CHAPTER 3

THE DRASTIC ANALYSIS

The term "vulnerability of groundwater to contamination" is based on natural environments which depend on the sensitivity of a groundwater system (Margat, 1968). The original concept of groundwater vulnerability based on the assumption that the physical environment may provide some degree of protection to groundwater with regard to contaminants entering the subsurface. Common routes for the transport of contaminants form soils to groundwater (groundwater is on portion of the hydrologic cycle, precipitation, stream flow, and reservoirs are main sources of that recharge into saturated zone and then become groundwater). Groundwater flows in pore spaces of porous materials and also naturally flows by hydraulic gradient. The velocity of the movement depends on hydrogeologic setting, medium properties, and pressure distribution. Therefore quantity and quality of groundwater also vary with depths, area extents and also in different geologic materials. Groundwater recharge at the land surface may be contaminated but it naturally purified to some degree as it percolates through the soil and other fine grained materials in the unsaturated zone. Different parts of the physical environment have varying capacities for attenuating contaminants. The contamination potential of the physical environment, with or without a rating system (Zaporozec, 1989), using several physical factors to evaluate the contamination potential.

3.1 Groundwater vulnerability map and DRASTIC method

The concept of groundwater vulnerability has been originated by the worldwide concern about the problems of groundwater contamination. Groundwater vulnerability maps are used as a guide for the location of future developments in an area, in order to minimize the impact that the projected development will have on the surrounding water resources. Natural vulnerability is a function of hydrogeology factors and specific vulnerability considers the potential impacts of specific land use and explicit contamination such as predicates. In the assessment of environmental tolerances both specific and natural vulnerabilities are need to be considered. Geographical Information System (GIS) was used to create a groundwater vulnerability map by overlaying the available hydrogeological data. GIS assisted to create systematic and efficient work, such as ArcView Software version 3.1 can be increased the speed, precision of mapping process and accuracy of model.

One model that could provide guidance for comparing groundwater vulnerability is the DRASTIC model. The DRASTIC model was developed for the U.S. Environmental Protection Agency by Aller and others (1987) and has been used to produce maps in many parts of the United States (United States Geological Survey, 1999, Harman and others, 2000, Osborn and others, 1998, and Kumar and others, 2003), in Portugal (Lobo-Ferreira and Oliveira, 2003), in Israel (Secunda and others, 1998), in Sweden (Rosen, 1994), in Australia (Piscopo, 2001), in Jordan (Al-Adamat and others, 2003), and in Thailand (Margane and others. 1998, Saykawlard. 1999, Thapinta and Hudak. 2002, and Kwansiririlul and others, 2004). The DRASTIC model has four assumptions: 1) the contamination is introduced at the ground surface,

2) the contaminant is flushed into the groundwater by precipitation, 3) the contaminant has the mobility of water, and 4) the area being evaluated by DRASTIC is 100 acres or larger (Osborn and others, 1998, Piscopo, 2001).

The DRASTIC evaluates pollution potential based on seven parameters including depth to water table, net recharge, aquifer media, soil media, topography, impact of vadose zone, and hydraulic conductivity. This is an acronym for the seven thematic maps used in the model. The seven thematic maps required for the DRASTIC model is shown in Table 3.1.

Table 3.1 The seven thematic maps required for the DRASTIC model (Thirumalaivasan and Karmegam, 2001).

Parameters	Description
D	Depth to water table – the greater depth to water, the lesser chance for the contaminant to reach it when compared to shallow water table
R	Net recharge – the process through which the contaminant is transported to the aquifer and hence the more recharge, the more vulnerability of the aquifer
A	Aquifer media – the attenuation characteristics of the aquifer material reflecting the mobility of the contaminant through the aquifer material
S	Soil m edia – t he d ifferent o f s oils t ypes h ave d iffering w ater h olding capacity and influence the travel time of the contaminant
T	Topography – the steep slope increase the speed of runoff and activate erosion which is composed of the pollutant
I	Impact of vadose zone – the texture of the soil in the unsaturated zone above the water table
C	Hydraulic conductivity – the amount of water percolating to reach the ground water through the aquifer is influenced by the hydraulic conductivity of the soil media

Determination of the DRASTIC index involves multiplying each factor weight by its point rating and summing the total. The higher sum values represent greater potential for groundwater pollution, or greater aquifer vulnerability. For a given area being evaluated, each factor is rated on a scale of 1 to 10 that indicates the relative pollution potential of the given factor for that area. Once all factors have been assigned a rating, each rating is multiplied by the assigned weight, and the resultant numbers are summed as follows:

$$\text{DRASTIC index} = D_rD_w + R_rR_w + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_w$$

Where:
r = rating for the area being evaluated
w = importance weight for the factor

Weights from 1 to 5 determine the relative importance of the factors with respect to each other. Ratings are obtained from tables for each factor, while the weights are determined from tables representing general applicability. Table 3.2 is shown the importance weights for factors.

