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Assessment of Water Quality in a Coal Burning Power Plant Area of Malaysia Using Multivariate Statistical Technique

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Abstract: This study presents the results of statistical analysis of a set of physico-chemical parameters measured at 3 month intervals between November 2007 and February 2009 in the coastal area of Kapar, Malaysia. The concentration of the natural radionuclide Po-210 ranged from 0.12±0.01-1.82±0.04 mBq/L and from 24.60-348.29 Bq/kg (dry weight) in the dissolved and particulate phases of water samples, respectively. In this study, multivariate statistical methods such as principal component analysis and multiple regression analysis were used to investigate the source of pollutants and determine water quality parameters as a predictor of Po-210 concentration, respectively. Based on the statistical analysis, it can be concluded that the source of pollutants in the Kapar coastal area is related to organic parameters and terrestrial input. On the other hand, pH was identified as a predictive variable for the concentration of Po-210 in the study area.

Key words: Po-210, water quality, PCA, multiple regression, predictive, concentration

INTRODUCTION

Given the rapid industrialization and human aggregation in Malaysia today, production and disposal of wastes into rivers and bays has become a common practice, resulting in significant degradation in water quality. The largest power station in Malaysia is the Sultan Salahuddin Abdul Aziz power station, located on the western coast of Malaysia at the Malacca Straits; it is the first power station with triple fuel firing capability (gas, oil and coal) in Malaysia. This power station lies between the mouthes of the Kapar Besar and Serdang Kecil Rivers and is adjacent to the coast. Two residential villages, Tok Muda and Sungai Serdang are situated along the coast. The power plant uses seawater as a source of cooling water and the sea is used as the pathway for transporting coal. Furthermore, the surrounding coastal area is the ultimate recipient of the fly ash that is produced by coal burning.

Coal emissions and biomass burning can be the reason for the unusually high levels of Po-210 in the coastal area (Marenco and Fontan, 1972). Po-210 ($T_{1/2}$ = 138.4 d) is an alpha emitter within the U-238 decay series; among natural radionuclides occurring in the ocean, alpha emitters are considered the most important because of their radiation exposure. The concentration of Polonium-210 in rivers, estuaries and coastal systems may vary widely due to the geology of the water shed and chemical weathering conditions. In addition, the bio-geochemical behaviour of Po-210 in coastal areas is complex because of land-sea air-mass interactions and their relation to fluctuations in mother nuclide Pb-210 levels in coastal atmospheric environments (Hussain *et al*., 1998; Kim *et al*., 2000; Tateda *et al*., 2003). The concentration and distribution of this radionuclide is interesting as it provides important information for the monitoring of environmental contamination. In addition, in order to provide an indication of changes in water resources induced by anthropogenic activities, the status of water quality needs to be actively monitored.

In recent years, multivariate statistical methods have been effectively applied to assessments of surface water quality and evaluations of spatial variations in ground and coastal water as well as for identification of latent pollution sources in marine sediments (Helena *et al*., 2000; Reisenhofer *et al*., 1998; Shin and Fong, 1999; Vega *et al*., 1998; Yeung, 1999; Ruggieri *et al*., 2011). A study focused on temporal trends analysis of in-situ rainfall and temperature record for Lodwar in Turkana County, Kenya using non-parametric Mann-Kendall test statistic (Z) at 5% significance level and reviled statistically significant seasonal maximum and minimum temperature trends (Alonso-Hernandez *et al*., 2002). In the field of radiochemistry such statistical analysis is not yet,

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extensively applied. Therefore, the present study was undertaken to investigate the distribution of Po-210 around Malaysia's coal burning power station and to evaluate its water quality status using multivariate statistical techniques.

MATERIALS AND METHODS

Sampling and radiochemical analysis: The study was carried out at the Kapar Coastal area which is not far from the Sultan Salahuddin Abdul Aziz Power Plant (SSAAPP). The samplings were conducted at 3 month intervals between November 2007 and February 2009. Water samples were collected from seven different stations (Fig. 1) using 25 L polypropylene bottles and water quality parameters were measured by calibrated multi-parameter YSI 6000 series.

