Assessment of Groundwater Pollution Potential Using GIS and Modified Drastic Model in Selangor, Malaysia

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ABSTRACT

This study covered the assessment of groundwater pollution potential using modified DRASTIC model and GIS based on hydro-geological environmental parameters Selangor State in Malaysia. The modification of ranges and ratings index in DRASTIC was done using GIS to accommodate hydro-geological settings to implement and adopt data according to Selangor hydro geological environmental parameters. The groundwater pollution potential map showed that the high risk groundwater pollution potential covered 17% of study area in west side of Selangor however, 27% of the east side of Selangor exposed to low risk groundwater pollution potential. Most of the affected area was considered in low land area along the coastal in shallow groundwater table alluvial aquifer. The results significantly show that groundwater pollution potential map was successfully developed using hydro-geological parameters for Selangor area.

Keywords: DRASTIC, GIS, Groundwater Pollution Potential, Selangor

1.0 INTRODUCTION

In Malaysia, the problem of groundwater quality can be expected due to rapid development of urbanisation, industrialisation and intense agricultural activities and coupled with increased groundwater abstraction rate. Urbanization, industrialization and agriculture activities affect large area of Selangor [1]. Agricultural and industrial activities have been identified as the main pollution sources to groundwater. Agricultural activities have been known using various types of chemicals as pesticides and fertilizers while the industrial development activities in Langat Basin were rapid and continue to increase [2]. Many industries including agricultural processing, mineral water bottling, manufacturing and golf courses are pumping the water from the groundwater [3]. With this rapid development, groundwater pollution has become an important environmental and human health issue.

Groundwater pollution refers to the sensitivity and changing in groundwater quality to contamination resulting from human activities at or near the surface for long periods [4] and the hydrogeology e.g. the aquifers are usually unconfined, shallow and highly permeable [5]. The original concept by [6] of groundwater pollution was based on the assumption that the physical environment may provide some degree of protection with regard to contaminants entering the subsurface water. Groundwater pollution has been used as an effective tool for planning, developing and management of groundwater resources [7].

In general, groundwater pollution assessment is categorized into three categories: index and overlay methods, statistical methods or process methods [8]. Index and overlay methods are very popular and have advantages because the information suitable for regional scale assessments and easy to implement, inexpensive to produce, use readily available data and often produce categorical results [9]; [10]. Index and overlay methods are based on combining different maps of the region by assigning a numerical index and use in GIS [5]. The DRASTIC is an index and overlay method that most recognized worldwide for groundwater vulnerability assessment [11].

US Environmental Potential Agency (EPA) published a standardized system for evaluating the potential for ground-water pollution on the basis of hydro geologic settings called DRASTIC [12]. DRASTIC has been applied in studies several times and also in worldwide for evaluating relative groundwater pollution [6]; [7]; [10]; [13-22]. The groundwater pollution potential map is developed by using GIS to combine all the thematic maps of hydro geological data layers according to DRASTIC parameters [23]. Groundwater pollution potential mapping has been widely used to show groundwater areas which are vulnerable to contamination [24].

The DRASTIC method has been modified by many researchers and scientists based on geological or hydrogeological settings, climate conditions, and other special situations [11]. Because DRASTIC was created for the purpose of evaluating features throughout the United States, the DRASTIC ranges and ratings had to be modified to fit local hydro geologic settings

[19] to get a better outcome [7]. DRASTIC have been modified based upon the specific regional data in Walawe basin, India, Arkansas, Jordan, Korea, Lanchan, Minnesota and others and the modified ranges and ratings have been accommodated to determine the local DRASTIC Index [6-7]; [13-19].

The purpose of this study is to provide a groundwater pollution potential map in the Selangor using modified DRASTIC model and GIS. The modified DRASTIC and combined data layers are developed by using the GIS application based on Selangor hydro-geological environment.