Table 3.2 Assigned weights for factors in generic DRASTIC (Aller and others, 1987).

Factor	Importance weight
Depth to water table (D)	5
Net recharge (R)	4
Aquifer media (A)	3
Soil media (S)	2
Topography (T)	1
Impact of vadose zone (I)	5
Hydraulic conductivity (C)	3

The depth to the water table is the primary important factor, because it determines the depth of material through which a contaminant must travel before reaching the aquifer; this factor can also be used to determine the contact time with the surrounding materials. Table 3.3 contains the ranges and ratings for the depth to water table. The ranges were determined based on what the study ground of groundwater professionals considered to be depths where the potential for groundwater pollution significantly changed (Aller and others, 1987).

Table 3.3 Evaluation of the depth to water table factor (Aller and others, 1987).

Depth to water table		
Range (ft.)	Range (m)	Rating
0-5	0.0-1.5	10
5-15	1.5-4.5	9
15-30	4.5-9.0	7
30-50	9.0-15.0	5
50-75	15.0-22.5	3
75-100	22.5-30.0	2
100+	30.0+	1

Net recharge refers to the total quantity of water that infiltrates from the ground surface to reach the aquifer. Net recharge includes the average annual amount of infiltration and does not take into consideration the distribution, intensity, or duration of recharge events. The ranges and ratings for net recharge are given in Table 3.4. The attenuation capacity of the aquifer media is evaluated on the basis of grain sizes, fractures, and solution openings. Ranges and ratings for the aquifer media factor are illustrated in Table 3.5. The soil medial is considered as the upper weathered zone of the earth that averages a depth of 6 ft or less from the ground surface. The soil media is evaluated on the basis of the type of clay present, the shrink/swell potential of that clay, and the grain size of the soil. The ranges and rating for the soil media factor is shown in Table 3.6.

Table 3.4 Evaluation of the net recharge factor (Aller and others, 1987).

Net annual recharge		
Range (in.)	Range (mm.)	Rating
0-2	0-500	1
2-4	500-1,000	3
4-7	1,000-1,750	6
7-10	1,750-2500	8
10+	2500+	9

Table 3.5 Evaluation of the aquifer media factor (Aller and others, 1987).

Aquifer media		
Range	Rating	Typical rating
Massive shale	1-3	2
Metamorphic/igneous	2-5	3
Weathered Metamorphic/igneous	3-5	4
Glacial till	4-6	5
Bedded sandstone, limestone, and shale sequences	5-9	6
Massive sandstone	4-9	6
Massive limestone	4-9	6
Sand and gravel	4-9	8
Basalt	2-10	9
Karst limestone	9-10	10

Table 3.6 Evaluation of the soil media factor (Aller and others, 1987).

Soil media	
Range	Rating
Thin or absent	10
Gravel	10
Sand	9
Shrinking and/or aggregated clay	7
Sandy loam	6
Loam	5
Silty loam	4
Clay loam	3
Muck	2
Nonshrinking and nonaggregated clay	1

In the DRASTIC methodology, topography refers to the slope and slope variability of the land surface. Table 3.7 contains the slope ranges chosen as significant relative to groundwater pollution potential. The vadose zone is defined as a zone above water table which is unsaturated or discontinuously saturated. The vadose zone is evaluated on the basis of grain sizes, fracturing and solution openings, and sorption potential. Table 3.8 displays the ranges and ratings for the impact of the vadose zone media factor. Finally, values for hydraulic conductivity are typically available from published hydrogeological reports in given geographical areas. The ranges and ratings of the hydraulic conductivity factor are given in Table 3.9.

Table 3.7 Evaluation of the topography factor (Aller and others, 1987).

Topography	
Range (% slope)	Rating
0-2	10
2-6	9
6-12	5
12-18	3
18+	1

Table 3.8 Evaluation of the impact of the vadose zone media factor (Aller and others, 1987).