A radiochemical separation method was used to estimate Po-210 in the samples (Flynn, 1968). About 25 L of water samples were filtered through pre-weighted Whatman® cellulose filter paper (pore size 0.45 μm). After drying the precipitated residue, Po-209 with a known activity was added as a yield tracer. Then, the samples were digested with nitric acid and perchloric acid. The solution was filtered and gently evaporated to dryness. Then the samples were dissolved in 50 mL of 0.5 M HCl along with a pinch of ascorbic acid to reduce Fe (3) and Po-210 was spontaneously deposited on brightly polished silver discs (2 cm diameter) for a period of 3-4 h at a temperature of 70-90°C. The discs were counted for Po-210 activity with an alpha spectrometer. The combined standard uncertainty of 2σ was calculated including all sources of uncertainty. The Po-210 deposition was carried out within 2 months of sampling and activities were calculated at the date of sampling.

The filtered water was acidified with concentrated nitric acid (HNO_3) and maintained at pH = 2. Then about 0.1 mL of 25 mgL^{-1} Fe^{3+} as carrier and 0.05 mL of 0.45 Bq mL^{-1} Po-209 as yield tracer were added to the water samples. After that, Na_2CO_3 was added to the sample and precipitated with ammonium hydroxide (NH_4OH). The iron (2) hydroxide [$Fe\ (2)\ (OH)_2$] precipitate was dissolved with nitric acid and perchloric acid ($HClO_4$). After heating the solution for 15 min, NH_4OH was added to maintain the pH at 8.0 and it was centrifuged in order to separate the solution and colloidal phase to obtain a solid $Fe\ (OH)_3$ precipitate. The precipitated residue was dissolved in $HclO_4$ and dried at a temperature of 70°C. It was then dissolved in 80 mL 0.5 M HCl, plated and counted according to the above-mentioned method.

Statistical analysis: All the statistical analyses were conducted using the analytical software SPSS (Version 14). The Shapiro-Wilk test was performed to examine the normality of the data set. To identify differences, Kruskal-Wallis and ANOVA tests were used. In the present study, Principal Component Analysis (PCA) was performed to identify the pollutant source in the Kapar coastal area. PCA is designed to transform the original variables into new, uncorrelated variables (axes), called principal components which are linear combinations of the original variables. The new axes lie along the directions of maximum variance (Shrestha and Kazama, 2007). This

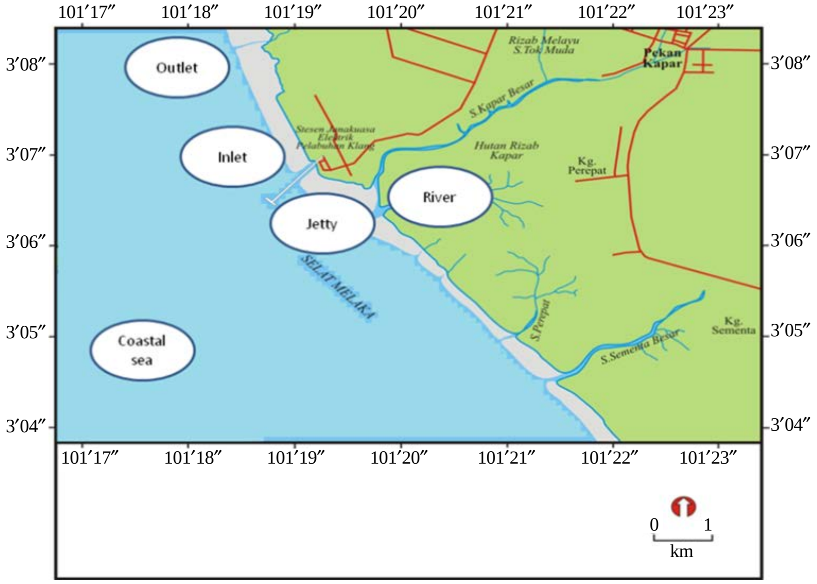

Fig. 1: The sampling location of Kapar coastal area

reduces the dimensionality of the data set by explaining the correlation amongst a large number of variables in terms of a smaller number of underlying factors (Principal Components or PCs), without losing much information (Vega *et al*., 1998; Helena *et al*., 2000; Wu *et al*., 2010). Each Principal Component (PC) can be expressed as follows:

$$zij = pci1\times1j+pci2\times2j+, ..., +pcimxmj \quad (1)$$

Where:

z = The component score
pc = The component loading
x = The measured value of the variable
I = The component number
j = The sample number
m = The total number of variables