2.0 METHODOLOGY

2.1 The Study Area

Selangor which is the study area is located at west coast of Peninsular Malaysia. The coordinate of study area is 3°20′N 01°30′E and it covers an area of approximately 50,810 square miles or 131,598 square kilometers. The study area has the largest population in Malaysia. It increased from 52 million in 2008 to 56 million in 2011. The topography of Selangor is more or less covered with low, flat and hilly lands. The area investigated were underlain by unconsolidated alluvial sediments mainly clay and sand which are underlie by sedimentary rocks of Devonian and Silurian-Ordovision ages, Quaternary alluvium deposits consists of clay, silt, gravels, pebbles and peat, Carboniferous, tertiary, and Permian-Jurassic ages. Being located within the equatorial belt, the average annual temperature is about 28°C and relative humidity is always over 80% throughout the year. Humidity is usually high. The average monthly rainfall varies from 90mm to 300mm and the annual average rainfall over the state amounts to about 2285 mm with large amounts falling in the mountainous northeast than on the plains.

2.2 Modified DRASTIC

DRASTIC is a method using subjective weighting and assignment of numerical values to factors, these factors and their weighting values, which were selected and calculated based on knowledge and understanding of groundwater pollution expert, can well reflect the key mechanisms of the groundwater pollution pathways [10]. The method known under the acronym DRASTIC, involves assigning numerical values to seven parameters and totalling a score. The hydro geologic factors that make up the acronym DRASTIC include Depth to the water table (D), Recharge (R), Aquifer media (A), Soil media (S), Topography (T), Impact of the vadose zone (I) and hydraulic Conductivity of the aquifer(C).

The input data such as borehole data, geological map, soil map, rainfall data and topography map were used to develop GIS database. To assess groundwater pollution potential within hydrogeologic settings, numerical ranking is used on the DRASTIC features. There are 3 significant parts, Weights, Ranges, and Ratings. Modified equation, ratings and ranges of DRASTIC were changed due to the study area hydro geologic settings.

The ranges rating modification were created using Geostatistical Analyst in ArcGIS. The steps in Geostatistical Analyst included Geostatistical method selections, semivariogram and covariance modelling, cross validation and lastly classification. The Geostatistical Analyst provides a number of interpolation techniques that use sample points to produce surfaces. The interpolation methods are divided into two types, deterministic and geostatistical methods. In this project, the geostatistical Kriging method is selected to interpolate the parameters. Two types of Kriging are carried out namely Ordinary Kriging and Indicator Kriging. The Ordinary Kriging produces the prediction map while the Indicator Kriging is more suitable to produce the probability map. Ordinary Kriging was used to produces the prediction map in this study.

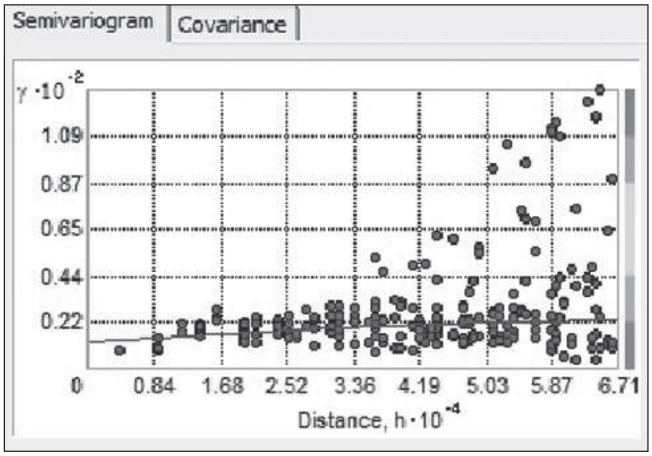

Figure 1: Semivariogram model

The Semivariogram and covariance function as quantifying the assumption those things nearby tend to be more similar than things that are far apart. They both measure the statistical correlation as a function of distance. The goal of semivariance and covariance modeling is to determine the best fit for a model that pass through the points in the semivariogram shown in the blue line in the diagram as shown in Figure 1.

While the cross validation is to diagnostics whether the parameters values are reasonable for map production. Before producing the final surface, the cross validation should be carried out to help making an informed decision as to which model provides the most accurate predictions. If the mean prediction error is near to zero, the model provides accurate prediction. The root mean square prediction error, mean standardized prediction error and average standard error should be as small as possible. The average root mean square prediction errors are computed as the square root of the average of the squared difference between observed and predicted values. The root mean square standardized prediction error should be close to one if the standard errors are accurate.

