Malaysian Journal of Mathematical Sciences 1(2): 181 - 192 (2007)

Creation of a Ground Water Quality Index for an Open Municipal Landfill Area

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ABSTRACT

Environmental indices are an example of index which are used to access the quantitative environmental matters in quantitative. The utilization rate of ground water as a source of clean water supply is still high especially in the areas which are lacking in clean water supply from the dams. Therefore, the ground water quality in these areas need to be monitor continuously to maintain the quality to be in safe level of consumption. Unfortunately, the suitable index to assess the ground water is yet to exist in Malaysia. This study was carried out to create a suitable ground water quality index to assess the ground water quality in a closed open municipal landfill site named Sabak, which is located near the village. The specific landfill site study is namely Sabak open landfill which located near Kampung Sabak, Kelantan, Malaysia and South China Sea. Six sampling stations had been considered in this study which focusing on 32 variables consists of heavy metal, inorganic non-metal, physical characteristic and aggregate indicator. The creation of index is based on two kinds of analyses: that are Principal Component Analysis and another analysis which I put as Benchmarking Analysis. The results showed that seven variables can be used as indicator variables. They were electric conductivity, total dissolved solids, salinity, nitrate, chemical oxygen demand and iron content. The scale used for the index is from 0 to 100 where the increment of the index referring to the improvement of the quality. Results of the application of this index at study site showed that the index value was 26.67 which means that the quality is low.

Keywords: Awareness level, environmental indices, open landfill, ground water quality, principal component analysis, benchmarking analysis

INTRODUCTION

Index is a numerical standardized value of evaluation on certain matter which is in composite form. Normally, this composite form has a qualitative characteristic. In this case, the evaluation process is not an easy process since there is no standard value used as a base of comparison of the evaluation. Therefore, the indices are the best way to be introduced to determine that particular standard value.

Environmental indices are one of the portions of the indices which refer to the numerical standardized value of evaluation on environmental matters that consists of several composite factors. For example, Harkins Index was developed to assess the water quality in rivers based on six indicators or composite factors that are dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, ammoniacal nitrogen, pH and total suspended solids (Norhayati, 1981).

Ground water had been taken as an alternative clean water supply in some states in Malaysia such as Kelantan, Perlis, Terengganu, Pahang, Kedah, Sarawak and Sabah (Mohamed Azwan, 2000). The importance of ground water as the alternative clean water supply also strengthened by clean water supply crisis when some states in the west of Peninsular Malaysia faced a dry duration especially in 1998. This crisis stimulated the government to come out with a policy of allocating a certain amount of money to study the feasibility of ground water as the alternative source of clean water supply.

Since the ground water is still important to the community, therefore it is important to ensure its quality is high at all time so that the consumer health is not compromised. However, there is none form of ground water quality index applied in Malaysia (Norli, 2003; Muslina, 2005).

The activity of waste disposal in open municipal landfills is one of the factors that could cause the ground water pollution due to lack of pollution control such as water proof layers on the embankment and the base of the landfill, leachate treatment pond and monitoring well. In this case, the infiltration of leachate would pollute the purity of the ground water. Moreover, the effect of this pollution would spread further following the land gradient causing an environmental hazard nearby (Shah, 2000).

MATERIALS AND METHODS

This study was conducted at the closed section part of Sabak open municipal landfill owned by Kota Bharu Municipal Council which located near a village named “Kampung Sabak” and South China Sea. To be more specific, this landfill area is situated besides Sabak River not far from Kitang Bay. Geographically, its location is at 6°10’N and 102°19’E. This landfill area is illustrated in *Fig. 1*.