Regression analysis includes any technique used for modelling and analysing several variables when the focus is on the relationship between a dependent variable and one or more independent variables. To identify water quality parameters that affect the concentration of Po-210 in water, multiple regression analysis was carried out. The k-variable multiple linear regression model is generally expressed by the relationship between a single outcome variable and several explanatory variables. The dependent variable is assumed to be a linear function of one or more independent variables plus an error introduced to account for all other factors, given as:

$$y_i = \beta_0+\beta_{1x1i}+\beta_{2x2i}+, ..., +\beta_{kxki}+e_i \quad (2)$$

Where, i = 1, 2, ..., n, y_i is the dependent variable and x_{1i}, ..., x_{ki} are the independent or explanatory variables. β_0 is the regression intercept, β_1, ..., β_k are the regression coefficients or regression parameters and e_i is the disturbance or error term. The dependent variable y_i is assumed to be a linear function of independent variables, x_{1i}, ..., x_{ki} plus an error, e_i introduced to account for all other others. The errors e_i are again due to measurement errors in y and errors in the specification of the relationship between y and x's. The goal of regression analysis is to obtain estimates of the unknown parameters β_1, β_2, ..., β_k which indicate how a change in one of the independent variables affects the values taken by the dependent variable.

RESULTS AND DISCUSSION

Physico-chemical parameters of the Kapar coastal area: The concentration of Po-210 in the water samples and the water quality parameters are listed in Table 1. The concentration of Po-210 in the dissolved phase of water samples collected from the Kapar costal area ranged from 0.12±0.01-1.82±0.04 mBq/L with a mean value of 0.69±0.34 mBq/L. Suspicions related to abnormal distribution were checked based on normality graphs and Shapiro-Wilk test statistics. The p-values of the Shapiro-Wilk test for the dissolved phase of the seawater ($p = 0.027$) indicated non-normal distribution of the data set. Therefore the non-parametric Kruskal-Wallis test was performed to compare sampling stations. A comparison between sampling sites using the Kruskal-Wallis test (χ^2) showed there were significant differences ($p = 0.001$) in Po-210 concentrations in the dissolved phase of surface water from the seven sampling locations. On the other hand, Po-210 concentrations in the particulate phase covered a wide range, varying between 24.60 and 348.29 Bq/kg (dry weight) with a mean value of 85.90±65.62 Bq/kg (dry weight). The Shapiro-Wilk test ($p = 0.000$) revealed a non-normal distribution in the data set of particulate Po-210 concentration.

At the $\alpha = 0.05$ level of significance of the Kruskal Wallis test (Chi-square), it can be concluded that there was no significant difference ($p = 0.067$) in the median test scores of particulate Po-210 concentrations between the seven sampling locations. Cherry and Shannon measured Po-210 activity in open ocean surface water and found that the values were approximately 0.30-2.4 mBq/L with an average value of 1 mBq/L which is considered a typical value. Therefore, the measured values in the present study are within the range of reported typical values. The concentration of Po-210 dissolved in water is comparable to the surface water concentration of Po-210 reported in other locations worldwide (Suriyanarayanan *et al*., 2008; Shaheed *et al*., 1997; Haridasan *et al*., 2001; Marbaniang *et al*., 2010; Shannon *et al*., 1970; Parfenov, 1974). However, 99% of the total Po-210 activity in surface seawater from the Kapar coastal area was derived from the particulate phase. A similar trend in Po-210 accumulation patterns in water samples was revealed for the North coast of Wales (Wildgust *et al*., 1998) and Kuala Selangor of Malaysia (Theng and Mohamed, 2005).

The average water temperature measured along the Kapar coastal area was 32.34°C with the lowest value observed in August 2008 at the river station and the highest value in May 2008 at the station outlet (Table 1). There was no significant difference [$F (6.34) = 2.06$, $p = 0.084$) in temperature measured along the coastal area. Generally, the lowest temperature was recorded in the river as the surroundings are covered with vegetation. Pallan reported that vegetation or trees

Table 1: The physic-chemical parameters of water from Kapar coastal area during different sampling period

