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Application of Factor Analysis in Geochemical Fractions of Heavy Metals in the Surface Sediments of the Offshore and Intertidal Areas of Peninsular Malaysia

(Aplikasi Analisis Faktor di dalam Logam Berat Fraksi Geokimia pada Sedimen Permukaan bagi Kawasan Luar Pantai dan Pasang Surut di Semenanjung Malaysia)

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ABSTRACT

In this study, heavy metal data (including four geochemical fractions) from offshore and intertidal sediments collected off the west coast of Peninsular Malaysia were analyzed using factor analysis. A similarity was found when comparing between offshore and intertidal sediments, where out of the 20 variables, five factors (resistant Cu, total Cu, resistant Pb, total Pb and total Zn) could be clearly selected on the basis of their high loadings as derived by factor analysis in both sediment sampling areas. However, the statistical outputs based on the present study using factor analysis cannot be practically acceptable mainly because the resistant fractions are not of anthropogenic origins and ecotoxicologists are more concern on the anthropogenic ones. Only a modification using a specific normalizing agent such as the nonresistant fraction, should be tested to show feasibility of the contribution of anthropogenic sources in the two sampling areas. However, a more comprehensive metal monitoring data should be compiled to complement the results obtainable from factor analysis, before a valid Malaysian Marine Sediment Pollution Index or Sediment Quality Guidelines, can be proposed to be established.

Keywords: Factor analysis; metals in sediment; Peninsular Malaysia

ABSTRAK

Di dalam kajian ini, data logam berat (termasuk empat fraksi geokimia) dari sedimen di kawasan luar pantai dan kawasan pasang surut dari pantai barat Semenanjung Malaysia telah dianalisis menggunakan analisis faktor. Perbandingan antara kawasan luar pantai dan pasang-surut menunjukkan bahawa daripada 20 pembolehubah, lima faktor (Cu rentang, Cu jumlah, Pb rentang, Pb jumlah dan Zn jumlah) telah dipilih berdasarkan muatan tinggi hasil analisis faktor pada kedua-dua kawasan sedimen tersebut. Namun demikian, output statistik berdasarkan kajian ini menggunakan analisis faktor tidak boleh diterima secara praktik kerana fraksi rentang bukan berasal daripada antropogenik dan ahli ekotoksikologi lebih berminat pada sumber antropogenik. Hanya modifikasi menggunakan agen pernormalan yang tertentu seperti fraksi tidak rentang, harus dicuba supaya sumbangan daripada sumber antropogenik di kedua-dua kawasan kajian boleh diketahui. Bagaimanapun, data pemonitoran logam yang komprehensif harus dikumpulkan dengan data menggunakan analisis faktor, sebelum suatu Indeks Pencemaran Sedimen Marin Malaysia atau Garis Panduan Kualiti Sedimen, boleh dipertimbangan.

Kata kunci: Analisis faktor; logam di sedimen; Semenanjung Malaysia

Introduction

According to Panda et al. (2010), the complexity of processes involved in trapping heavy metals in different geochemical phases points to the importance of multidimensional statistical treatment. One of the multivariate analysis, principal component analysis (PCA) or factor analysis (FA), with the use of coefficients of linear correction, can serve such purpose (Wenning & Erickson 1994). Several types of mathematical models have been used in the source apportionment studies. FA is a part of the multivariate model (Pekey et al. 2004, 2005).

Multivariate analysis, such as correlation analysis and PCA, are widely used (Alves et al. 2009; Simeonov et al. 2000; Soares et al. 1999; Yu et al. 2000; Yu et al. 2001) in environmental data analysis because of their inherent abilities in correlating relationships among numerous variables. Although the PCA has been used to discriminate compositional patterns (Barona & Romero 1997), the FA is a more adequate multivariable technique when the goal is not only to reduce the number of variables but also to detect structures in the relationships between variables (Maiz et al. 2000). FA was performed by evaluation of principal components and computing the eingenvectors. In this study, only the eingenvalues higher than 1 (Kaiser criterion), giving a cumulative variance above 80% (although some studies suggested above 85%), were retained (Davies & Sampson 1973). Afterwards, the rotation of the principal components was carried out by the Varimax normalised method. Factors with eigenvalue >1 were selected (Davies & Sampson 1973). Factor loadings equal to or less than 1.0 were eliminated because those below 1.0 were considered insignificant.

Therefore, the objective of this study was to identify the important sources of metal geochemical fractions and total metals using FA and to provide a basis for future establishment of Malaysian Sediment Quality Index.

MATERIALS AND METHODS

The data of the four geochemical fractions of Cd, Cu, Pb and Zn in the surface sediments of the offshore and intertidal areas of the west coast of Peninsular Malaysia were obtained from those reported by Yap et al. (2002, 2003, 2005). The offshore area consisted of 20 samplings sites in the Straits of Malacca while the intertidal area consisted of 26 sampling sites in the west coast of Peninsular Malaysia. The four fractions considered were the 1) 'easily, freely, leachable or exchangeable (EFLE)' (F1), 2) 'acid-reducible' (F2), 3) 'oxidisable-organic' (F3) and 4) 'resistant' (F4) fractions. Prior to all the statistical analyses, an additive logarithmic transformation [$\log_{10}$ (mean + 1)] was performed on all the data to remove the effects of orders of magnitude difference between variables to avoid negative numbers (Brakstad 1992; Zar 1996). In addition, usually the environmental data from contaminated areas are positively skewed (Tobias et al. 1997) and therefore, the arithmetic values were log10 transformed so that it is nearer normal distribution (Zar 1996).

