FACTOR-CLUSTER ANALYSIS AND ENRICHMENT STUDY OF MANGROVE SEDIMENTS-AN EXAMPLE FROM MENGKABONG, SABAH

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Abstract

This paper examines the tidal effects in the sediment of Mengkabong mangrove forest, Sabah. Generally, all the studied parameters showed high value at high tide compared to low tide. Factor-cluster analyses were adopted to allow the identification of controlling factors at high and low tides. Factor analysis extracted six controlling factors at high tide and seven controlling factors at low tide. Cluster analysis extracted two district clusters at high and low tides. The study showed that factor-cluster analysis application is a useful tool to single out the controlling factors at high and low tides. This will provide a basis for describing the tidal effects in the mangrove sediment. The salinity and electrical conductivity clusters as well as component loadings at high and low tide explained the tidal process where there is high contribution of seawater to mangrove sediments that controls the sediment chemistry. The geoaccumulation index (I_{geo}) values suggest the mangrove sediments are having background concentrations for Al, Cu, Fe, and Zn and unpolluted for Pb.

Abstrak

Kertas kerja ini mengkaji kesan pasang surut ke atas sedimen hutan paya bakau Mengkabong, Sabah. Analisis "*factor*" dan "*cluster*" digunapakai dalam menentukan faktor yang mengawal pada keadaan pasang surut. Analisis "*factor*" telah mengekstrak enam faktor pada air pasang dan tujuh faktor pada air surut. Analisis "*cluster*" pula telah mengekstrak dua bahagian utama pada keadaan air pasang dna surut. Kajian ini menunjukkan aplikasi analisis "*factor*" dan "*cluster*" adalah sangat berguna dalam mendapatkan faktor yang mengawal sedimen pada keadaan pasang-surut. Ini menjadi panduan bagi menerangkan kesan pasang surut terhadap sedimen hutan paya bakau Mengkabong, Sabah. Hubungan saliniti dan kekonduksian elektrik pada analisis "*cluster*" dan nilai analisis "factor" pada pasang surut menerangkan sumbangan air laut ke atas sedimen yang mengawal kimia sedimen tersebut. Indeks geoakkumulasi menerangkan bahawa sedimen hutan paya bakau adalah berada dalam keadaan asalnya bagi Al, Cu, Fe dan Zn serta tidak tercemar bagi Pb.

Keywords: mangrove surface sediment, tide, factor-cluster analysis, geoaccumulation index

Introduction

Mangrove sediments were extensively studied all around the world (India, Australia, Brazil, Malaysia, Arab, China, Thailand etc). A study done by Kehrig *et al.*[1] in Jequia mangrove forest, Brazil concluded that the mangrove forest has been polluted with heavy metals by the anthropogenic sources surrounding the estuary. While study done by Kamaruzzaman *et al*. [2] concluded the concentration of heavy metals in Kerteh mangrove forest were generally below the levels found in polluted and unpolluted estuaries and mangroves. Sediments act as sinks and sources of contaminants in aquatic systems because of their variable physical and chemical properties [3, 4, 5, 6]. Pekey [4] demonstrated that heavy metals tend to be trapped in the aquatic environment and accumulate in sediments.

Tidal current activity is mainly confined to mangrove channels. Outside the channels, mainly on the upper tidal-flats, tidal current velocities decrease and sediment entrainment is frequently ascribed to wave action. The role of tidal processes on intertidal surface sediments is frequently stated but the differences at these stages have seldom been investigated, apparently because of methodological constraints [7]**.** A multivariate statistical approach allows the researhers to manipulate more variables [8]. Factor Analysis (FA) and cluster analysis (CA) were the statistics methods used in the interpretation. FA and CA often used together to check the results and provide grouping of each variable. FA and CA are explanatory tools in multivariate statistical analysis to discover and interpret relationships between variables [9, 10, 11, 12, 13]. According to Facchinelli *et al*. [13], FA and CA are often used together to check the results and provide grouping of each variable. Yongming *et al*. [9] explained that FA is widely used to reduce data and to extract a small number of factors depending on the correlation matrix, whereas CA is performed to further classify elements of different sources on the basis of their similarities chemical properties. Hierarchical cluster analysis using dendograms identifies relatively homogeneous groups of variables in similar properties and combines clusters until only one is left.

