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# The Assessment of Mangrove Sediment Quality in Mengkabong Lagoon: An Index Analysis Approach

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Abstract: The objectives of this study are to use different types of indexes to assess the current pollution status in Mengkabong lagoon and select the best index to describe the Mengkabong sediment quality. The indexes used in this study were Enrichment Factor (EF), Geo-accumulation Index (Igeo), Pollution Load Index (PLI) and Marine Sediment Pollution Index (MSPI). Different indexes give diverse status of Mengkabong lagoon sediment quality. MSPI has an advantage over the earlier indexes and viewed as a simple summary of the state of the sediment. However, the heavy metal assessment indices are not to be used as the only indicator for sediment quality. Site-specific, biological testing and ecological analysis of existing benthic community related to sediment contamination are needed for final decision making in the case of Mengkabong lagoon.

Key words: Heavy Metals; Indexes; Sediment Quality; Surface Sediment.

## INTRODUCTION

Heavy metal cycling is a serious problem addressed in mangrove environment (Marchand et all, 2006; Pekey, 2006). The high concentrations of heavy metals are derived from anthropogenic inputs from industrial activities around the estuary such as discarded automobiles, batteries, tires, waste water disposal etc (Shriadah, 1999; Bloom and Ayling, 1977). For an example, study done by Bloom and Ayling (1977) in Derwent Estuary revealed high concentration of zinc and lead due to a zinc refining company found near the estuary. Moreover, the study by Kehrig et all, (2003) suggests that metal concentrations in sediment samples from Jequia mangrove forest, Brazil, have significantly exceeded the natural concentration of heavy metals. The results indicated a significant anthropogenic input of zinc, lead, chromium, copper and methyl mercury. Sediments act as sinks and sources of contaminants in aquatic systems because of their variable physical and chemical properties (Pekey, 2006; Marchand et all, 2006; Rainey et all, 2003; Evans et all, 2003). Analysis of pollutants in sediments is vital as they were adsorbed by material in suspension and by fine-grained particles (Shriadah, 1999). Pekey (2006) demonstrated the heavy metals tend to be trapped in aquatic environment and accumulate in sediments.

According to Caeiro et all, (2005), the concentration of metal contaminants' can be classified into three types which are (i) contamination indices- which compare the contaminants with the clean or polluted stations measured elsewhere; (ii) background enrichments indices- which compare the results for the contaminants with the baseline or background levels and (iii) ecological risk indices- which compare the results for the contaminants with Sediment Quality Guidelines (SQG). Environmental quality indices are a powerful tool for development, evaluation and conveying raw environmental information to decision makers, managers, technicians' or for the public. In recent decades, different metal assessment indices applied to estuarine environment have been developed (Caeiro et all, 2005; Spenner and Macleod, 2002). Sediment quality values are a useful to screen the potential for contaminants within sediment to induce biological effects and compare sediment contaminant concentration with the corresponding quality guideline (Spencer and Macleod, 2002). These indexes evaluate the degree to which the sediment-associated chemical status might adversely affect aquatic organisms and are designed to assist sediment assessors and managers responsible for the interpretation of sediment quality (Caeiro et all, 2005). It is also to rank and prioritize the contiminated areas or the chemicals for the further investigation (Farkas et all, 2007).

### Aim and Subject of the Research

The subject of this research involves the surface sediments collected at high and low tide. Due to the increasing developments in Mengkabong lagoon, the study aims to (1) use different types of indices to aggregate and assess the heavy metal contamination of Mengkabong mangrove sediment (2) select the best index to describe the Mengkabong lagoon sediment quality.

## RESEARCH METHODOLOGIES AND METHODS

### Study Area

This study took place in Mengkabong mangrove forest, Tuaran District, West Coast of Sabah which is 40 km away from Kota Kinabalu. The total of study area spread over from latitude 06$^{0}$06’N to 06$^{0}$11’N and longitude 116$^{0}$08’E to 116$^{0}$ 13’E. The Mengkabong mangrove forest consists of two shallow spurs, with the southern spur forming the administrative boundary between Tuaran and Kota Kinabalu Districts. This spur ends in Salut Bay which is entirely surrounded by Kota Kinabalu Industrial Park. The southern spur of the estuary has been significantly degraded already and there is little left to protect. The northern spur is much larger and more irregular. There is still abundant and high quality mangrove remaining around the estuary (EIA 1992; ELP 2003).

