and very low. The output that is produced is capable of being used for further investigations and assessment, especially at larger scale.

RESULTS AND DISCUSSION

The ground water potential map of the Langat Basin area is shown in Figure 3. In order to produce the map, a GIS model has been used, to integrate thematic maps such as annual rainfall, lithology, lineament density, land use, topography elevation, slope steepness, drainage density and soil type. Each thematic layer consists of a number of polygons, which correspond to different features. The polygons in each of the thematic layer has been categorized, depending on the suitability/relevance to the ground water potential, and suitable weights were assigned. The values of the weightage are based on Krishnamurthy *et al.* (1996 & 1997). Finally, all the thematic layers were integrated using the ground water potential model to derive the final derived layers. The formula of the ground water potential model is as shown below:

$$GW = RF + LT + LD + LU + TE + SS + DD + ST$$

where:

RF:annual rainfall, LT:lithology, LD:lineament density, LU:land use, TE:topography elevation, SS:slope steepness , DD:drainage density and ST:soil type.

The Quantile classification method (ESRI, 1996) has been applied to group the various polygons in the final integrated layers into different categories such as very high, high, moderate, low and very low for the groundwater

Table 8: Soil type.

Soil Series	Soil Type	Weight
Keranji	Clay	10
Melaka-Durian-Muncung	Gravel clay-silty clay-clay	20
Muncung-Seremban	Fine sandy clay	20
Prang	Clay	10
Regam-Jerangau	Coarse sandy clay-clay	30
Selangor-Kangkung	Clay	10
Serdang-Bugor-Muncung	Fine sandy clay loam-fine sandy clay-clay	30
Serdang-Kedah	Fine sandy clay loam	30
Urban Land	Sandy clay	30
Steep Land	Coarse sandy clay	40
Peat Land	Clay	10
Tanah Lombong	Sand	50
Telemung-Akob-Lanar Tempatan	Sandy loam-sandy clay	30

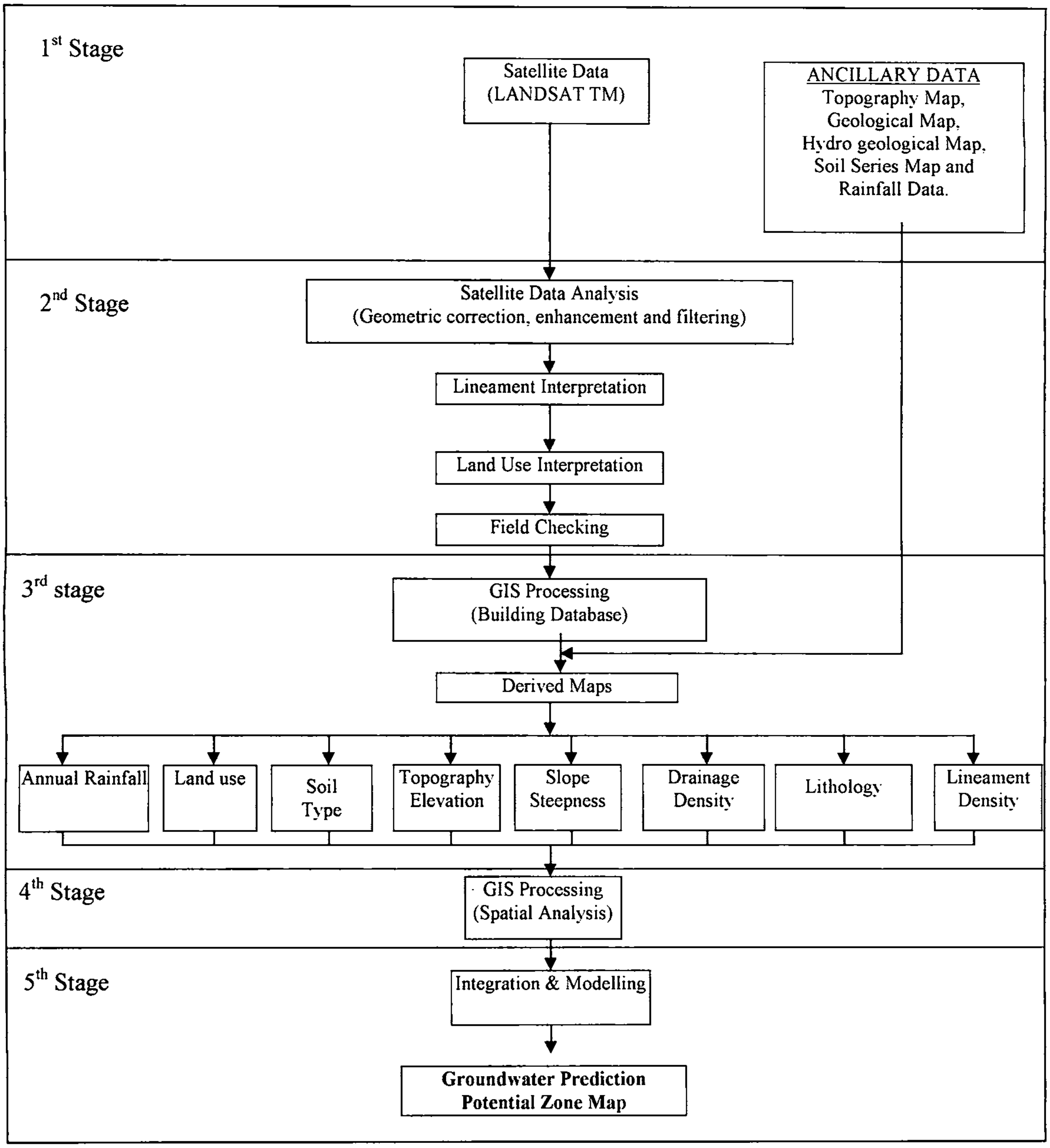

Figure 2: Methodology flowchart for groundwater potential zone mapping.

prediction potential zone map. The score values of the area and polygons in the final map are shown in Table 9.