The purpose of this study was: (1) to determine the physicochemical parameters (pH, electrical conductivity and salinity), granulometric fractions, organic matter, heavy metals (Al, Cu, Fe, Pb and Zn) and base cations (Ca, Mg, Na and K) at high and low tides; (2) to identify the controlling factors by using factor analysis (FA) and cluster analysis (CA) at high and low tides and (3) to gauge the degree of anthropogenic influence on heavy metals concentration in mangrove sediment using geo-accumulation index (I_{geo}).

Materials and Methods

Study Area

This study was conducted in Mengkabong mangrove forest, Tuaran District, West Coast of Sabah which is 40 km away from Kota Kinabalu. The total of study area spreads over from latitude $06^0$06'N to $06^0$11'N and longitude $116^0$08'E to 116^0 13'E (Figure 1). Mengkabong lagoon formerly earmarked as the Mengkabong Forest Reserve, but released by the Forestry Department to become a state land. The Mengkabong mangroves, Tuaran District, experienced a 15% decrease from 1991 to 2000. In 1991 the mangroves covered 12.6 km^2 while in 2000 it was 10.7 km^2. Most of the mangroves have been lost due to the spread of rural development such as housing, aquaculture projects and surrounded by an industrial zone, Kota Kinabalu Industrial Park (KKIP) [14]. 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 are still abundant and high quality mangroves remaining around the estuary [15, 16].

Soil Sampling and Analysis

The sampling strategy was to study the spatial variability and tidal effects on a number of parameters. Mangrove sediments were sampled randomly and taken in triplicates with an auger at 33 stations from March 2006 to November 2006 (Figure 1) at low and high tide. The exact position of each sampling site was recorded using Global Positioning System (GPS). The sampling was done based to the accessibility to the mengrove forest. Mangrove surface sediments were choosen for this study as this layer controls the exchange of metals between sediments and water [17].

Sampling bottles and the laboratory apparatus were acid soaked in diluted nitric acid before the analysis. After acid soaking, they were rinsed thoroughly first with tapwater and then with distilled water to ensure any traces of cleaning reagent were removed. Finally, they were dried and stored in a clean place. The sediments were kept cool in an icebox during transportation to the laboratory. The physicochemical measurements of the surface sediment were made as soon as possible in the Environmental Science Laboratory, School Science and Technology, Universiti Malaysia Sabah. The physicochemical parameters (pH, electrical conductivity and salinity) were measured on 1:2 soil to water ratio extracts as soon as the samples reached the laboratory [18]. The pH, electrical conductivity and salinity electrodes were calibrated before the measurements were taken.

For other analyses, the surface sediments were air-dried, and after homogenization using pestle and mortar, passed through a 2-mm mesh screen and stored in polyethylene bags. Organic matter was determined by using loss on ignition method while Granulometric analysis was done using pipette method [18]. For the determination of heavy metals, the samples were digested using aqua regia. Approximately 2g of each sample was 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 [18] stated that aqua regia is adequate for extraction of total metals in soil sample and is widely used in most soil analyses. For base cations (Na, K, Ca and Mg), the method used in this study is the measurement of exchangeable cations using ammonium acetate. Heavy metals and base cations were analyzed using AAS with air/acetylene (Cu, Fe, Pb, Zn, Na, K, Ca and Mg) and nitrous oxide-acetylene (Al) at specific wavelengths (Atomic Absorption Spectrometer Perkin Elmer 4100).