Fig. 1: The location of study area

Sampling had been conducted for three years . The site was as illustrated in *Fig. 2*. To ensure that the site was fairly studied, six sampling stations had been chosen strategically in

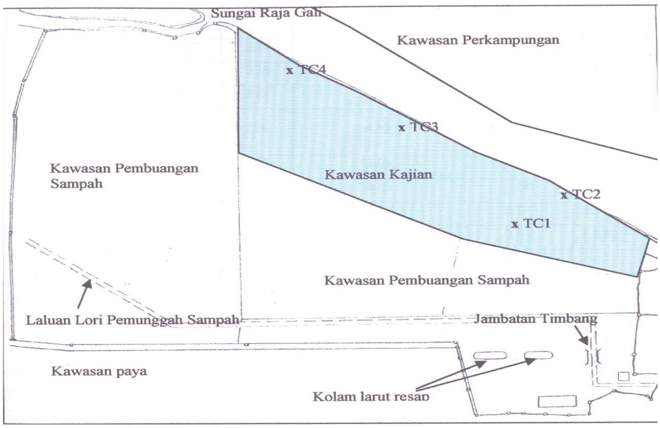

Fig. 2: The sampling station

the site. Two of the stations were at the middle right and left of the site as a representative of the middle area. Another three stations were located at the side which facing river in front of the village since this landfill was not a sanitary landfill and therefore the leachate can flow from everywhere to the river. Finally another station was chosen at the opposite site which facing the pond.

Sampling was taken in a frequency of once a month for the first 16 months and once in two months thereafter. All precautions in the standard practices had been taken out to prevent the sampling.

32 variables had been considered in this study consisting of heavy metals, physical characteristics and aggregate indicators. Table 1 shows the list of the variables studied.

TABLE 1
Classification of variables

Heavy metal	Inorganic non-metal	Physical characteristic	Aggregate indicator
Copper	Dissolved oxygen	Temperature	BOD*
Zinc	pH	Salinity	COD*
Iron	Ammoniacal nitrogen	Electric conductivity	Phenol
Lead	Nitrate	Turbidity	
Chromium trivalent	Nitrite	Total suspended solid	
Chromium hexavalent	Phosphate	Total dissolved solid	
Nickel	Sulfate		
Cobalt	Sulfide		
Manganese	Free chlorine		
Silver	Cyanide		
Tin	Arsenic		
Aluminium	Boron		
Mercury			

* BOD - Biochemical oxygen demand
COD - Chemical oxygen demand

RESULTS AND DISCUSSION

Normality test had been conducted before the principal component analysis (PCA) could be run. This is because one of the main conditions of PCA is that the data must fulfill the normality assumption (Rencher, 2002). In this study, the technique chosen for normality test is the Q-Q plot since this plot would not only tell the distribution of the data but would also gives a hint on the step needs to be taken in order to restructure do if the data do not follow the normal distributed ion. *Figs. 3* to *6* below show some of the Q-Q plots for the actual data.

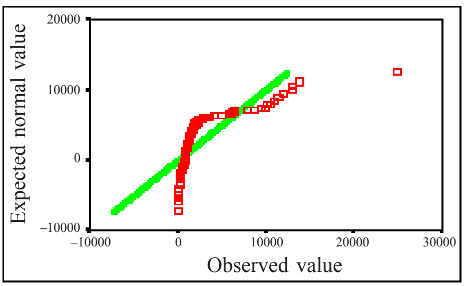

Fig. 3: Electrical conductivity

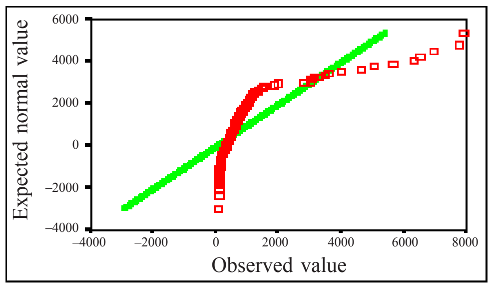

Fig. 4: Total dissolved solids

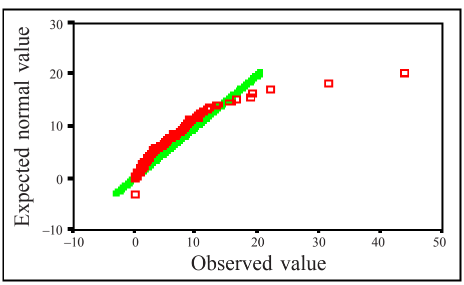

Fig. 5: Nitrate

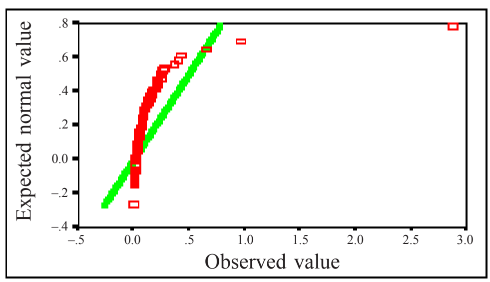

Fig. 6: Nitrite

From the Q-Q plots, it was found that the actual data do not fulfill the normality assumption and need to be log-transformed to log as a restructuring. *Figs. 7* to *10* in the following shows the Q-Q plots for the same variables after restructuring.