After model validation, the classification was generated to produce the new range and rating. The classification divided into 5 ranges using Geometric Interval. Geometric Interval is a classification scheme where the class breaks are based on class intervals that have a geometrical series. Each range for each DRASTIC parameter had been evaluated with respect to determine the relative significance to groundwater pollution potential. The modified ranges were assigned rating of 5 indicated for high potential to groundwater pollution, rating of 4 indicated for moderate high, rating of 3 indicated for moderate, rating of 2 indicated for moderate low and rating of 1 indicated for low potential to groundwater pollution.

Table 1: Drastic parameters with the associated DRASTIC weight [12]

Parameter	Weight
D : Depth to water	5
R : Recharge	4
A : Aquifer media	3
S : Soil Media	2
T : Topography	1
I : Impact of Vadose zone	5
C : Hydraulic Conductivity	3

Then the seven parameters are assigned weights ranging from 1 to 5 due to their relative importance is shown in Table 1. The most significant factors have weights of 5 and the least significant a weight of 1. Under this system, the higher the score, the greater the assumed sensitivity of ground water to contamination. This score was accomplished by the committee using a Deplhi approach, which quantifies the opinions from single and multiple experts and may not be changed [12].

The DRASTIC index is calculated by multiplying each factor weight by its point rating and summing the total. The DRASTIC Index is the summed value that makes it possible to identify areas more susceptible to groundwater pollution potential. The higher the DRASTIC Index means the higher groundwater pollution potential. The governing equation for the DRASTIC index is according to the following Equation (1) below:

$$DRASTIC\ Index = D_R D_W + R_R R_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W + C_R C_W \qquad (1)$$

Where, D, R, A, S, T, I and C are the seven parameters in DRASTIC and the subscripts R and W are the ratings and weights, respectively.

3.0 RESULT

3.1 Depth to Water

Depth to water is important because it determines the depth of material through which a contaminant must travel from the ground surface to the water table. A deeper water table implies less chance for contamination to occur because of the longer transport time, greater opportunity for chemical reaction and the occurrence of pollutant attenuation. A shallow depth to water table will lead to a higher groundwater pollution rating and deeper depth to water will lead to a smaller groundwater pollution rating. Approximately 114 water well log records are on file for Selangor State. Each of these well log provided generalized depth to water information. The depth to water were divided into 5 ratings such as 5 for depth (0.04-0.91m), 4 for depth (0.91-1.14m), 3 for depth (1.14-2.01m), 2 for depth (2.01-5.36m) and 1 for depth (5.36-18.3m), is shown in Table 2 and map in Figure 2.

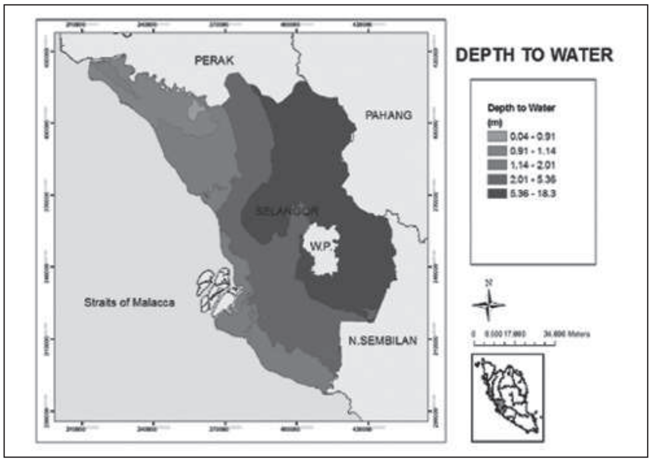

Figure 2: Depth to Water of Selangor

3.2 Recharge

Recharge represents the amount of water per unit area of land that penetrates the ground surface and infiltrates to reach the aquifer. The recharge is the amount of water from precipitation and artificial sources such as solid and liquid contaminants available to migrate down to the groundwater and does not take into consideration the distribution, intensity or duration of recharge events. The factors used to generate the recharge map include slope and rainfall. The equation calculates the ability of an area to act as a recharge zone. The recharge value was then grouped into a range of values that are given a rating. The following Equation (2) was used to construct a recharge value.

$$Recharge = Slope\ \%\ Rating + Rainfall\ Rating \qquad (2)$$

The Rainfall layer was obtained by digitizing a ten years mean of annual rainfall (mm/year) from fifteen representative rainfall stations. Table 2 and map in Figure 3 shown the recharge classification; rating 4 (range 6 to 8) and 5 (range 8 to 10).