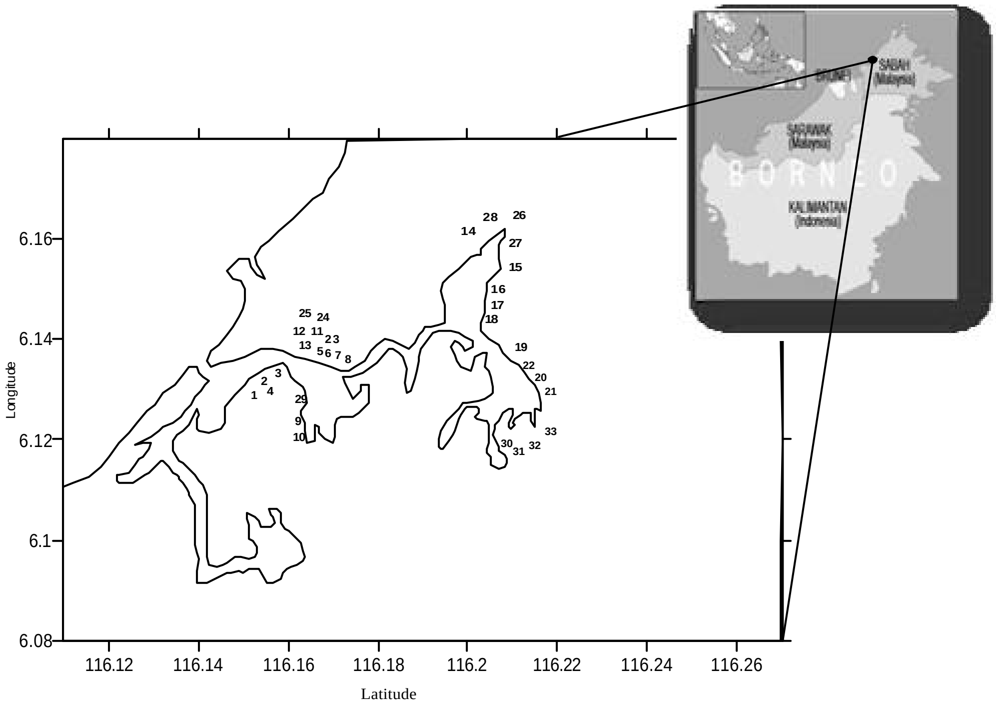

Figure 1: Sampling locations of Mengkabong and mangrove surface sediment sampling sites (n=33)

Results

Descriptive Statistics

The descriptive statistics of physico-chemical properties (pH, salinity, electrical conductivity) granulometric fraction, organic matter, heavy metals (Al, Cu, Fe, Pb and Zn) and base cations (Ca, Mg, Na and K) showed high value at high tide compared to low tide (Table 1).

Factor Analysis (FA)

Factor analysis (FA) was applied to discover and interpret relationships between variables at high and low tides. The results showed a different trend at high tide and at low tide. Tables 2 and 3 display the factor loadings with a Varimax rotation as well as the eigenvalues, percentile of variance and cumulative percentage at high and low tides. In reference to the eigenvalues, six factors at high tide and seven factors at low tide were extracted as they have eigenvalues greater than 1 (Tables 2 and 3). The bold values in Tables 2 and 3 are the factor loadings greater than 0.5 which taken in the determination of factors at high and low tide.

At high tide (Table 2) , factor one accounted for 22% of total variance and is mainly characterized by high levels of salinity, electrical conductivity and clay fraction. Factor two accounted for 13% of the total variance with sand loadings. Factor three consits of Cu and K with total variance of 11%. Factor four characterized by 9% of total variance with high loadings of Fe, Ca and Al. Factor five with 8% of total variance, contains high loading of Na and pH. Factor six with 7% of total variance is characterized by high loading of Pb.