### Soil Sampling and Analysis

The sampling strategy was to study the spatial variability and tidal effects in a number of parameters. A total of 33 surface sediments samples were collected randomly and taken in triplicates with auger from March 2006 to November 2006 (Figure 1) at high and low tide. The exact position of each sample was recorded using Global Positioning System (GPS). The mangrove surface sediments were chosen for this study as this layer controls the exchange of metals between sediments and water (El Nemr et all, 2006).

The laboratory apparatus were acid soaked (nitric acid) before the analysis. After acid soaked, it is rinsed thoroughly with tap water and distilled water to ensure any traces of cleaning reagents were removed. Finally, it is dried and stored in a clean place (Radojevic and Bashkin, 1999). The sediments were kept cool in icebox during the transportation to the laboratory (Al-Shiwafi et all, 2005; Jung et all, 2005). The surface sediments air-dried and after homogenization using pestle and mortar, it is passed through a 2-mm mesh screen and stored in polyethylene bags based on method used by Romic and Romic (2003) for further analysis. Before the determination of these heavy metals was conducted, the samples are digested using aqua regia digestion. Approximately 2g of each sample digested with 15 mL of aqua-regia (1: 3 HCl: $HNO_3$) in a Teflon bomb for 2h at 120$^{o}$C. After cooling, the digested samples were filtered and kept in plastic bottles before the analysis. Radojevic and Bashkin (1999) stated that aqua regia has ability to extract all the metals in soil sample and widely used in most of the soil analysis. The samples were then analyzed for heavy metals and base cations using AAS with specific flame and wavelength (Atomic Absorption Spectrometer Model Perkin Elmer 4100).