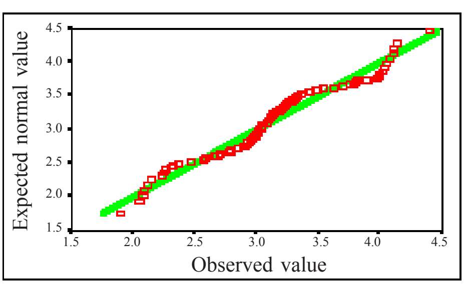

Fig. 7: Electrical conductivity

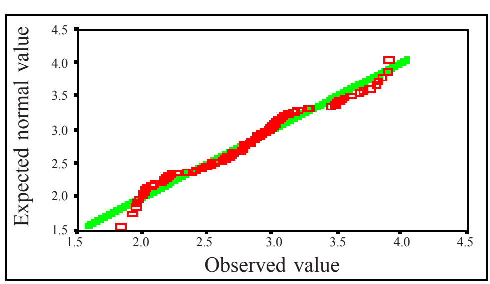

Fig. 8: Total dissolved solids

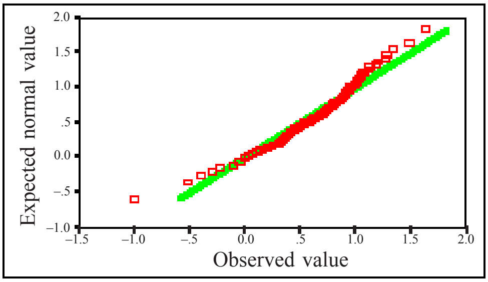

Fig. 9: Nitrate

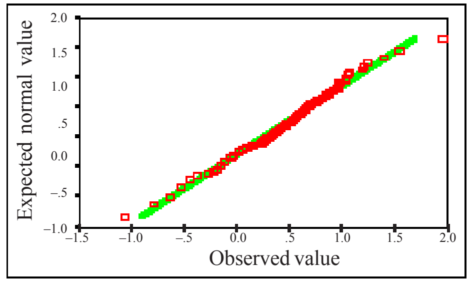

Fig. 10: Nitrite

Another important condition of PCA is the degree of correlation of the variables. In order to have a good result of this analysis, the variables should be correled to each other as much as it can. Table 2 shows the percentage of correlation between actual variables and log variables for certain ranges of correlation coefficients.

TABLE 2
Ranges of coefficients of correlation

Range	Actual variable (%)	Restructuring variable (%)
0.00 - 0.20	73.892	5.911
0.21 - 0.40	18.966	11.576
0.41 - 0.60	5.172	10.591
0.61 - 0.80	1.232	16.749
0.81 - 1.00	0.739	55.172

From the Table 2, it seems that the degree of multi-colinearity among variables is high and therefore PCA is suitable to conduct. Results of the PCA is in Table 3 as follows.

TABLE 3
Results of the PCA using restructuring data

					Component matrix after varimax rotation	
Com-ponent	Eigen value	% of variance	% of variance cumulative	Log of variable variable	1st component	2nd component
1	21.7493	74.9974	74.9974	LGCUPRUM	0.986071473	-0.16632213
2	7.25074	25.0026	100	LGCHLORINE	0.984667946	-0.17443921
3	5.7E-15	2E-14	100	LGCYANIDE	-0.982089763	0.188413633
4	1.3E-15	4.5E-15	100	LGSULFIDE	0.973171335	-0.23008162
5	6.6E-16	2.3E-15	100	LOGTEMP	-0.973067119	-0.23052198
6	5.2E-16	1.8E-15	100	LOGTSS	0.96734555	-0.25346122
7	3.8E-16	1.3E-15	100	LOGAMMO	0.952951277	0.303123513
8	3.5E-16	1.2E-15	100	LOGFERUM	0.948536188	-0.31666875
9	2.7E-16	9.5E-16	100	LGPHOS	-0.944769465	0.327735652
10	2.5E-16	8.8E-16	100	LOGCRHEX	0.942647971	-0.33378856
11	1.9E-16	6.6E-16	100	LOGCRTRI	0.930507342	-0.36627324