Impact of the vadose zone media		
Range	Rating	Typical rating
Confining layer	1	1
Silt/clay	2-6	3
Shale	2-5	3
Limestone	2-7	6
Sandstone	4-8	6
Bedded limestone, sandstone, shale	4-8	6
Sand and gravel with significant silt and clay	4-8	6
Metamorphic/igneous	2-8	4
Sand and gravel	6-9	8
Basalt	2-10	9
Karst limestone	8-10	10

Table 3.9 Evaluation of the hydraulic conductivity factor (Aller and others, 1987).

Hydraulic conductivity	
Range (gpd/ft^2)	Rating
1-100	1
100-300	2
300-700	4
700-1,000	6
1,000-2,000	8
2,000+	10

The result of DRASTIC indices are represented a relative measure of groundwater vulnerability in study area. It was a nationwide categorization of counties into those with high, medium, or low vulnerability to groundwater pollution. The higher are the greater the vulnerability of the aquifer to contamination and the lower is not free from groundwater contamination; however, it is less susceptible to contamination. Table 3.10 was suggested divisions and associated map c olor codes (Aller and others, 1987). The colors of the spectrum were chosen to show relative vulnerability to pollution. The warm colors (red, orange, and yellow) indicate the greatest potentially vulnerability area; the cool colors (blue, indigo, and violet) indicate areas of lower vulnerability to pollution. The two shades of green depict the middle ranges.

Table 3.10 Suggested national color code for DRASTIC index ranges (Aller and others, 1987).

DRASTIC index range	Color
<79	Violet
80-99	Indigo
100-119	Blue
120-139	Dark green
140-159	Light green
160-179	Yellow
180-199	Orange
>200	Red

The DRASTIC methodology has been prepared to assist planners, managers, and administrators in the task of evaluating the relative vulnerability of areas to groundwater contamination from various sources of pollution. Similar hydrogeologic parameters should produce similar vulnerability. The DRASTIC vulnerability map, additionally, can be used as screening tools for policy decision making in groundwater management. Table 3.11 is a guide to the amount of groundwater assessment required for a development that requires consent in any of the five aquifer vulnerability classes.

Table 3.11 Groundwater assessment for developments that require consent (Australian Water Resources Council, 1992).

Vulnerability classification	Groundwater assessment requirements
Low	*Groundwater contamination assessment report* A desk study is required to identify the concerns and potential risk to groundwater or the environment, and the need for any further action to be presented in the development application. A standard format hydrogeological report would most likely result.
Low-moderate	*Site investigation with monitoring* A potential risk is indicated by the vulnerability map requiring site investigation and groundwater monitoring. The extent of work should involve a limited amount of site investigation, soil and water sampling and testing, definition of flow systems and reporting, in addition to a desk study.
Moderate	*Detailed site investigation and monitoring* For moderate vulnerability areas, or where the previous levels of investigation indicate a demonstrated risk to groundwater, a detailed groundwater site investigation is required. The work should include an ongoing monitoring program, details on the protection design factors, (natural attenuation, physical barriers, etc) in addition to the previous levels of investigation.
Moderate high	*Demonstrated groundwater protection system* The risk to groundwater, as demonstrated by the vulnerability map, is an area in which contamination to groundwater cannot be tolerated. The work should include a desk study, detailed site investigation, and implementation of an on-going monitoring program, as indicated above. In addition, the protection design system incorporating natural attenuation, hydraulic barriers, physical barriers etc, need to be demonstrated, to be effective. The proposal will need to include a feasibility plan for a clean-up, in addition to a detailed monitoring and ongoing assessment program.
High	*Demonstrated remedial action plan/prohibition* This classification identifies the area as having a potential risk so great as to warrant a demonstrated remedial action plan. The work should include a desk study, site investigations, ongoing monitoring, plus a demonstrated remedial action plan for clean-up, which analyses the effectiveness of the remediation approach in achieving designated water quality criteria. The financial capacity of the responsible party to enact the plan should also be evaluated. In the event that the risk to groundwater is unacceptable, an activity may be banned by the responsible authority.

3.2 Parameters and database design

In study area, DRASTIC feature is assigned a weight relative to each other in order of importance from 1-5 by the most significant is allocated five and the least significant is allocated one. The main seven parameters consists of depth to water table, net recharge, aquifer media, soil media, topography, impact of vadose zone, and hydraulic conductivity that would be used in DRASTIC were defined (Table 3.12).

The concept of groundwater vulnerability is that some land areas are more vulnerable to groundwater contamination than others. Results of vulnerability assessment are portrayed on a map showing cells or polygons, which have different level of vulnerability.

Table 3.12 Assigned weights for DRASTIC features.