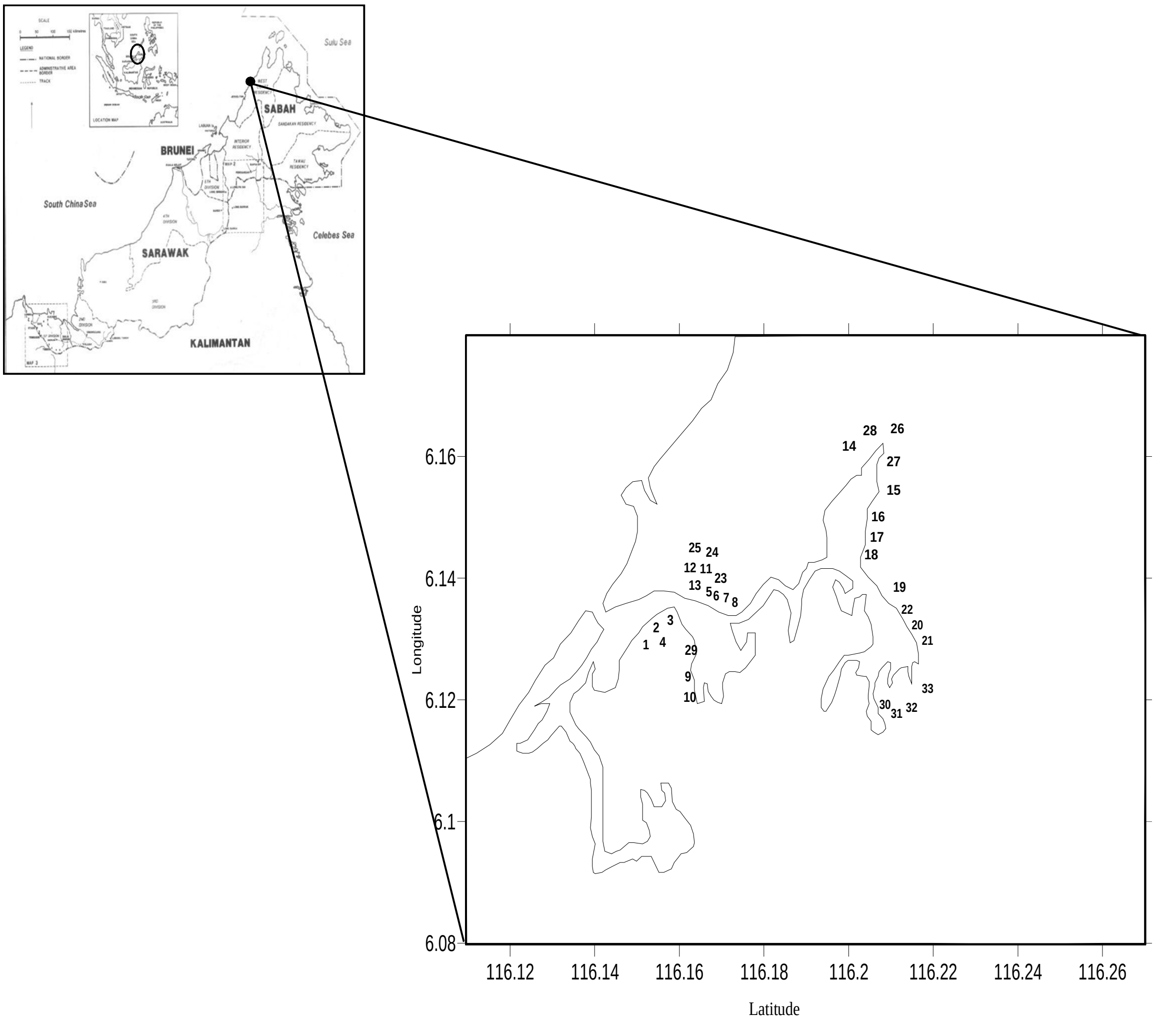

Figure 1. Sampling locations of Mengkabong and mangrove surface sediment sampling sites (n=33)

### Background Enrichments Indixes (Indixes Calculation)

The enrichment factor is the relative abundance of a chemical element in a soil compared to the bedrock (Hernandez et all, 2003). Enrichment factor is a convenient measure of geochemical trends and is used for comparison between areas. It is applied widely in mangrove geochemical studies (Ramanathan et all, 1999; Abraham, 1998; Soto-Jime´nez et all, 2001; Kamau, 2002; Qu et all, 1993; Kehrig et all, 2003). The formula below used by Hernandez et all, (2003) has been applied to the studied heavy metals in this study to assess the anthropogenic and lithogenic contribution (Eq. 1.1 and Eq. 1.2).

$$[M]\text{Lithogenic} = [Al]_{Sample}\ X\ ([M]/[Al])_{Lithogenic} \quad (\text{Eq. } 1.1)$$

Where $([M]/[Al])_{\text{Lithogenic}}$ corresponds to the average ratio of the earth crust

The anthropogenic heavy metals can be estimated as formula shown below:

$$[M]\text{Anthropogenic} = [M]\text{Total} - [M]\text{Lithogenic} \quad (\text{Eq. } 1.2)$$

The Geoaccumulation Index ($I_{geo}$) introduced by Muller (1979) was also used to assess metal pollution in sediments besides enrichment factor. Geoaccumulation index is expressed as in Eq. 1.3. Table 1 shows the shows the geoaccumuation index which includes seven grades. It includes various degrees of enrichment above the background value ranging from unpolluted to very polluted sediment quality. The highest grade (class six) reflects 100-fold enrichment above the background values (Singh et all. 2003).

$$I_{geo} = \text{Log}_2\,(C_n/1.5B_n) \qquad (\text{Eq. } 1.3)$$

$C_n$ = measured concentration of heavy metal in the mangrove sediment,

$B_n$ = Geochemical background value in average shale (Turekian and Wedepohl, 1961) of element, n 1.5 is the background matrix correction in factor due to lithogenic effects

The Pollution Load Index (PLI) proposed by Tomlinson et all, (1980) has been used that refers the heavy metal concentrations (Eq. 1.4). The Pollution Load Index (PLI) is obtained as Concentration Factors (CF). This CF is the quotient obtained by dividing the concentration of each metals. The PLI of the place are calculated by obtaining the n-root from the n-CFs that were obtained for all the metals. With the PLI obtained from each place, the PLI (Ray et all, 1998; Soares et all, 1999). This index is quickly understood by unskilled personal in order to compare the pollution status of different places.

$CF = C_{metal} / C_{\text{Background value}}$ CF= Contimination Factor

$$PLI = n\sqrt{(CF1 \times CF2 \times CF3 \times \ldots\ldots\ldots \times CFn)}$$
(Eq. 1.4)

$^n$ = number of metals

Varies from 0 (unpolluted) to 10 (highly polluted)

Marine Sediment Pollution Index (MSPI) has the advantage over the earlier indices that it gives different weights to each contaminant (Eq. 1.5). The application of a PCA to identify important variables from a monitoring program can reduce sampling resources. Parameters that do not show significant spatial variations can be analyzed with lesser frequency than those that have been identified as more important from the results of the PCA. Also the use of the PCA allows successful assessment of the source of the contamination, since this multivariate analysis tool does not need any linear assumption and establishes and quantifies the correlations among the original variables in the dataset when the goal is to reduce the number of variables (Caeiro et all, 2005; Shin and Lam, 2001). Table 2 shows the MSPI index to interpret the sediment condition.