12	1.8E-16	6.1E-16	100	LOGPH	-0.929680053	0.368368022
13	1.3E-16	4.6E-16	100	LGCOBALT	0.924583853	-0.38097861
14	1E-16	3.5E-16	100	LOGCOD	-0.903956905	-0.42762357
15	7E-17	2.4E-16	100	LOGZINC	-0.902920286	0.429808046
16	3.2E-17	1.1E-16	100	LOGTURB	0.854483578	-0.51947841
17	-2E-17	-6.7E-17	100	LOGBOD	-0.853737808	0.520703136
18	-4E-17	-1.4E-16	100	LOGNICKEL	-0.770074137	0.637954406
19	-9E-17	-3E-16	100	LGMANGAN	0.725745523	-0.68796325
20	-1E-16	-4.5E-16	100	LGSULFATE	-0.010777838	-0.99994192
21	-2E-16	-5.4E-16	100	LOGSALIN	-0.086127006	0.996284166
22	-2E-16	-6E-16	100	LGNITRITE	0.243451634	-0.96991304
23	-2E-16	-7.9E-16	100	LOGCONE	-0.472726203	0.88120936
24	-3E-16	-9E-16	100	LGLEAD	-0.491118418	0.871092819
25	-3E-16	-1.1E-15	100	LOGDIOX	-0.575634729	0.817706952
26	-3E-16	-1.2E-15	100	LGNITRATE	0.579008714	0.815321354
27	-4E-16	-1.5E-15	100	LOGTDS	-0.625605083	0.780139911
28	-1E-15	-3.9E-15	100	LOGPHENOL	-0.646717177	-0.76272989
29	-1E-15	-3.9E-15	100	LGBORON	-0.69912567	0.71499881

From the table, the first four columns at the left showed the valus of eigen value for each component. Using the procedure of eigen value of at least 1.0000 as the base point to conclude that a certain component is important, therefore it could be concluded that there are only two main components developed from the actual variables and these two components were enough to explain all the hidden structures of the whole variables. The compositions of these two components was shown in the three columns at the right of the Table 3 above.

In this study, an index for ground water quality is created by determining the main variables from each classification of variables. In the process of choosing the suitable variables as the index indicators, the first main component from each classification were focus. The reason is the first main component is the most dominant component. Tables 4 to 7 below shows the results of PCA for each term.

TABLE 4
Results of the principal component analysis for logarithmic values of the heavy metals

				Component matrix after varimax rotation			
Com ponent	Eigen value	% of variance	% of variance cumulative	Log of variable	1st component	2nd component	3rd component
1	3.138346	34.87051	34.871	LGCUPRUM	0.908722	0.13603	0.1644235
2	1.999098	22.21220	57.083	LOGFERUM	0.852455	-0.14215	0.0205397
3	1.464013	16.26681	73.350	LOGCRHEX	0.769807	0.00114	0.3995104
4	0.867000	9.633331	82.983	LGCOBALT	0.682590	-0.02458	-0.2683600
5	0.636248	7.069422	90.052	LGLEAD	-0.129146	0.86407	0.0606652
6	0.417664	4.640709	94.693	LOGZINC	0.476284	0.78103	0.0939658
7	0.227233	2.524809	97.218	LGMANGAN	0.192789	-0.58879	0.3457137
8	0.145495	1.616609	98.834	LOGNICKEL	0.185937	0.32896	-0.8523390
9	0.104904	1.165603	100.00	LOGCRTRI	0.236962	0.20743	0.7794941

From Table 4, it could be concluded that there are only three main components developed from the actual variables. The compositions of these three components was shown in the three columns of component matrix at the right. The main variables in the first component were cuprum, ferum, chromium hexavalent and cobalt.