3.3 Aquifer Media

Aquifer media refers to the characteristics of the consolidated or unconsolidated rock that serve as an aquifer. The Aquifer media was obtained using the existing geological map. The aquifer media is classified as limestone, alluvial, volcanic and igneous rock. The rating of aquifer media is based on the grain size and the more fractures or opening within the aquifers, the higher the permeability and lower the attenuation capacity; consequently the greater the pollution potential. Aquifer ratings were assigned

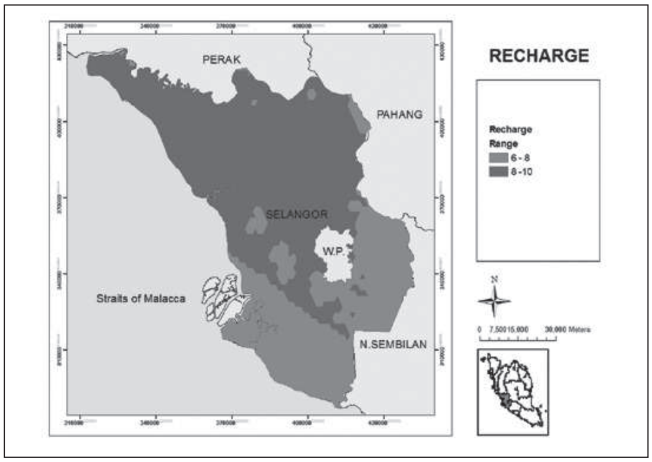

Figure 3: Recharge of Selangor

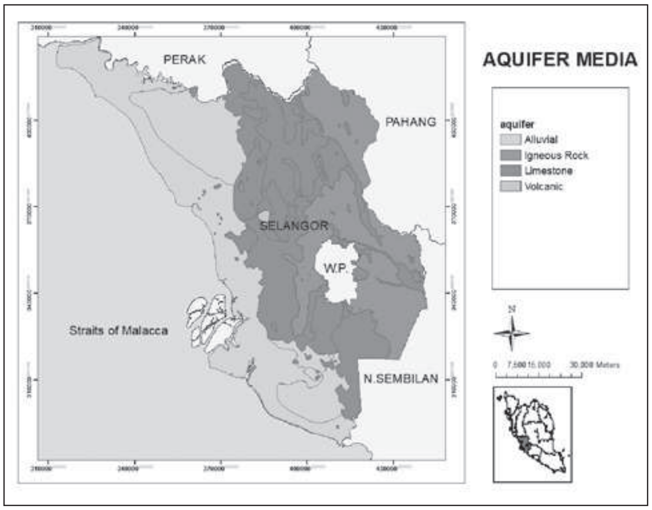

Figure 4: Aquifer Media of Selangor

rating 4 for alluvial, 3 for igneous rock, 2 for limestone and 1 for volcanic rock. The aquifer media map is presented in Figure 4 and the information is shown in Table 2.

3.4 Soil Media

Soil media refers to the portion unsaturated zone located between the surface and the uppermost bedrock. The characteristics of the soil influence the amount of recharge infiltrating into the groundwater, pollutant dispersion and others. With reference to the soil series of Selangor, the soil types were classified into groups. According to the rating scheme with reference to [25] suitable values were assigned to each soil group. The rating ranges of the different soil type are represented in Table 2 and soil type map in Figure 5.

3.5 Topography

Topography is considered as the slope and slope variability of the ground surface. Areas with low slope tend to retain water longer and allow a greater infiltration of recharge water and a greater potential for contaminant migration. Areas with steep slopes, having large amount of run-off and smaller amount of infiltration are less vulnerable to groundwater contamination.