$$MSPI = (\Sigma ni{=}1\ qiwi)2/\ 100 \quad (\text{Eq. } 1.5)$$

qi is the sediment quality rating of the i contaminant wi the weight attributed to the i variable (proportion of eigenvalues obtained from the results of a principal component analysis, PCA)

Table 1. Geoaccumulation index (Muller, 1979) of Heavy Metal Concentration in Sediment *

| Geoaccumulation index | Class | Pollution Intensity |
|---|---|---|
| 0 | 0 | Background concentration |
| 0-1 | 1 | Unpolluted |
| 1-2 | 2 | Moderately to unpolluted |
| 2-3 | 3 | Moderately polluted |
| 3-4 | 4 | Moderately to highly polluted |
| 4-5 | 5 | Highly polluted |
| >5 | 6 | Very highly polluted |

*Source: Singh et all, (2003)

Table 2. MSPI Index for Sediment Condition

| LOCATION | Al | Cu | Fe | Pb | Zn |
|---|---|---|---|---|---|
| Present Study | 2410.94-35393.25 | 2.12-49.25 | 1434-18360 | 24.28-69.15 | 11.69-93.25 |

## RESULTS

Table 3 presents the heavy metal concentration in Mengkabong lagoon mangrove sediment. The calculated values of the enrichment factors of the elements in the sediment samples of Mengkabong mangrove were shown in Figure 2. The black line in the box indicates the median value of each studied metals at high and low tide. The ends of the vertical lines indicate the minimum and maximum data values of each metal. The calculated enrichment factor calculated values are greater than 1. This indicates enrichment by either natural processes or anthropogenic influences (Neto et all, 2006; Huang and Lin, 2003; Shotyk et all, 2000). Since EF values of Pb, Zn and Cu which are higher 1, the anthropogenic and lithogenic percentage were calculated (Figure 3). The calculated $I_{geo}$ values for the Mengkabong mangrove sediment were given in Table 1 and remain in either class 0 or class 1, which indicates that investigated mangrove sediments in Mengkabong mangrove sediment are unpolluted. While computing the pollution load index (PLI) of sediments of the studied region, average world shale of these elements were taken as the background values. The PLI value range from 0.08 to 0.17 (Table 4) confirmed that Mengkabong mangrove sediments are in unpolluted condition. Based from Tables 5, 6, 7 and 8 shows the component loading and sediment quality rating from Principal Components Analysis at high and low tide. The variables were selected for the index calculation if the absolute value of its component loading was greater than 0.7, suggested by Comrey and Lee (1992) is Fe and Pb at high tide where as Al, Cu and Fe at low tide. The bold value shows the component loadings that will be used together with sediment rating in the MSPI calculation. The weights calculation for each selected variables at high and low tide is shown in Table 7. The MSPI range from 11.5-14.9 indicated that the Mengkabong mangrove sediment is in excellent condition. The MSPI value confirms that it is in low contamination condition (Soares et all, 1999).