TABLE 5
Results of the PCA for log inorganic non-metals

				Component matrix after varimax rotation				
Com-ponent	Eigen value	% of variance	% of variance cumulative	Log of variable	1st com-ponent	2nd com-ponent	3rd com-ponent	4th com-ponent
1	2.449	22.262	22.262	LGCHLORINE	0.782	0.097	0.174	0.133
2	1.823	16.575	38.837	LGNITRITE	0.743	-0.184	-0.193	0.179
3	1.603	14.575	53.413	LGNITRATE	0.715	-0.027	-0.012	0.009
4	1.162	10.561	63.974	LGSULFIDE	0.561	0.020	0.421	-0.213
5	0.864	7.850	71.824	LGPHOS	0.145	0.814	-0.175	-0.129
6	0.775	7.045	78.869	LOGAMMO	-0.214	0.776	0.061	0.135
7	0.718	6.530	85.399	LGSULFATE	0.107	0.367	0.692	0.320
8	0.638	5.802	91.201	LOGPH	0.413	0.241	-0.677	-0.158
9	0.426	3.875	95.077	LGCYANIDE	0.350	-0.283	0.590	-0.199
10	0.342	3.111	98.188	LGBORON	0.123	0.141	0.126	0.777
11	0.199	1.812	100.00	LOGDIOX	0.018	-0.464	-0.058	0.600

From Table 5, it could be concluded that there are four main components developed from the actual variables. The main variables in the first component were free chlorine, nitrite, nitrate and sulfide.

TABLE 6
Results of the principal component analysis for log physical characteristics

				Component matrix after varimax rotation		
Com-ponent	Eigen value	% of variance	% of variance cumulative	Log of variable variable	1st component	2nd component
1	2.764516	55.29032	55.290	LOGCONE	0.911670	-0.20675
2	1.386547	27.73095	83.021	LOGSALIN	0.888544	-0.08837
3	0.351116	7.022318	90.044	LOGTDS	0.884706	-0.08279
4	0.311161	6.223227	96.267	LOGTURB	-0.027716	0.92639
5	0.186659	3.733184	100.00	LOGTSS	-0.234309	0.88115

From Table 6, it could be concluded that there are only two main components developed from the actual variables. The main variables in the first component were electric conductivity, salinity and total dissolved solids.

TABLE 7
Results of the PCA for log aggregate indicators

Component	Eigen value	% of variance	% of variance cumulative	Component matrix after varimax rotation: Log of variable	Component
1	1.496761	74.83806	74.838	LOGCOD	0.86509
2	0.503239	25.16194	100.00	LOGBOD	0.86509

From Table 7, it could be concluded that there are only one main component developed from the actual variables. This component has BOD and COD as its main variables.

All these main variables from each classification were then reanalyzed using PCA to determine which variables were really dominant to be chosen. The results of PCA on these variables were shown in Table 8.

TABLE 8
Results of the PCA for all main variables in every group of classification

				Component matrix after varimax rotation				
Component	Eigen value	% of variance	% of variance cumulative	Log of variable	1st component	2nd component	3rd component	4th component
1	4.065	31.269	31.269	LOGCONE	0.933	0.107	-0.010	0.053
2	2.980	22.922	54.191	LOGTDS	0.895	0.068	0.329	0.016
3	2.033	15.636	69.827	LOGSALIN	0.889	-0.086	-0.280	0.071
4	1.197	9.211	79.039	LGCHLORINE	0.079	0.873	0.200	-0.187
5	0.792	6.094	85.133	LGCUPRUM	0.093	0.793	-0.253	0.019
6	0.687	5.282	90.415	LOGCRHEX	-0.028	0.749	0.492	0.278
7	0.504	3.874	94.289	LGNITRITE	0.408	0.664	-0.038	0.323
8	0.384	2.954	97.243	LOGFERUM	-0.313	0.585	0.051	0.486
9	0.146	1.123	98.365	LOGBOD	-0.142	-0.303	0.860	0.016
10	0.092	0.704	99.069	LOGCOD	0.328	0.182	0.785	0.190
11	0.067	0.513	99.582	LGSULFIDE	-0.193	0.447	0.621	0.046
12	0.045	0.348	99.929	LGCOBALT	0.095	-0.019	0.205	0.874
13	0.009	0.071	100.00	LGNITRATE	0.564	0.183	-0.078	0.578