Table 1: Physico-chemical properties, organic matter, granumetric fraction, Heavy metals and base cations (Sa=salinity; EC= electrical conductivity; OM=organic matter)

Parameter		Min	Mean	Max	SD
pH	HT	5.4	6.5	7.6	0.4
	LT	4.5	6.1	7.2	0.6
Sa (%)	HT	1.5	4.5	7.4	2.2
	LT	0.1	0.5	1.5	0.4
EC(mS/cm)	HT	2.1	6.8	11.4	2.6
	LT	0.4	2.6	4.8	1.0
OM (%)	HT	6.4	9.0	11.7	1.3
	LT	1.4	2.5	5.2	0.8
Sand (%)	HT	91.9	93.6	95.1	0.8
	LT	91.7	95	97.3	1.7
Silt (%)	HT	2.5	3.6	5.2	0.8
	LT	0.4	2.7	6.4	1.8
Clay (%)	HT	2.2	2.8	4.2	0.4
	LT	1.3	2.4	2.9	0.4
Na (g kg^{-1})	HT	14.2	47.5	83.5	0.96
	LT	2.5	41.6	92.7	0.35
K (g kg^{-1})	HT	5.7	9.4	16.0	2.5
	LT	2.4	7.8	10.6	1.8
Mg (g kg^{-1})	HT	2.0	5.3	9.2	1.8
	LT	1.0	3.8	7.6	1.9
Ca (g kg^{-1})	HT	2.6	21.3	52.9	41.7
	LT	1.5	16.2	47.7	15.1
Fe (g kg^{-1})	HT	3.4	7.7	14.2	2.7
	LT	1.4	6.8	18.4	4.0
Cu (mg kg^{-1})	HT	4.1	28.0	49.0	14.0
	LT	2.1	19.0	44.0	13.0
Zn (mg kg^{-1})	HT	24.0	57.0	93.0	17.0
	LT	12.0	41.0	73.0	17.0
Pb (mg kg^{-1})	HT	24.0	52.0	69.0	11.0
	LT	34.0	41.0	47.0	3.0
Al (g kg^{-1})	HT	4.4	14.8	3.5	8.2
	LT	2.4	9.5	2.4	6.0

Table 2: Rotated Component Matrix of Mengkabong mangrove forest at high tide

Variable	Factor					
	1	2	3	4	5	6
pH	-0.03	-0.12	-0.16	-0.11	**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
Mg	-0.29	0.45	0.37	0.05	-0.26	0.11
Ca	-0.02	0.09	-0.04	**0.81**	-0.06	-0.05
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
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 3: Rotated Component Matrix of Mengkabong mangrove forest at low tide

Variable	Factor						
	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
Mg	-0.16	**0.83**	0.13	0.09	0.02	-0.23	0.05
Ca	-0.20	**0.63**	-0.19	0.04	0.20	0.21	-0.03
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
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

(Sa=salinity; EC= electrical conductivity; OM=organic matter)

At low tide (Table 3), factor one accounted for 24% of total variance and is mainly characterized by high levels of silt, Al and Zn. Factor two accounted for 13% of the total variance with Mg, Ca and Pb loadings. Factor three consits of Cu and clay with a total variance of 10%. Factor four is characterized by 9% of total variance with high loadings of salinity and K. Factor five, with 8% of total variance, contains high loading of pH while factor six, with 7% of total variance, is characterized by high loading Fe. Factor seven has 6% of total variance with Na loading.

Cluster Analysis (CA)

Cluster analysis (CA) was performed on the data set using average linkage between groups (Rescaled Distance Cluster). Although not substantially different from FA, CA can be used as a substitute method to confirm the results of FA. The results are illustrated in the dendrograms on Hierarchical Cluster Analysis (Figures 2 and 3). At high tide (Figure 2), two district clusters can be identified. Cluster one contains salinity, electrical conductivity, clay, organic matter, Cu, Pb and K. Cluster two contains pH, silt, sand, Na, Zn, Al, Fe, Mg and Ca. At low tide (Figure 3), two district clusters were observed, Cluster one contains silt, Al, Fe, K, Zn, electrical conductivity and salinity; Cluster two contains Ca, Mg, organic matter, clay, sand, pH, Pb, Cu and Na.