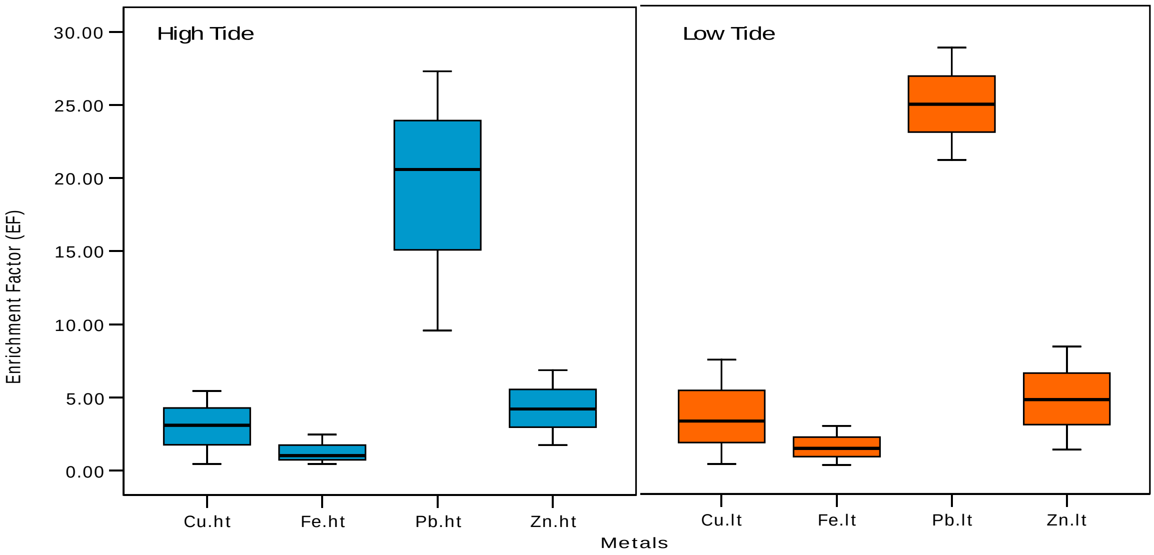

Figure 2. The EF of Heavy Metals in Mengkabong Mangrove Sediment at High and Low tide

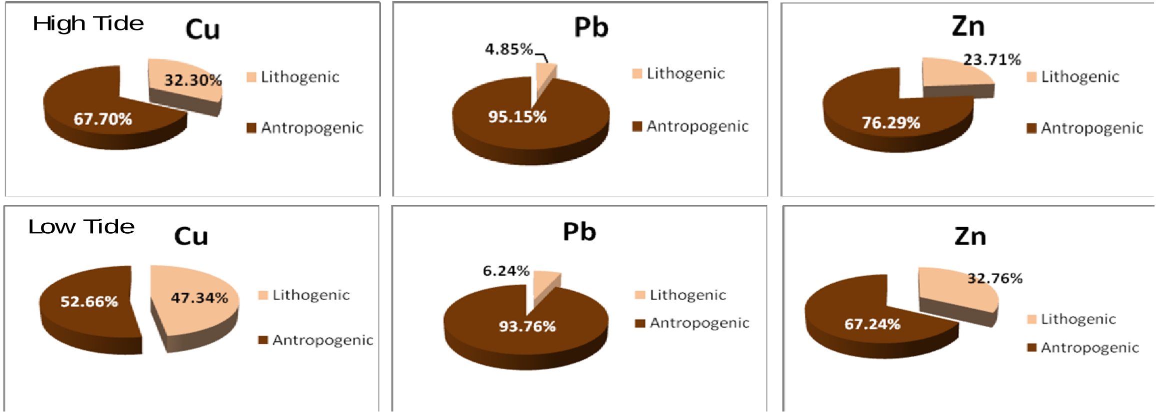

Figure 3. Copper, Lead and Zinc Anthropogenic, and Lithogenic Proportion in Mengkabong Mangrove Sediment at High and Low Tide

Table 3 The heavy metal concentration in Mengkabong lagoon mangrove sediment (mg/kg)

| LOCATION | Al | Cu | Fe | Pb | Zn |
|---|---|---|---|---|---|
| Present Study | 2410.94-35393.25 | 2.12-49.25 | 1434-18360 | 24.28-69.15 | 11.69-93.25 |

Table 4. Geo-accumulation Indexes (Muller, 1979) of Heavy Metals Concentration in Sediment of Mengkabong Mangrove Forest

| Geoaccumulation index | Pollution Intensity | Heavy Metals |
|---|---|---|
| 0 | Background concentration | Al, Cu, Fe, Zn |
| 0-1 | Unpolluted | Pb |
| 1-2 | Moderately to unpolluted | |
| 2-3 | Moderately polluted | |
| 3-4 | Moderately to highly polluted | |
| 4-5 | Highly polluted | |
| >5 | Very highly polluted | |

Table 5. The Pollution Load Index for Mengkabong Mangrove Sediment

| Metals | High Tide | Low Tide |
|---|---|---|
| Al | 0.19 | 0.12 |
| Cu | 0.62 | 0.42 |
| Fe | 0.16 | 0.14 |
| Pb | 2.61 | 2.03 |
| Zn | 0.6 | 0.44 |
| PLI | 0.17 | 0.08 |