From Table 8, it could be concluded that there were four main components developed from the variables. It was clearly seen that the first component has all the main variables in physical characteristics as the main variables but in order to have a good index, this index must also consider the other classifications. Therefore, based on Hair *et al*. (1998), nitrate, nitrite, COD and ferum could be also considered as the main variables in the first component.

The next step in creating this ground water quality index is the determination of the value range. In this study, a kind of anlysis which I called benchmarking analysis was used together with the Raw Water Standard Permitted Concentration Limit set up by the Malaysian

Ministry of Health (1990) to assist in determine the range. Table 9 shows the range for benchmarking analysis used in this study.

TABLE 9
The range of benchmarking analysis

Variable	Concentration range	Benchmarking scale value
Electric conductivity	$x \le 40$	10
	$40 < x < 20000$	$\frac{(\log 20000 - \log x)}{(\log 20000 - \log 40)} \times 10$
	$x \ge 2000$	0
Total dissolved solid	$x \le 50$	10
	$50 < x < 1500$	$\frac{(\log 1500 - \log x)}{(\log 1500 - \log 50)} \times 10$
	$x \ge 1500$	0
Salinity	$x \le 1$	10
	$1 < x < 20$	$\frac{(\log 20 - \log x)}{\log 20} \times 10$
	$x \ge 20$	10
Nitrate	$x \le 1$	10
	$1 < x < 10$	$(1 - \log x) \times 10\ 0$
	$x \ge 10$	0
Nitrite	$x = 0$	10
	$0 < x < 1$	$(-\log x) / 3.001$
	$x \ge 1$	0
COD	$x \le 1$	10
	$1 < x < 10$	$(1 - \log x) \times 10$
	$x \ge 10$	0
Ferum	$x = 0$	10
	$0 < x < 1$	$\frac{-\log x}{2.01} \times -10$
	$x \ge 1$	0

The range for benchmarking analysis in this study is from 0 to 10. In this case, when the concentrations surpassed the maximum limit set by the Ministry of Health, the value is zero. The reason is the relationship between the quality and the concentration should be as given by formula.

$$\text{Quality} = 1 / \text{concentration}$$

Figs. 11-17 show the relationship between the value of benchmarking analysis and the concentration for all variables taken as index indicator.