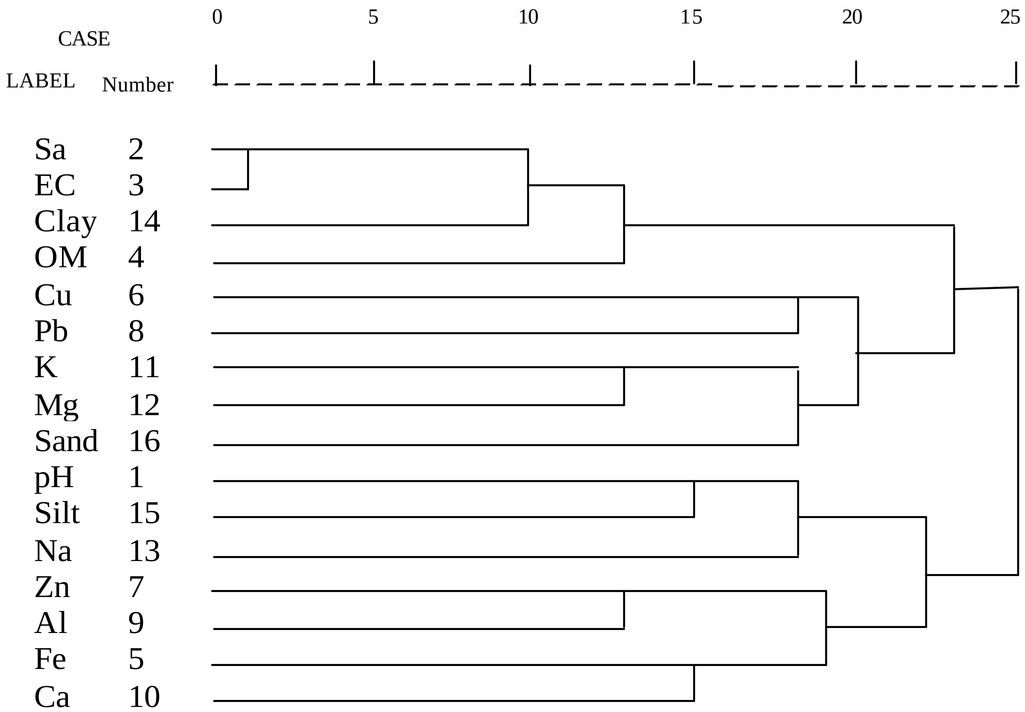

Figure 2: Dendrogram showing hierarchical cluster analysis at high tide (Sa=salinity; EC= electrical conductivity; OM=organic matter)