Parameters/Station	Nov-07	Feb-08	May-08	Aug-08	Nov-08	Feb-09
Po-210 in dissolve phase (mBq/L)						
Ash pond	NA	0.9±0.03	1.82±0.04	0.92±0.05	1.36±0.02	0.94±0.13
River	0.82±0.04	0.22±0.01	0.92±0.05	0.86±0.02	0.93±0.03	0.81±0.04
Estuary	0.90±0.05	0.24±0.01	0.95±0.01	0.91±0.01	0.78±0.01	0.57±0.03
Inlet	0.33±0.01	0.12±0.01	0.42±0.02	0.35±0.03	0.45±0.02	0.24±0.01
Jetty	1.07±0.03	0.8±0.05	1.09±0.05	0.95±0.01	0.82±0.04	0.60±0.03
Outlet	0.79±0.01	0.22±0.01	0.84±0.01	0.72±0.02	0.55±0.01	0.33±0.01
Coastal sea	0.55±0.02	0.15±0.01	0.69±0.02	0.51±0.04	0.39±0.01	0.50±0.02
Po-210 in particulate phase (Bq/kg)						
Ash pond	NA	84.78±3.78	348.29±15.54	151.67±6.77	135.22±6.24	129.54±4.32
River	48.37±2.17	24.6±1.1	137.32±6.13	102.6±4.58	63.27±3.94	55.32±3.45
Estuary	79.9±2.15	26.19±1.12	201.7±9	72.45±3.23	52.45±1.23	50.21±1.09
Inlet	51.83±2.31	25.9±1.56	108.91±4.86	39.7±81.78	33.62±2.18	28.78±2.34
Jetty	89±2.25	44.02±0.18	125.74±5.61	42.35±1.89	50.75±2.99	61.89±3.57
Outlet	60.9±2.19	28.69±0.52	209.69±9.36	59.67±2.66	49.43±3.05	50.33±1.35
Coastal sea	149±2.23	50.09±1.79	210.37±9.39	75.56±3.37	56.52±2.15	55.51±2.33
Temperature (°C)						
Ash pond	NA	31	30.8	32.3	37.5	33
River	33.55	31	34.6	27.3	31.1	29.3
Estuary	31.8	31.3	32.7	32.2	33.2	29.7
Inlet	33.9	32.3	30.5	31.2	32.5	30.1
Jetty	33.5	33.3	30.5	29.3	32.5	30
Outlet	35.2	34.1	40.7	38.3	36.7	30.2
Coastal sea	31.6	30	40.5	29.3	30.7	29.5
Salinity (psu)						
Ash pond	NA	10	31.5	27.2	28.7	27.7
River	5.2	8.1	20.3	4.3	0.8	1.3
Estuary	15.5	27.6	30.4	16.6	13.1	3.5
Inlet	29.4	28.5	30.9	30.8	25.3	27.8
Jetty	27.9	29	31.2	29.2	25.7	28.6
Outlet	28	30.3	31	29.7	27.8	30.4
Coastal sea	28.8	31.1	31.9	28.4	28.3	31.3
DO (mg/L)						
Ash pond	NA	11.3	7.72	7.1	8.71	10.7
River	7.55	0.9	1.25	1.85	0.17	1.2
Estuary	6.93	4.3	6.43	5.05	3.24	2.5
Inlet	7	4.6	5.93	6.85	4.46	5.02
Jetty	6.07	5.33	6.09	3.2	5.58	5.18
Outlet	3.9	5.05	9.5	6.17	6.83	5.93
Coastal sea	4.91	4.98	8.69	7.2	5.62	6.55
Conductivity (mS/cm)						
Ash pond	NA	47	54	42.63	192.6	43
River	44.82	42.2	32.7	33.5	14.7	24
Estuary	38.07	43.1	47.1	26.93	19.55	57
Inlet	43.47	46.1	47.6	46.7	39.93	43.41
Jetty	43.83	46	48.1	49.61	40.11	44.5
Outlet	42.13	47.1	55.5	58.2	43.92	46.9
Coastal sea	33.63	46.3	53.8	48.32	44.15	48.2
pH						
Ash pond	NA	8.45	7.74	7.74	6.06	7.9
River	8.29	7.97	6.5	6.06	5.68	7.46
Estuary	8.9	8.14	5.26	6.26	6.56	6.6
Inlet	8.2	8.78	7.2	7.9	7.31	7.43
Jetty	8.5	8	7.5	8.5	7.4	7.4
Outlet	8.36	8.5	6.5	7.67	7.68	7.23
Coastal sea	8.11	7.92	6.4	7.4	7.5	6.77
Turbidity (NTU)						
Ash pond	NA	5.76	6.14	6.66	2.67	7.94
River	8.96	85.6	24.8	33.33	41.7	68.7
Estuary	20.3	18.7	14	19.9	44.2	46.7
Inlet	24	23.5	20.4	25	8.21	20.5
Jetty	23.9	23	13.2	5.16	28.15	74.3
Outlet	20	19.4	9.25	5.02	8.01	54.9
Coastal sea	76.2	7.76	8.78	5.07	8.55	19.3

and plants growing along the banks of a river prevent the sun from heating up the river. Temperature tends to increase towards the sea because the sun shines directly on the water and is