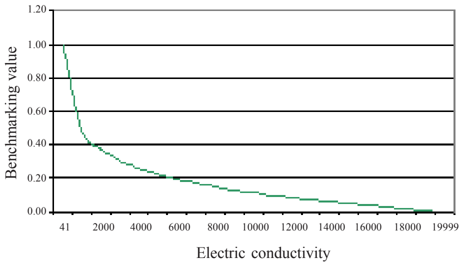

Fig. 11: Electrical conductivity

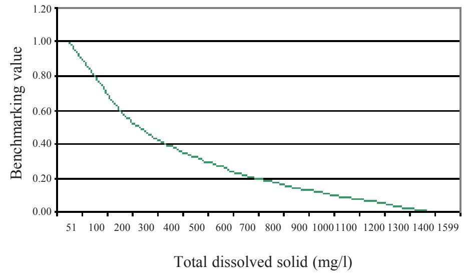

Fig. 12: Total dissolved solids

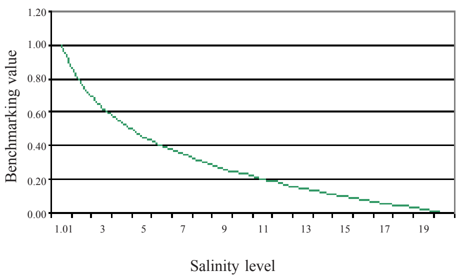

Fig. 13: Salinity

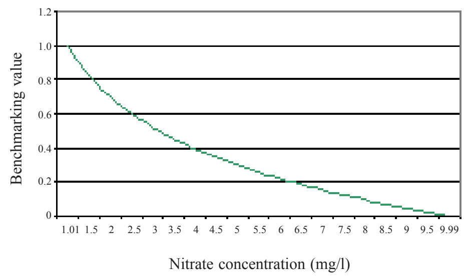

Fig. 14: Nitrate

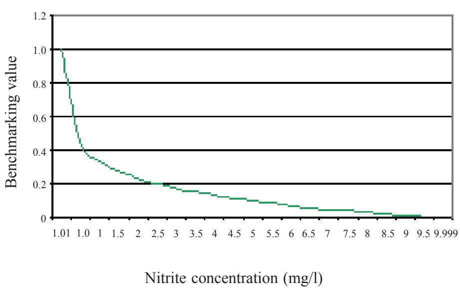

Fig. 15: Nitrite

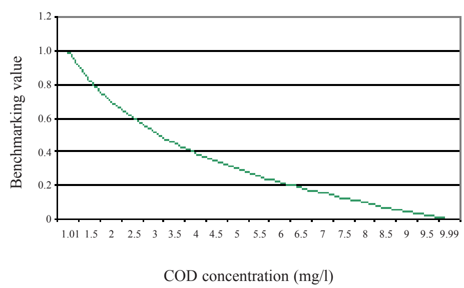

Fig. 16: COD

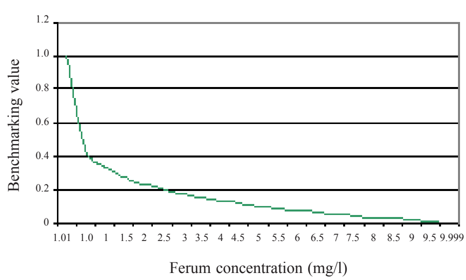

Fig. 17: Ferum

From the benchmarking range, a radar plot could be drawn to determine the shape of the polygon within the range of each variable. *Fig. 18* shows the radar plot for the study area in the last sampling.

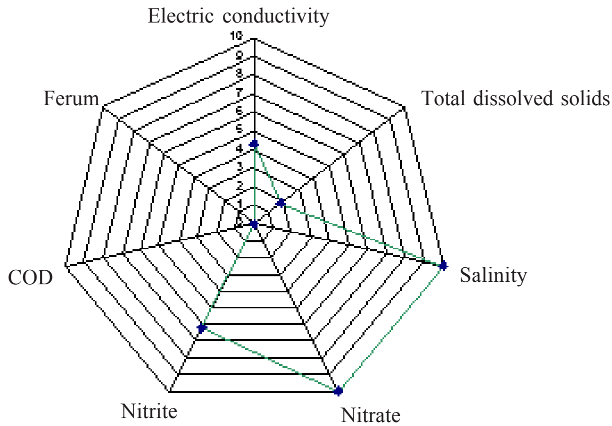

Fig. 18: Radar plot for benchmarking analysis

The ground water quality index referred to the percentage of the polygon area. The area of the polygon was calculated using the following formula.

$$A = \Sigma(0.5 \times \sin(360/7) \times \text{left value} \times \text{right value})$$

In this formula, left and right refer to the side of a triangle within a polygon. It was found that the percentage of the area of the polygon in *Fig. 18* was 26.67%. This means that the index for this site in the last sampling is 26.67 which is quite low.

Sensitivity analysis had been done on this index and it was found that for every drop of 0.1 in benchmarking value in any variable, the index would be decrease by 0.3.

CONCLUSION

This study showed that the main variables that were so dominant in the study area were electric conductivity, total dissolved solids, salinity, nitrate, nitrite, COD and ferum with the first three main variables being the main variable in physical characteristics. One of the reasons of this phenomenon is the impact of sea. The wave pressure makes the water integrated with the polluted ground water and therefore the ground water become more salty.

This index is highly sensitive. Therefore, practically, it is very useful and suitable to monitor the ground water quality especially in the areas which have the same activity as the study site location where the utility rate of ground water quality as an alternative clean water supply is high. Hopefully, the risk level will decrease and at the same time raise the consumer awareness level on the importance of maintaining the ground water quality.

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