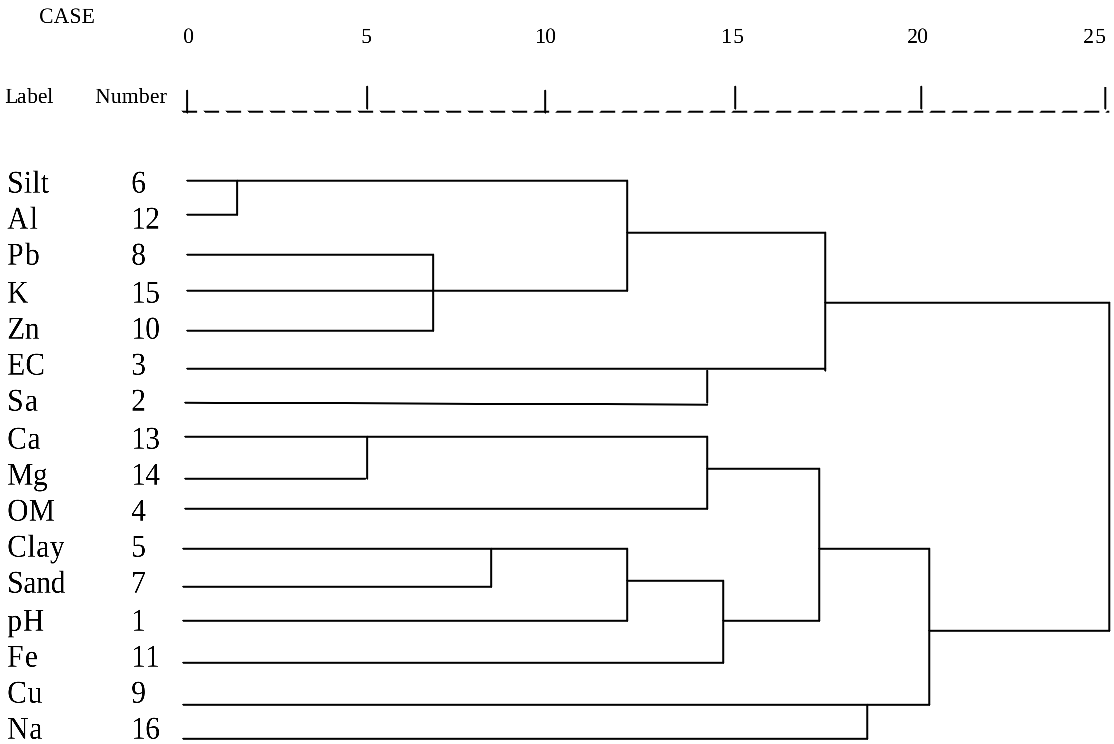

Figure 3: Dendrogram showing hierarchical cluster analysis at low tide (Sa=salinity; EC= electrical conductivity; OM=organic matter)

Geo-accumulation index (I_{geo})

The geoaccumulation index (I_{geo}) introduced by Muller [19] was also used to assess metal pollution in sediments . Geoaccumulation index is expressed as follows:

$$I_{geo} = \text{Log}_2 (C_n/1.5B_n) \qquad \text{(Eq. 1)}$$

where C_n = measured concentration of heavy metal in the mangrove sediment, B_n = geochemical background value in average shale [20] of element n, 1.5 is the background matrix correction in factor due to lithogenic effects.

Discussion

At high tide, FA results (Table 2) contain salinity, electrical conductivity and clay fraction (factor one). This match with the associations in cluster one results at high tide. Salinity and electrical conductivity clusters at the distance of one (Figure 2), shows that the contributions of seawater during high tide in Mengkabong. According to Church [21], seawater contains 3.5% of salinity of which 90% is fully ionized ions and high salinity explained the high load of salinity and electrical conductivity at high tide. The salinity and electrical conductivity then form another cluster with organic matter and clay fraction. These associations then formed another cluster with FA results (factor one, factor six and factor three). While factor three consists of Cu and K, with total variance of 11% in agreement with CA results (cluster one) with the association of Cu, Pb, Mg, K and sand. Tidal flooding can bring additional ions such as K, Mg and Na into the system and allows ion exchange to occur, such as between K and Cu [22]. Grande *et al*. [23] obtained the similar findings between K and Cu, who observed a negative correlation with marine indicators such as K. The new condition induced by tidal clash causes precipitation of metals such as Cu. These associations are mainly related to anthropogenic inputs and reflect the complexing nature of clay. Liu *et al* [24] explained that Pb most probably arises from indirect sources for instance atmospheric deposition. Based on FA (factor four, factor five and factor six) and CA (cluster 2), Al, Ca, Fe and Zn were correlated in FA and CA results. The CA results showed the relationship between Al, Ca, Fe and Zn at the distance of 12, 15 and 19. pH value in estuarine sediments is one of the important factor that regulates the concentration of dissolved metals in water and sediment [23, 25]. The CA results showed associations between pH, Na silt and Mg. According to Hsue and Chen [25], seawater plays an important role in buffering the pH change. The process of tidal clash occurs in the Mengkabong mangrove forest where the influx of seawater from the high tide resulted in major inputs of selected cations which were then adsorbed by the sediment (clay, silt and sand). The association between Mg and sand is strongly controlled by biogenic carbonates and plays an important role as a dilutant material of the heavy metals in the samples [26]. Biogenic carbonates are the dominant source of Ca, an abundant and important component in shallow marine biota sands as well as plays vital a role in the marine biogeochemical cycle. [27, 28].