Table 2: Interim national water quality standards for Malaysia

		Classes					
Parameters	Unit	I	IIA	IIB	III	IV	V
DO	mg/L	7	5-7	5-7	3-5	<3	<1
pH	-	6.5-8.5	6-9	6-9	5-9	5-9	-
Conductivity*	umhos/cm	1000	1000	-	-	6000	-
Salinity (%)	(%)	0.5	1	-	-	2	-
Temperature	°C	-	Normal	-	Normal	-	-
			+2°C	2°C	-	-	-
Turbidity	NTU	5	50	50	-	-	-

Related parameters, only one recommended for use class uses; class 1: Conservation of natural environment water supply 1-practically no treatment necessary. Fishery 1-very sensitive aquatic species; Class 2A: Water supply 2-conventional treatment required fishery 2-sensitive aquatic species; Class 2B: Recreational use with body contact; Class 3: Water supply 3-extensive treatment required. Fishery 3-common, of economic value and tolerant species livestock drinking; Class 4: Irrigation; Class 5: None of the above

therefore, able to quickly warm the surface. The highest temperature was found at the station outlet where the cooling system discharges hot water from the power plant. At the same time, comparatively higher water temperatures were observed in the ash pond because of the lentic characteristic of the water body as well as the ash dumped from the power plant. However, temperature values at all sampling points were within the Interim National Water Quality Standards for Malaysia's (INWQS) threshold level for the support of aquatic life and water supply for public and industrial uses (Table 2).

From the salinity results it can be concluded that there was a wide fluctuation in the range of salinity with the lowest value observed at the river sampling point (0.8 psu) in November 2008 and the highest value from the coastal sea sampling point (31.9 psu) in May 2008. Moreover, comparatively higher salinity was observed at the ash pond which is linked to the sea. The average salinity values ranged from 6.96 psu (river) to 30.2 psu (coastal sea) and showed a gradual increase from upstream to downstream stations along the coastal area. Abowei (2010) also observed a similar result along the Nkoro River of Nigeria. There was a statistically significant difference in the salinity as determined by one-way ANOVA test [F (6, 34) = 13.89, p = 0.000]. In this study, the average salinity was recorded at 2.3% which is greater than the recommended value of INWQS which states that 0.1% salinity is recommended for aquatic life (Table 2). River inputs, influx of groundwater, variable evaporation rates, freshwater runoff with rainfall and tidal and ocean currents may all influence salinity levels in coastal waters.

Conductivity is an important parameter of water quality as a measure of the total amount of dissolved salts or the total quantity of dissolved ions in water. In the present study, the conductivity values ranged from 14.7 mS/cm at the river station in November 2008-60.33 mS/cm at the ash pond at the same time. In the one-way ANOVA analysis, the significant value of homogeneity was 0.000 which indicates significant variance. In addition, there was no significant difference in conductivity between the two sites [F (6, 34) = 1.77, p = 0.13]. Generally, the lowest conductivity was found at the river station and values increased towards the sea. On the other hand, comparatively higher values of conductivity were recorded at the ash pond, due to the higher salinity at this sampling point. Edokpayi *et al.* (2010) recorded conductivity values of 27.65 and 26.02 mS/cm during the dry and rainy seasons, respectively which are much lower than those in the present study. The average conductivity recorded, 42530 μS/cm is much higher than the recommended threshold levels for Malaysia (Table 2).

Dissolved Oxygen (DO) values obtained along the coastal area of Kapar ranged from 0.17 mg/L at the river sampling station in November 2008-11.3 mg/L at the ash pond in February 2008. Meanwhile, the mean DO was 23.56 mg/L. The homogeneity of variance test for one-way ANOVA revealed a value of 0.634 which indicates that the variances are significantly different. There was a significant difference between sampling sites with regards to DO concentration [F (6.34) = 7.68, p = 0.000]. From the post hoc test, it can be seen that the DO of the ash pond differs significantly from those of the river, estuary, inlet and jetty sampling stations. Similarly, the DO concentration in the river was significantly different from those at the power plant inlet, outlet and coastal sea stations. There was an increase in DO between the river and the open sea because the tide helps to increase DO in that body of water. Abowei (2010) also observed a higher DO value at the upstream sampling station than at the downstream station. Similar trends were also reported by Hart and Zabbey (2005) for woji creek and by Connell and Miller (1984) for the Trans-Amadi creek. These findings support the present study. Surprisingly, a very high value of DO was observed at the ash pond. This might be the result of photosynthesis by aquatic vegetation as oxygenation in an aquatic ecosystem is the result of an imbalance between the processes of photosynthesis, degradation of organic matter and reaction (Aston, 1980). Levels of DO with concentrations greater than 8 mg/L are not usually recommended for raw water supplies (DOE, 1985). In addition, the DO level of the ash pond is higher than the threshold level for Malaysian surface water (Table 2).