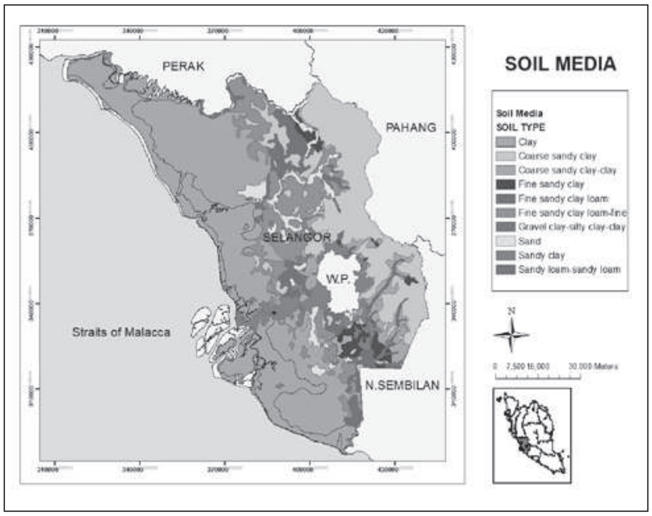

Figure 5: Soil Media of Selangor

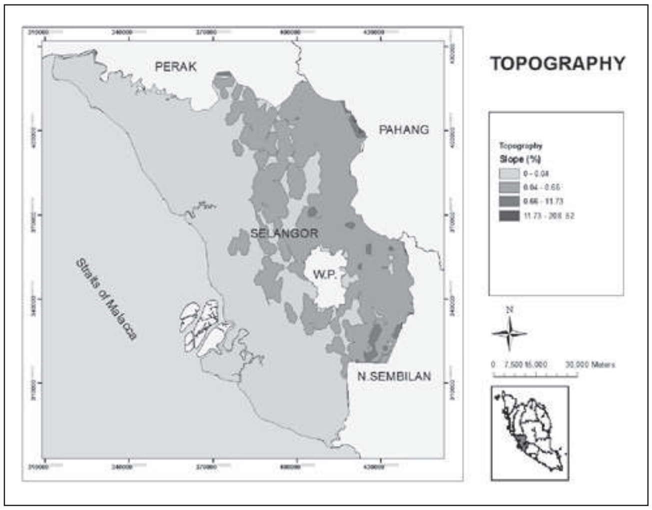

Figure 6: Topography of Selangor

The Topography layer was constructed from Digital Terrain Model (DTM) generated by merging all sheets in raster format. Topography in slope percent is divided into 5 ranges. Figure 6 shown the topography map (slope %) with rating 5 for slope (0-0.04%), 4 for slope (0.04-0.66%), 3 for slope (0.66-11.73%), 2 for slope (11.73-208.64%) and 1 for slope >208.64% (Table 2).

3.6 Impact of Vadose Zone

The vadose zone is defined as the zone above the water which is unsaturated or discontinuously saturated. The vadose zone consists of the material existing as the surface soil, as well as the bedrock layers without a holding capacity for ground water. The impact of pollution on the vadose zone is measured based on the thickness, porosity, and permeability of all material within the vadose zone.

The Equation (3) used for Impact of Vadose Zone incorporates Soil Media and Depth to Water. This Impact of Vadose Zone then grouped into ranges which are given a rating.

$$\text{Impact of Vadose Zone} = \text{Soil Media Rating} + \text{Depth to Water Rating} \tag{3}$$

Impact of Vadose zone divided into 4 ranges; 4 for range (6-8), 3 for range (4-6), 2 for range (3-4) and 1 for range (2-3). The Impact of Vadose zone map is presented in Figure 7 and the rating ranges are shown in Table 2.

3.7 Hydraulic Conductivity

Hydraulic conductivity refers to the ability of the aquifer materials to transmit water, which in turn, controls the rate at which groundwater will flow under a given hydraulic gradient. The rate is affected by the material, porosity, and gradient of the aquifer. The ratings and ranges of Hydraulic Conductivity represented in Figure 8 and Table 2.

3.8 DRASTIC Index

The DRASTIC Index gives a numerical value that identified areas which are more likely to be susceptible to groundwater pollution potential relative to one another. The DRASTIC index generated provides only a prediction and is not designed to

Table 2: Modified DRASTIC

Rating	Depth to Water (m)	Recharge	Topography (% slope)	Impact of Vadose Zone	Hydraulic Conductivity (m/d)	Aquifer Media	Soil Media
5	0.04 – 0.91	8 – 10	0 – 0.04	8 – 10	1.82 – 2.17		Sand
4	0.91 – 1.14	6 – 8	0.04 – 0.66	6 – 8	1.43 – 1.82	Alluvial	Coarse sandy clay
3	1.14 – 2.01	4 – 6	0.66–11.73	4 – 6	1.00 – 1.43	Limestone	Sandy loam-sandy loam, Coarse sandy clay-clay, Fine sandy clay loam-fine to sandy clay-clay, Fine sandy clay loam, Sandy clay
2	2.01 – 5.36	3 – 4	11.73–208	3 – 4	0.53 – 1.00	Volcanic	Fine sandy clay, Gravel clay-silty clay-clay
1	5.36 – 18.3	2 – 3	>208	2 – 3	0.02 – 0.53	Igneous Rock	Clay

produce absolute answers or to represent units of groundwater pollution. A new raster data file for the DRASTIC Index was created according to the DRASTIC Index equation using the weighted sum overlay in spatial tools using the seven individual raster layer created above.