Table 6. Rotation Component Matrix at High Tide

| | Factor | | | | | |
|---|---|---|---|---|---|---|
| Component | 1 | 2 | 3 | 4 | 5 | 6 |
| pH | -0.03 | -0.12 | -0.16 | -0.01 | 0.86 | -0.08 |
| Sa | 0.90 | 0.09 | -0.09 | 0.08 | 0.01 | -0.14 |
| EC | 0.87 | 0.16 | -0.16 | -0.04 | -0.14 | -0.09 |
| OM | 0.45 | 0.29 | 0.34 | -0.40 | -0.03 | 0.15 |
| Clay | 0.65 | -0.19 | 0.24 | -0.25 | -0.35 | 0.20 |
| Silt | -0.37 | -0.84 | -0.10 | 0.10 | 0.20 | -0.07 |
| Sand | 0.04 | 0.96 | -0.03 | 0.03 | -0.02 | -0.03 |
| Al | -0.38 | 0.13 | -0.57 | 0.64 | 0.04 | 0.17 |
| Cu | 0.01 | 0.09 | 0.56 | 0.02 | 0.19 | 0.38 |
| Fe | 0.01 | -0.20 | 0.26 | 0.65 | -0.14 | 0.30 |
| Pb | -0.08 | 0.04 | -0.07 | 0.09 | 0.01 | 0.88 |
| Zn | -0.54 | -0.24 | -0.44 | 0.05 | -0.46 | -0.13 |
| Na | -0.15 | -0.11 | 0.09 | -0.12 | 0.64 | 0.11 |
| K | -0.21 | 0.06 | 0.75 | 0.20 | -0.17 | -0.23 |
| Ca | -0.02 | 0.09 | -0.04 | 0.81 | -0.06 | -0.05 |
| Mg | -0.29 | 0.45 | 0.37 | 0.05 | -0.26 | 0.11 |
| Initial Eigenvalue | 3.52 | 2.11 | 1.71 | 1.48 | 1.31 | 1.06 |
| Percent of Variance | 21.98 | 13.20 | 10.67 | 9.26 | 8.21 | 6.64 |
| Cumulative Percent | 21.98 | 35.18 | 45.84 | 55.11 | 63.32 | 69.96 |

Table 7. Sediment Quality Rating For Each Of The Variables Selected From The Principal Component Analysis at High Tide

| Sediment Quality Rating | Fe (mg/kg) | Pb (mg/kg) |
|---|---|---|
| 10 | BDL < x<3415.9 | 24.3 < x< 24.3 |
| 20 | 3415.9 < x< 4798.4 | 24.3< x< 37.9 |
| 30 | 4798.4 < x< 5139.8 | 37.9 < x< 43.8 |
| 40 | 5139.8 < x< 6381.4 | 43.8 < x< 52.3 |
| 50 | 6381.4 < x< 7368.1 | 52.3 < x< 53.9 |
| 60 | 7368.1 < x< 7785.1 | 53.9 < x< 56.5 |
| 70 | 7785.1 < x< 8999.4 | 56.5< x< 58.9 |
| 80 | 8999.4 < x< 9600.8 | 58.9 < x< 61.1 |
| 90 | 9600.8 < x< 11565.5 | 61.1 < x< 64.2 |
| 100 | 11565.5 < x< 14169 | 64.2 < x< 69.2 |

Table 8. Rotation Component Matrix at Low Tide

| | Factor | | | | | | |
|---|---|---|---|---|---|---|---|
| Component | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| pH | -0.09 | 0.32 | 0.01 | 0.03 | 0.80 | -0.16 | 0.16 |
| Sa | -0.17 | 0.01 | -0.03 | 0.73 | 0.04 | -0.37 | 0.04 |
| EC | 0.28 | 0.24 | 0.01 | -0.12 | -0.75 | -0.14 | 0.13 |
| OM | -0.04 | 0.45 | -0.42 | 0.33 | -0.15 | 0.33 | -0.11 |
| Clay | -0.52 | -0.06 | 0.61 | 0.11 | 0.10 | -0.32 | -0.08 |
| Silt | 0.91 | -0.18 | -0.08 | 0.06 | -0.26 | 0.04 | 0.03 |
| Sand | -0.89 | 0.21 | -0.05 | -0.09 | 0.26 | 0.03 | -0.02 |
| Al | 0.78 | 0.20 | -0.18 | -0.29 | 0.22 | 0.11 | -0.12 |
| Cu | -0.07 | 0.06 | 0.84 | 0.10 | -0.09 | 0.17 | 0.01 |
| Fe | 0.05 | 0.03 | 0.05 | -0.03 | -0.01 | 0.87 | 0.06 |
| Pb | 0.33 | 0.58 | 0.23 | -0.34 | -0.13 | 0.15 | -0.10 |
| Zn | 0.57 | -0.12 | -0.45 | 0.25 | -0.26 | 0.03 | -0.22 |
| Na | -0.05 | -0.01 | 0.02 | 0.06 | 0.02 | 0.06 | 0.97 |
| K | 0.24 | 0.07 | 0.19 | 0.81 | 0.11 | 0.32 | 0.05 |
| Ca | -0.20 | 0.63 | -0.19 | 0.04 | 0.20 | 0.21 | -0.03 |
| Mg | -0.16 | 0.83 | 0.13 | 0.09 | 0.02 | -0.23 | 0.05 |
| Initial Eigenvalue | 3.89 | 2.04 | 1.63 | 1.49 | 1.27 | 1.11 | 1 |
| Percent of Variance | 24.26 | 12.73 | 10.21 | 9.34 | 7.92 | 7 | 6.28 |
| Cumulative Percent | 24.26 | 36.99 | 47.20 | 56.53 | 64.45 | 71.45 | 77.72 |