In this study, very low levels of DO were recorded in the river; probably due to the discharge of organic matter from terrestrial and agricultural run off. Other studies indicate that DO recorded from Malaysian river water has been known to range from 0.80-8.80 mg/L. Edokpayi *et al.* (2010) reported a range of DO between 4.6 and 6.6 mg/L during the rainy season and 4.4 to 6.1 during the dry season. Coastal waters typically require a minimum of 4.0 mg/L and do better with 5.0 mg/L of oxygen to provide for optimum ecosystem functioning and highest carrying capacity (UNESCO-WHO., 1978). Those values are within the range of this present study.

The lowest pH level recorded along the Kapar coastal area was 5.26 in May 2008 and the highest value of 8.9 was recorded in November 2007 at the same location. There were no significant differences in pH values at the different sampling locations [F (6.34) = 1.0, p = 0.38]. Low pH values are found in natural waters rich in organic matter (Wetzel, 1983) and this was especially evident in the river and estuary where there were inputs of terrestrial runoff rich in organic matter. Surface waters normally have pH values of between 6.5 and 8.5 and are only rarely outside the range of 4-9 (Thanapalasingam, 2005). A decrease in pH would increase metal availability, leading to greater uptake by organisms which can then cause physiological damage to aquatic life. However, in the present study, the average range of pH, 6.56-7.72 is within the normal range. A fall in pH may allow release of toxic metals that would otherwise be absorbed by sediment and essentially be removed from the water system. Similarly, the average level of pH measured along the Kapar coastal area was 7.44 which is within the INWQS threshold range for all classes (Table 2). Therefore, it can be assumed that, in terms of pH level, water in the Kapar coastal area is still suitable for supporting aquatic life.

In the present study, the turbidity of water samples varied from 2.69 NTU at the ash pond in November 2008-68.7 NTU at the river in February 2009. There were no significant differences in turbidity values at different locations. The highest average turbidity was recorded at the river (35.41 NTU) because of its terrestrial input and lower depth. Wong reported that the growth of phytoplankton (chlorophyll a) and suspended solids makes water turbid and values are always high near coasts and estuaries. This finding also supports the present study. The average turbidity values at all stations during the 6 month sampling period was 22.58 NTU which is less than the INWQS threshold range for all classes (Table 2).

Source identification of water quality using principal component analysis: Principal Component Analysis (PCA) was carried out to identify the source of pollutants in the Kapar coastal area because this technique can extract latent information and explain the structure of available data in detail (Wu *et al.*, 2010). Before applying PCA, normality was checked using the Shaprio-Wilk test which revealed a non-normal distribution in the water quality parameters other than DO and pH. Therefore, the non-normal distributed data was first log transformed and then used for further analysis. A correlation analysis was applied and the results are presented in Table 3. The highest positive correlation existed between salinity and conductivity, whereas the highest negative correlation was demonstrated between dissolved oxygen and turbidity.

The Kaiser-Meyer-Olkin (KMO) measure was applied to examine the suitability of the dataset for principal component analysis. KMO is a measure of sampling adequacy that indicates the proportion of variance. The KMO value must be greater than 0.5 (Wu *et al.*, 2010). In this study the KMO value was calculated as 0.7, indicating that PCA could achieve a significant reduction in the dimensionality of the original data set. The results of the PCA are presented in Table 4 and the scree plot of principal components is shown in Fig. 2. The projection of the original variables on the subspace of the PCs is called loading and coincides with the correlation coefficients between PCs and variables (Razmkhah *et al.*, 2010; Vega *et al.*, 1998). Component loadings can be used to determine the relative importance of a variable as compared to other variables in a PC and do not reflect the importance of the component itself (Ouyang *et al.*, 2006). Therefore, positive values for each component are related to important inputs and negative values correspond to low inputs (Parinet *et al.*, 2004). However, two principal components accounting for 65.42% of the total variance were retained on the basis of the eigenvalue greater than one rule. PC1 contributed 43.29% of the total variance because of the strong positive loading for DO (0.864), salinity (0.751) and conductivity (0.780), compared to a moderate positive correlation for temperature (0.553), weak positive correlation for Po-210 (0.422) and strong negative correlation for turbidity (-0.769). On the contrary, PC2 explained 22.131% of total variance which was considered of less importance. PC2 only had a strong positive loading for pH (0.847) and a strong negative loading for Po-210 (-0.73).