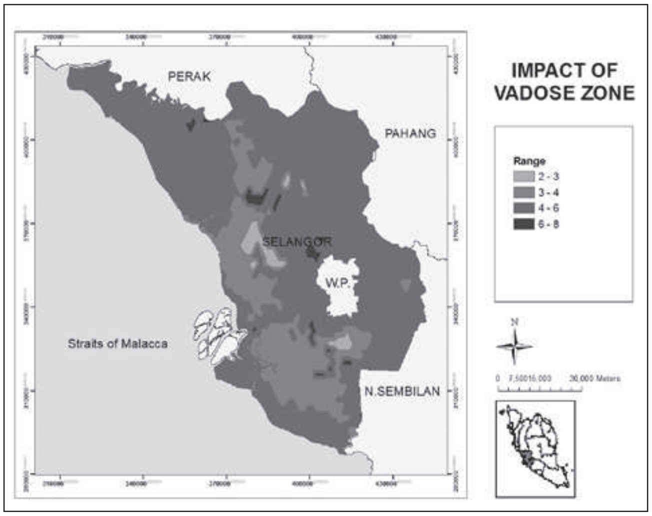

Figure 7: Impact of Vadose Zone of Selangor

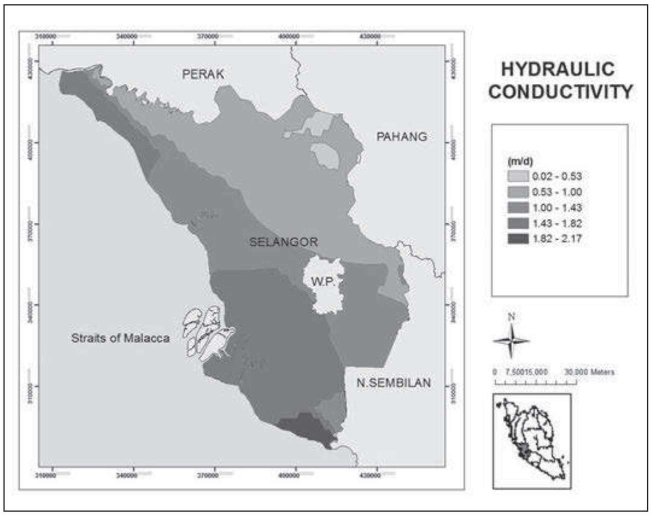

Figure 8: Hydraulic Conductivity of Selangor

The resulted DRASTIC index values in this study are between 48 to 94. The DRASTIC Index divided into five classes of groundwater pollution potential (GPP); low (48-63), moderate low (63-70), moderate (70-72), moderate high (72-79) and high (79-94). The higher the Index value means the greater relative groundwater pollution potential. The resulted show that 14% of the area study is under high GPP, 21% moderate high GPP, 10% moderate GPP, 29% moderate low GPP and 27% low GPP. The ranges of classification and affected area are presented in Table 3.

The groundwater pollution potential map (GPP) of Selangor is shown in Figure 9. The elevated northwest part with some dispersed in the middle of the study area displayed high GPP. These areas have shallow water table, high recharge, permeable soil and lesser slope that very well supporting the chances of getting groundwater pollution potential. Moderate high GPP ranked groundwater resources are found in similar terrains area as the high risk class where high recharge potential, shallow depth to water, permeable aquifer and high impact of vadose zone. Moderate GPP contributed to the smallest area. These areas include of the unconsolidated sediments, low slope, relatively deep water table and soil permeability are moderate to slow. Moderate low GPP are quite prevalent in the middle of study area. The characterised predominantly by moderate to steep slopes, deep water table and impermeable soil and aquifer and low potential for recharge. Lastly, the GPP map showed that the eastern part of the study area. This is mainly due to the characterised by deep water table, less porous soil and aquifer, low recharge potential and impact of vadose zone and very steep topography. These areas with low potential need not necessarily mean that it is free from groundwater pollution but it is relatively less susceptible to pollute compare to the other area.