Table 9. Sediment Quality Rating For Each Of The Variables Selected From The Principal Component Analysis at low tide

| Sediment Quality Rating | Cu (mg/kg) | Fe (mg/kg) | Al (mg/kg) |
|---|---|---|---|
| 10 | BDL < x< 3.9 | BDL < x< 1434.6 | 2410.9 < x< 2410.9 |
| 20 | 3.9 < x< 5.5 | 1434.6 < x< 2457.8 | 2410.9 < x< 3407.5 |
| 30 | 5.5 < x< 10.6 | 2457.8 < x< 4098.1 | 3407.5< x< 4482.5 |
| 40 | 10.6 < x< 16.8 | 4098.1 < x< 5982 | 4482.5< x< 5508.9 |
| 50 | 16.8 < x< 19.7 | 5982 < x< 6457.2 | 5508.9< x< 6460.8 |
| 60 | 19.7 < x< 22 | 6457.2< x< 7886.7 | 6460.8< x< 8562.2 |
| 70 | 22 < x< 25.2 | 7886.7< x< 8312.2 | 8562.2 < x< 9538 |
| 80 | 25.2 < x< 29.2 | 8312.2< x< 9547.1 | 9538< x< 14434.5 |
| 90 | 29.2 < x< 39.1 | 9547.1< x< 9798.3 | 14434.5< x< 21422.81 |
| 100 | 39.1 < x< 43.5 | 9798.3 < x< 10380 | 21422.81< x< 24462.7 |

Table 10. The Weight Calculation for Each Selected Variables

| PC | Eigenvalue | Relative eigenvalue | Variable | Loading value | Relative loading value on same PC | Weight (relative eigenvalue x relative loading value) |
|---|---|---|---|---|---|---|
| High Tide | | | | | | |
| 4 | 1.5 | 0.58 | Fe | 0.65 | 1 | 0.58 |
| 6 | 1.1 | 0.42 | Pb | 0.88 | 1 | 0.42 |
| Total | 2.6 | 1.000 | | | | |
| Low Tide | | | | | | |
| 1 | 3.8 | 0.59 | Al | 0.78 | 1 | 0.59 |
| 3 | 1.6 | 0.25 | Cu | 0.84 | 1 | 0.25 |
| 6 | 1.1 | 0.17 | Fe | 0.87 | 1 | 0.17 |
| Total | 6.5 | 1.000 | | | | |