A summary of the results (Table 10), shows that almost all alluvial plains have high potential of groundwater occurrence. Where as, in steeply mountainous areas underlain by granite with low lineament density, the potential for groundwater is very low. Meanwhile in hard rock areas, the groundwater potential is high in areas with high lineament density and low drainage density.

Bore hole data collected by the Minerals and Geoscience Department were used to compare the final results with the actual field data.

Table 9: Score values of the area polygons in the final map.

Score value	Class of groundwater zone	Estimate of discharge rate
> 285	Very High	> 22 m^3/hour/well
260 – 380	High	18 – 22 m^3/hour/well
245 – 255	Moderate	14 – 18 m^3/hour/well
230 – 240	Low	10 – 14 m^3/hour/well
< 225	Very Low	< 10 m^3/hour/well

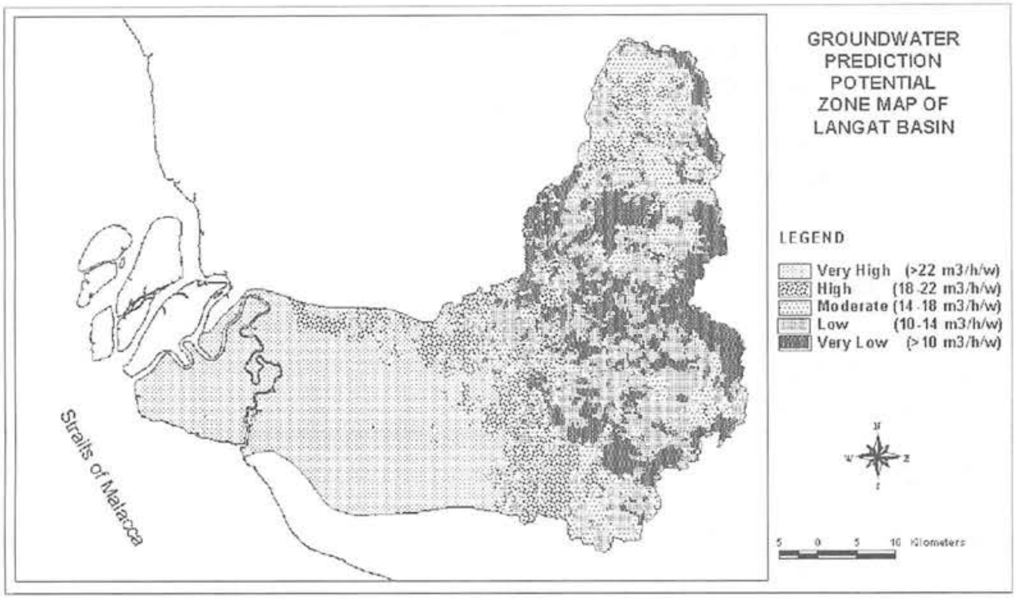

Figure 3: Groundwater potential map of the Langat Basin.

Table 10: Summary of the results.

Layers\ Potential Zone	Very High	High	Moderate	Low	Very Low
Rainfall (mm)	M/L	H	VH	M	M/L/VL
Landuse	Agriculture/ Water body/ Wetland	Agriculture/ Water body/ Scrub	Forest	Agriculture	Forest/ Cleared land/ Urban
Soil Type	Clay	Fine sandy clay loam/ Fine sandy clay/ Clay	Coarse sandy clay / Sandy loam/ Sandy clay/ Clay	Gravel clay/ Coarse sandy clay/ Silty clay/ Clay	Coarse sandy clay
Lithology	Alluvium	Phylite-Schist-Quarzit	Phylite-Schist-Quarzit/ Granite	Granite	Granite
Lineament Density (km/km^2)	NE	VH	M/H	VL	L
Elevation (m)	<20	<20/ 20-100	20-100	20-100/ 100-500	100-500/ >1000
Slope (%)	0-7/8-20	21-55	21-55/ 56-140	56-140	>140
Drainage Density (km/km^2)	VL/L/M	VL/M	M/H	M/VH	L/M

Note :

	Rainfall (mm)	Lineament Density (km/km^2)	Drainage Density (km/km^2)
VL (Very Low)	1500-1750	<0.0015	<0.0010
L (Low)	1750-2000	0.0015-0.0035	0.0010-0.0025/
M (Moderate)	2000-2250	0.0035-0.0055	0.0025-0.0040
H (High)	2250-2500	0.0055-0.0075	0.0040-0.0055
VH (Very High)	2500-2700	>0.0075	>0.0055
NE – No Effect			

CONCLUSIONS

Based on this study, several conclusions can be made and they are:

i. The indicators of groundwater occurrences are related to the hydrological cycle and these are rainfall distribution, land use, soil types, lithology, geological structures, elevation, slope and drainage features of the area.
ii. Satellite data has proven to be very informative and useful for surface study, especially in detecting surface features and characteristics such as lineaments and land use.
iii. In order to predict the groundwater potential zones, different thematic maps have been prepared. These include annual rainfall distribution, land use, lithology, lineament density, topography elevation, slope steepness, drainage density and soil type.
iv. In subsurface study, remote sensing could be used more effectively if it is supported by a suitable GIS approach or techniques and good background knowledge of the related application.

v. Integrated assessment of thematic maps using a model developed based on GIS techniques is the most suitable method for groundwater potential prediction zoning.
vi. The methods and results of this study were effective only for groundwater zone prediction in hard rock terrain, but was less effective in the alluvium environment.

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