Silt and Al clusters at the distance of 1 (Figure 2) and this association clusters with Fe (factor six in FA) at low tide. Salinity and electrical conductivity clusters at the distance of 14 at low tide. This distance is far higher compared to the association of electrical conductivity and salinity at high tide (Figures 2 and 3) which elaborates the lower contributions of seawater at low tide compared to high tide. FA results (Table 3) at low tide shows factor one accounted for 24% of total variance and is mainly characterized by high levels of silt, Al, Z n and EC. Cluster one (Figure 3) shows the silt and Al is associated at the distance of 1. Besides, there is also an association of Zn of factor one in FA with Fe (factor six in FA), K and salinity (factor four in FA). Zhou *et al*. [28] stated that besides anthropogenic enrichment, heavy metals occur naturally in silt and clay-bearing minerals of terrestrial and marine geological deposits. The natural occurrence of heavy metals complicates the assessment of potentially contaminated estuarine sediments. The measureable concentrations of metals do not automatically infer anthropogenic enrichment in the estuary. Therefore, heavy metal enrichment assessment is conducting in detail. While association of K is explained as a function of ionic strength. According to Hussien and Rabenhurst [29], K is a monovalent cation with low replacing power compared with divalent cations such as Fe, Zn etc. Cluster 2 at low tide (Figure 3) shows the groups of Ca, Mg, organic matter, clay fraction, sand fraction, pH, Pb, Cu and Na. These associations are consistent with FA results with the loading factor of factor two, factor three, factor five and factor seven. In coastal environments such as in mangroves, the relationship between granulometric fractions, organic matter, base cations and heavy metals are become as functions of ionic strength of sediment solution and surface cation complexation [29]. The concept of cation exchange capacity at low tide implies that ions will be exchanged between wetlands, colloid surface and the surrounding water. Sediment organic matter has higher ion exchange capacity than sediment colloids and plays an important role in cation exchange capacity [30]. The replacing power of the cation exchange complex depends on its valence, ionic strength, its diameter in hydrated form and its concentration in water. This clarifies the loadings of marine indicator divalent cations (Mg, Ca) together with organic matter and Pb due to the ionic strength. The role in buffering the pH change at low tide was also observed Hussien and Rabenhurst [29].

The I_{geo} showed that all the heavy metals are in Class 0 and Class 1 (Table 4) at high and low tide. This suggests that the mangrove sediment of Mengkabong is having background concentrations for Al, Cu, Fe, and Zn and unpolluted for Pb. Karbassi *et al*. [31] detailed that I_{geo} values can be used effectively and more meaningful in explaining the sediment quality. In addition, Soto-Jimenez and Paez- Osuna [32] explained that the input of metals into sediment that are located seawards to be low in the total concentration of most of the elements and this could be due to the mixing of enriched particulate material with relatively clean marine sediments.

Table 4: Geoaccumulation indexes (Muller 1979) of heavy metals concentration in sediment of Mengkabong mangrove forest

Geoaccumulation index	Pollution Intensity	Heavy Metals (I_{geo} class for Mengkabong lagoon sediment)
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	

Conclusion

The studied parameters showed high values at high tide compared to low tide. The study showed that factor and cluster analysis are useful tool to indentify the controlling factors of sediment data at high and low tide. Factor analysis extracted six factors at high tide and seven factors at low tide. While cluster analysis results illustrated two clusters at high and low. The salinity and electrical conductivity clusters as well as component loadings at high and low tide explained the tidal process where there is high contribution of seawater to mangrove sediment. The tidal flooding brings additional ions such as K, Mg and Na into system become the governing factor that controls the sediment chemistry. The I_{geo} value of heavy metals showed that the Mengkabong mangrove sediment are having background concentrations for Al, Cu, Fe, and Zn and unpolluted for Pb.

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