Table 3: The modified DRASTIC for the study area

DRASTIC Index	Classification	Area (km^2)	% of the study area
79-94	High	1064	14
72-79	Moderate High	1620	21
70-72	Moderate	761	10
63-70	Moderate Low	2307	29
48-63	Low	2099	27

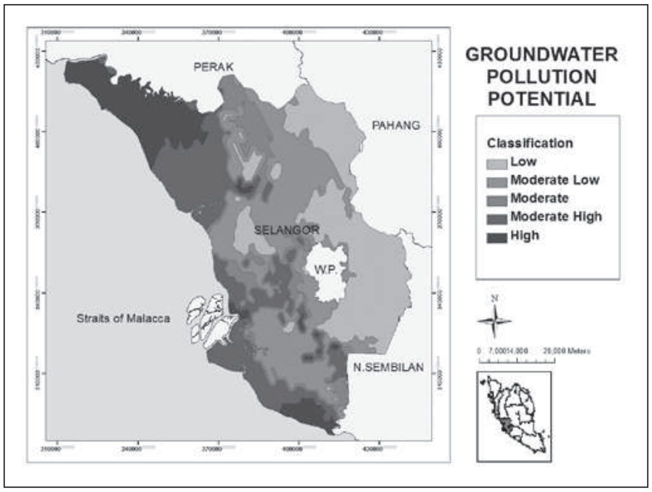

Figure 9: Map of Groundwater Pollution Potential

3.9 Validation of the Modified DRASTIC

A statistical summary of the seven parameters index incorporated in DRASTIC index was presented in Table 4. The confusion matrix summarizes the classification of the observations, which is the ratio of the number of observations that have been well classified over the total number of observations. The accuracy of spatial classification using standard mode, forward stepwise mode and backward stepwise mode are very convincing because the high percentage of confusion matrix. From this result, the modification of DRASTIC is significant and acceptable.

4.0 CONCLUSION

Seven parameters were used to represent the natural hydro geological setting of the Selangor; Depth to Water, Recharge, Aquifer media, Soil Media, Topography, Impact of vadose zone and hydraulic Conductivity called DRASTIC. The conventional DRASTIC develop by US according to the hydro geological environment. Due to the difference between Malaysia and US hydro geological, the modified DRASTIC has derived in this study. The GIS successfully provided a tool to modify based on local hydro geological environment and produced a groundwater pollution potential map.

The method to develop the new ratings and ranges for each DRASTIC parameter can be applied to other country in Malaysia with appropriate modification based on the local hydro geological. The groundwater pollution potential map in this study is only show the relative potential area to pollute and not represent the absolute values. The advantages of this method are low cost, can be used in extensive regions and easy to collect data that required.

This study has concluded that 14% of the study area is high groundwater pollution potential and located at the coastal eastern part of Selangor. The eastern part has lower water table, high recharge, permeable soil and lesser slope. About 27% of the study area is classified as low groundwater pollution potential, which prevalent in the middle of study area. The characterized predominantly by moderate to steep slopes, deep water table and impermeable soil and aquifer and low potential for recharge. The resultant for the entire study area reflects mostly low to moderate low potential.

For areas that have high groundwater pollution potential zone, local authorities should be allowed to manage groundwater resource and monitor the policy and decision to act accordingly based on the groundwater resource evaluation and groundwater pollution assessment. This project serves as a foundation to build upon and provide techniques that may be used for future groundwater research. ■

Table 4: Summary for Standard Analyst Mode, Forward and Backward Stepwise Mode

	Standard Analyst Mode	Forward Stepwise Mode	Backward Stepwise Mode
From \ To	% correct		
High	78.95%	78.95%	78.95%
Low	71.43%	71.43%	71.43%
Moderate	46.67%	40.00%	40.00%
Moderate high	51.85%	48.15%	48.15%
Moderate low	92.31%	94.87%	94.87%
Total	**71.96%**	**71.03%**	**71.03%**

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PROFILES

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