Table 3: Correlation matrix of water quality parameters for Kapar coastal area

Variables	Po-210 (water)	DO	pH	Temperature	Salinity	Conductivity	Turbidity
Po-210 (water)	1.000						
DO	0.418	1.000					
pH	-0.400	0.176	1.000				
Temperature	0.271	0.396	-0.086	1.000			
Salinity	0.130	0.528	0.265	0.304	1.000		
Conductivity	0.116	0.574	0.269	0.231	0.631	1.000	
Turbidity	-0.304	-0.624	-0.054	-0.358	-0.395	-0.500	1.000

Table 4: Loadings and eigenvalues of water quality parameters in significant principal components for kapar coastal water samples

Po-210 (water)	PC1 (0.422)	PC2 (-0.738)
DO	0.864	-0.049
pH	0.190	0.847
Temperature	0.553	-0.317
Salinity	0.751	0.284
Condductivity	0.780	0.304
Turbidity	-0.769	0.106
Eigenvalues	3.030	1.549
Variance (%)	43.292	22.131
Cumulative (%)	43.292	65.423

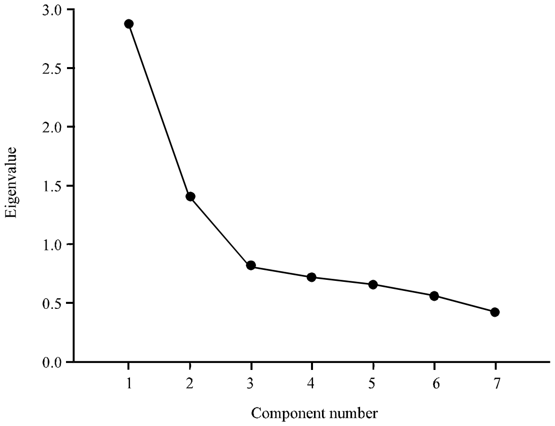

Fig. 2: Scree plot of PCA on the water quality parameter of Kapar coastal area

Dissolved oxygen in seawater comes from mixing (where the surface meets the atmosphere) and as a by-product of photosynthesis. However, the amount of dissolved oxygen in seawater varies considerably with temperature and salinity. Oxygen availability in the sea can also be affected by human activities on land. For example, nutrient run-off from farmland can cause rapid growth of phytoplankton, resulting in phytoplankton 'blooms'. When these large numbers of organisms die, the sharp increase in decomposition depletes oxygen levels. On the other hand, variations in ocean salinity can occur due to several factors. The most common factor is the relative amount of evaporation or precipitation in an area. If there is more evaporation than precipitation then salinity increases. If there is more precipitation (rain) than evaporation then salinity decreases. Another factor that can change salinity in the ocean is a very large river emptying into the ocean. Furthermore, conductivity increases as the salt content of the water increases. As a result, it is clear that the coastal area of Kapar is affected by organic-related pollutants and terrestrial input.

Estimated multiple regression model for determining predictors of Po-210 concentration: Multiple regression analysis was carried out to determine the predictor parameter for Po-210 in water of the Kapar coastal area. The hypotheses used in this study are:

$$H_0: \beta_2 = \beta_3 = ... = \beta_k = 0$$

(i.e., all the slope coefficients are simultaneously zero) H_1 = Not all the slope coefficients are simultaneously zero. The model of multiple linear regression can be represented as:

$$y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{3i} + \beta_4 x_{4i} + \beta_5 x_{5i} + \beta_6 x_{6i} + e_i$$

Where:

y_i = Response variable (Po-210 in water)
β_0 = Constant variable
β_1 = Coefficient of first control variable, x_{1i}
β_2 = Coefficient of second control variable, x_{2i}
β_3 = Coefficient of third control variable, x_{3i}
β_4 = Coefficient of fourth control variable, x_{4i}
β_5 = Coefficient of fifth control variable, x_{5i}
β_6 = Coefficient of sixth control variable, x_{6i}
x_{1i} = Controlled variable (DO)
x_{2i} = Controlled variable (pH)
x_{3i} = Controlled variable (temperature)
x_{4i} = Controlled variable (salinity)
x_{5i} = Controlled variable (conductivity)
x_{6i} = Controlled variable (turbidity)
e_i = Error