## DISCUSSSIONS

Different metal assessment indexes were used and discussed. The different indexes give diverse status of Mengkabong sediment quality. Pekey (2006) noted similar findings as this study and elobrated that the enrichment factor of Pb is higher in locations that located near to industrial areas, where in this case the industrial are being, Kota Kinabalu Industrial Area (KKIP). KKIP is located nearby the Mengkabong mangrove forest. This is supported by study done by Mokhtar et all, (1994) in Inanam River estuary (study location). The study is focused on water quality in Inanam estuary (current study location), metals were given special focus due to the fact that the polluted Likas River flows into the Inanam estuary. The Likas River has a number of light industries, motor workshops and poultry farms along its banks, and these are potential sources of pollution. Domestic waste discharge from the village at the estuary is also an important source of pollution. The Likas River comprises of two tributaries: The Inanam River II which is short and the Likas River which is long. Pig farms, poultry farms and mechanical workshops, aquaculture ponds near the Ko-Nelayan, housing park project were found along the Inanam River II. Domestic effluents also flow into this river. The sources of pollution along the Likas River are industrial effluents such as food and beverage factories, and also domestic effluents from the population living along this river. According to Caeiro et all, (2005), the EF and $I_{geo}$ does not aggregate all the contaminants into one value. It is necessary to use the estimation of natural background in order to provide a precise identification of anthropogenic heavy metals and their sources. Geochemical background levels used in EF and $I_{geo}$ were the values in crust and shale in order to recognize the anthropogenic enrichment. O'Reilly et all, (1995) explained that other factors such as an abundance of coarser particles, mineral composition and physico-chemical environment. It may reduce the natural metal concentrations below the background levels used. Furthermore, the applications of all these indexes at present cannot provide information on the effects of the combination of pollutants on the estuarine biota. Yet, it can provide the public some understanding about the quality of the estuarine sediment. Tomlinson et all, (1980) elobrated that the application of PLI provides a simple way in assessing estuarine sediment quality. It is vital that all the necessary variables for the construction of PLI would be readily available. This is to analyse all variables together which will rise the index value and provide valuable imformation and advice for the policy and decision makers on the estuarine quality. Eventhough the MSPI index does not evaluate the potential adverse effect and difficult to compare with others, it shows more accurate value and significant correlation with benthic and toxicity data (Caeiro et all, 2005; Shin and Lam, 2001). MSPI has an advantage over the earlier indexes. The development of MSPI involves the use of PCA to interpret sediment chemical composition and calculated the pollution scores derived from the PCA results. One of the main PCA function is to reduce the complexity of the data, and shows the important variables in the loading factors as an indicator of sediment pollution from anthropogenic sources. It gives different weights to each variable, which the absolute value of its component loading greater than 0.7, suggested by Comrey and Lee (1992) will be taken into the MSPI calculation. The MSPI viewed as a simple summary of the state of the sediment quality compared to Sediment Quality Triad for public information. Sediment Quality Triad is much more complex which encompasses sediment chemistry, biological community and toxicity data (Chapman et all, 1997). The applications of multivariate methods (principal component analysis) considered more sensentive in analysis of benthic community changes and as well as sediment quality. In order to improve the PCA loading value, large sample size, at least 200 cases should be included for adequate scientific information and the formulation of the MPSI index (Shin and Lam, 2001).

## CONCLUSIONS

Different metal assessment indexes were used and their applicability to interpret the pollution status in Mengkabong lagoon was discussed. All the EF's values of all heavy metals (Cu, Fe, Pb, Zn) are greater than 1. Since EF values of Pb, Zn and Cu were higher 1, the anthropogenic and lithogenic percentage were calculated. The results showed that more than 50% of the calculated EF values for Pb, Zn and Cu are from anthropogenic sources. The sources of pollution include industrial effluents such as food and beverage factories, and also domestic effluents from the population living along this Inanam River. While, the Igeo showed that all the heavy metals are in Class 0 and Class 1. The PLI values range from 0.08 to 0.17 while MSPI values range from 11.5 to 14.9. From PLI values, the Mengkabong mangrove sediments are in unpolluted condition. This is also supported by MSPI values that the Mengkabong mangrove sediment is in excellent condition. The MSPI values belong to Class A confirming that it is in low contamination condition. Based on these calculated indexes, MSPI was chosen as having an advantage over the earlier indexes. MSPI uses PCA to interpret sediment chemical composition and calculated the pollution scores derived from the PCA results. It reduces the complexity of the data, and shows the important variables in the loading factors as an indicator of sediment pollution from anthropogenic sources.

## IMPLICATIONS OF THIS STUDY AND FUTURE RESEARCH RECOMMENDATIONS

The implication of this study, it suggested that MSPI is the best index in explaining the sediment quality of Mengkabong lagoon. The applications of multivariate methods (principal component analysis) considered more sensentive in analysis of benthic community changes and as well as sediment quality. In order to improve the PCA loading value, large sample size should be included for adequate scientific information and the formulation of the MPSI index. However, future research should includes site-specific, biological testing and ecological analysis of existing benthic community structure (crabs, mollusks, mudskippers) related to sediment contamination for final decision making in the case of Mengkabong lagoon. In future developments, organic compounds (pesticides, PAHs and PCBs) will be intergraded into the contamination evaluation which can be correlated with other parameters. Furthermore, the integration of contamination assessment with biota and toxicity evaluation will be carried out in each management unit to allow a weight of evidence for sediment quality assessment.

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