	Subclass	Weight	Type		Remarks
			Before	After	
D	Depth to water table	5	Points	Polygon	Based on static water level monitoring data.
R	net Recharge	4	Points	Polygon	Based on annual rainfall.
A	Aquifer media	3	Polygon	Polygon	Based on hydrostatigraphic units.
S	Soil media	2	Polygon	Polygon	Base on approximating soil permeability for soil types.
T	Topography	1	Polyline	Polygon	Base on percent slope derived from contour lines.
I	Impact of vadose zone	5	Polygon	Polygon	Based on geology and hydrogeologic study.
C	hydraulic Conductivity	3	Points	Polygon	Based on pumping test.

3.3 Data processing

Data essential for DRASTIC analysis were obtained from Department of Groundwater Resources, Department of Mineral Resources, Department of Land Development, and Royal Irrigation Department. Transportation network, soil, topographic elevation, rivers and streams, land use, and geologic information were stored in vector based. Features can be stored as points (well locations, and place classes), lines (roads, streams, and contour lines), and polygon (soil types, watersheds, land use, vegetation), The data can be stored in the ArcView Geographical Information System (GIS). For sources data ArcView are stored as layer, the geometric location, and attribute information of graphic features in shape file format.

The data processing steps to used cell or polygon on the map as follow:

3.3.1 Depth to water table

The depth to water table feature was constructed from water level monitoring data from Department of Mineral Resources in digital format. Labels were given to each point. The shape file was opened in ArcView to display and check its attributes. Wall shape table was edited in Excel and insert to table in ArcView. After that, the coverage of well was taken to interpolate surface using interpolate grid in surface menu. Then, the class of depth to water table was reclassified according to the DRASTIC table, for rating using reclassify in analysis menu. This grid should only have values between 1 and 10.

3.3.2 Net recharge

The recharge shape file was computed from annual rainfall data in four stations from Meteorological Department and Royal Irrigation Department (1964-2003) in digital format. Labels were given to each point. The shape file was opened in ArcView. After that, the coverage of recharge was taken to interpolate surface using interpolate grid in surface menu. The class of recharge was reclassified for rating using reclassify in analysis menu.

3.3.3 Aquifer media

The aquifer media shape file was computed from hydrogeologic group data in labels as polygons from Department of Mineral Resources in digital format. The shape file was opened in ArcView again. Next, the aquifer media shape file was changed to grid file before reclassify by convert to grid in theme menu. After that, the class of aquifer media was reclassified for rating using reclassify in analysis menu.

3.3.4 Soil media

From soil map of Department of Land Development, soil types were regrouped. There are 31 types of soil unit in Phuket Island was computed from soil permeability group data in labels as polygons in digital format. The shape file was opened in ArcView again. After that, the soil media shape file changed to grid file before reclassify by convert to grid in theme menu. Next, the class of soil media was reclassified for rating using reclassify in analysis menu.

3.3.5 Topography

The topography shape file was computed from contour data in labels as polyline from Department of Mineral Resources in digital format. The step of processes: first step, the contour shape file was opened in ArcView. Second step, change contour shape file to TIN file by create TIN from features in surface menu. Third step, the TIN file changed to grid file by convert to grid in theme menu. After that, derive slope by surface menu. Then, the class of percent slope was reclassified for rating using reclassify in analysis menu.

3.3.6 Impact of vadose zone

The impact of vadose shape file was computed from geologic group data in labels as polygons from Department of Mineral Resources in digital format. First, the shape file was opened in ArcView again. Second, the geologic shape file changed to grid file before reclassify by convert to grid in theme menu. And then, the class of impact of vadose was reclassified for rating using reclassify in analysis menu.

3.3.7 Hydraulic conductivity

The hydraulic conductivity shape file was computed from pumping test data from Royal Irrigation Department in digital format. Labels were given to each point. The shape file was opened in ArcView. Then, the coverage of pumping test wells was taken to interpolate surface using interpolate grid in surface menu. The class of hydraulic conductivity was reclassified for rating using reclassify in analysis menu.

After that, the seven grid files were brought into the same view to process the next step of analysis. Map calculation was used for the spatial analyze. Then, the grid files were calculator to determine the vulnerability values by the DRASTIC equation as follows:

$$\text{DRASTIC index} = D_rD_w + R_rR_w + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_w$$

Where:
r = rating for the area being evaluated
w = important weight for the factor

The result was added to be theme in the view. Reclassify the DRASTIC grid into 5 classes consist of low, moderately low, moderate, moderately high, and high. The product is called vulnerability map of Phuket Island.