The estimated results of the multiple regression model on Po-210 activity in relation to environmental parameters are summarized in Table 5. Overall, the estimated result is satisfactory because it fulfils the following criteria for good results. First, the R^2 which is a

Table 5: Results of the multiple regression analysis for the prediction of Po-210 concentration in water

Variables	Estimated coefficient (β)	SE
Constant	6.04 (1.41)^{NS}	4.26
DO ()	0.12 (2.61)^{NS}	0.04
pH ()	-0.34 (-3.33)**	0.10
Temperature ()	0.23 (0.21)^{NS}	1.08
Salinity ()	0.013 (0.09)^{NS}	0.13
Conductivity ()	-0.19 (-0.44)^{NS}	0.43
Turbidity ()	-0.02 (-0.22)^{NS}	0.13

Number of observation: 41; df of regression: 6; R: 0.641; R^2: 0.411; Adjusted R^2: 0.308; Standard error of the estimate: 0.531; F-value: 3.962; Figures in parentheses denote the t-values of the regression coefficients; **Indicate significant at 0.05 level; NS Indicates not significant

measure of the goodness of fit of the estimated regression model was estimated to be 0.415. In general, R^2 results for samples where the observations are different units at a single point in time ("cross section") are often quite low. This usually occurs because there is much more random variation across individual units at a point in time than across time for the same unit. The adjusted R^2 value tells us that our model accounts for 31.2% of the variance in the criterion variable. Second, the ANOVA table assesses the overall significance of the model. In our model, $p<0.05$; thus, it can be considered significant. Third, to identify the occurrence of multicollinearity, VIF values were calculated. VIF values were found to be <2.5 in all analyses; thus, it can be concluded that there is no multicollinearity problem.

The estimated final multiple regression equation for Po-210 concentration in water and water quality parameters is as follows:

$$\begin{aligned} Y = {} & 6.04+0.12X_1-0.34X_2+0.23X_3+0.01X_4-0.19X_5-0.02X_6 \\ & (1.41)\quad (2.61)\quad (-3.33)\quad (0.21)\quad (0.09)\quad (-0.44)\quad (-0.22) \end{aligned}$$

In the above equation, the figures in parentheses are the t-values of the regression coefficients. Table 5 shows that most of the explanatory variables are not significantly related to the Po-210 concentration in the water as indicated by the R^2, adjusted R^2 and F-values. In this model, the variable pH (X_2) is shown to be statistically significant ($p<0.05$) but negatively related to the Po-210 concentration of the water. This indicates that the acidic nature of water can accelerate the concentration of Po-210 in the water body. The acidic nature of surface waters is attributed to the presence of humic acid associated with the biological decomposition of vegetation buried in the water body (Offiong and Edet, 1998). Organic matter also influences the level of pH and it is well known that Po-210 concentration is related to organic matter. Higher organic matter content usually leads to a higher occurrence of decomposition and thereby influences the pH level (Lai and Norajiki, 1988). Connell and Miller (1984) stated that a decrease in pH would increase metal availability, in turn leading to greater uptake by organisms that can cause physiological damage to aquatic life. On the other hand, water acidity leads to the dissolution of toxic metal from the sediment (Preda and Cox, 2000). Therefore, it can be concluded that in the Kapar coastal area, pH can be used as a predictor variable for the concentration of Po-210.

CONCLUSION

The measurement of dissolved and particulate activities of Po-210 revealed that Po-210 was concentrated to a greater degree in suspended particles than in seawater. There were significant differences (p = 0.001) in Po-210 concentrations in the dissolved phase of surface water from seven sampling locations, whereas no significant differences were observed in the particulate phases. The observed values of salinity, DO and conductivity are higher than those called for in the Interim National Water Quality Standards for Malaysia (INWQS). However, the temperature, pH and turbidity values are within the range of the threshold level.

In this study, principal component analysis was used for pollution source identification in the Kapar coastal area. The results of the principal component analysis suggested that the parameters responsible for variations in water quality mainly related to organic parameters and terrestrial sources. In addition, this study used multiple linear regression to build a forecasting model for Po-210 concentration. Based on the output of the multiple regression analysis, it can be concluded that only pH can be a predictor of the concentration of Po-210 in the Kapar coastal area. Furthermore, the multivariate statistical method used here can be recommended as a useful tool to assess water quality as well as in the field of radiochemical analysis.

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