To understand the geochemical process in the study area, the whole data set was analyzed separately for FA (based on eigenvalues above 1) using statistical software STATISTICA for Windows (StatSoft, Inc., USA, 1995, Version 8.0).

RESULTS AND DISCUSSION

The cumulative percentage was 80.31% with six factors for offshore sediments in the Straits of Malacca (Tables 1 and 2) and 87.5% with five factors for intertidal sediments of the west coast of Peninsular Malaysia (Tables 3 and 4).

For the offshore sediments, the results derived from FA are given in Tables 1 and 2. Table 2 also includes factor loadings, eigenvalues and variance explained by each factor. The six factors were obtained, which explained approximately 80.31% of the total variance, with the first factor accounting for 35.82%, the second factor for 14.17%, the third factor for 9.78%, the fourth factor for 8.56%, the fifth factor for 6.44% and the sixth factor for 5.54%. The first factor was characterized by high loadings (≥ 0.70) of Cu(F1), Cu(F4), total Cu, Pb(F4), total Pb, Zn(F4) and total Zn, and moderate loadings (0.53-0.62) of Cu(F2), Cu(F3), Cd(F3), total Cd, Pb(F1) and Pb(F2), and weak loadings (0.35-0.47) of Cd(F1), Pb(F3), and Zn(F1). The second factor was heavily loaded with Pb(F3) and Zn(F3), and a weak loading with Cu(F1), Cd(F2), total Pb and Zn(F1). The third factor displayed moderate loading of Cu(F2) and Pb(F2). The fourth factor was characterized by high loading of Cd(F4) (0.79), and moderate loading (0.52-0.69) of Cd(F2) and total Cd. Therefore, of the 20 variables, only seven factors (Cu(F1), Cu(F4), total Cu, Pb(F4), total Pb, Zn(F4) and total Zn) were selected on the basis of their high PCA loadings (≥ 0.70). Since all of these parameters are positively loaded with this factor, this factor might represent a mixture of crustal and anthropogenic signatures, the latter could be likely due to shipping activities because the Straits of Malacca is an active shipping waterway in the world (Hamzah 1997; Yap et al. 2002, 2003).

For the intertidal sediments of the west coast of Peninsular Malaysia, the results derived from FA are given in Tables 3 and 4. The five factors were obtained, which explained approximately 87.5% of the total variance, with the first factor accounting for 40.8%, the second factor for 17.1%, the third factor for 12.6%, the fourth factor for 11.0%, and the fifth factor for 5.93%. The first factor was characterized by high loadings of Cu(F1), Cu(F4), total Cu, Pb(F3), Pb(F4), total Pb, Zn(F3), Zn(F4) and total Zn, a moderate loadings of Cu(F3), Cd(F1), total Cd and Zn(F2), and a weak loading of Cu(F2), Pb(F1), Cd(F1), Cd(F3), Cd(F4), total Cd and Zn(F1). The second factor was moderately loaded with Pb(F1) and Cd(F4), and a weak loading with Pb(F4), total Pb and Cd(F1). The third factor displayed moderate loading of Cd(F2) and total Cd, and a weak loading with Pb(F2), Cd(F1),

TABLE 1. Eigenvalue, percentage total variances and cumulative total variances for factors derived by factor analysis, based on offshore sediments in the Straits of Malacca (N= 31).

Factor number	Eigenvalue	Total variance (%)	Cumulative (%)
1	7.16	35.82	35.82
2	2.83	14.17	49.99
3	1.96	9.78	59.77
4	1.71	8.56	68.33
5	1.29	6.44	74.77
6	1.11	5.54	80.31

TABLE 2. Factor loadings rotated matrix for heavy metals and their geochemical fractions, based on offshore sediments of the Straits of Malacca (N= 31).

Parameters	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Cu(F1)	0.71	0.36				
Cu(F2)	0.53		0.65			
Cu(F3)	0.53				-0.63	
Cu(F4)	0.81					
Total Cu	0.85					
Cd(F1)	0.36					0.47
Cd(F2)		0.30		0.52		0.36
Cd(F3)	0.62					
Cd(F4)				0.79		
Total Cd	0.62			0.69		
Pb(F1)	0.55					
Pb(F2)	0.55		0.63			
Pb(F3)	0.47	0.75				
Pb(F4)	0.70				0.54	
Total Pb	0.79	0.37			0.34	
Zn(F1)	0.35	0.47				
Zn(F2)						
Zn(F3)		0.85				
Zn(F4)	0.87					
Total Zn	0.86					
Eigenvalue	7.16	2.83	1.96	1.71	1.29	1.11
Percentages of variance	35.82	14.17	9.78	8.56	6.44	5.54

Note: F1= easily, freely, leacheable or exchangeable fraction; F2= acid-reducible fraction; F3= oxidisable-organic fraction; F4= resistant fraction. Total= summation of F1, F2, F3 and F4.
Extraction method: Principal component analysis

TABLE 3. Eigenvalue, percentage total variances and cumulative total variances for factors derived by factor analysis, based on intertidal sediments of the west coast of Peninsular Malaysia (N= 26).

Factor number	Eigenvalue	Total variance (%)	Cumulative (%)
1.	8.17	40.83	40.83
2.	3.42	17.12	57.95
3.	2.53	12.63	70.58
4.	2.20	11.00	81.57
5.	1.19	5.93	87.50

and Cd(F3). The fourth factor contained weak loading of Cu(F1), Pb(F1), Pb(F2), and Pb(F4). Lastly the fifth factor was heavily loaded with Pb(F2) and a weak loading with Cd(F2). Therefore, of the 20 variables, only eight factors (Cu(F4), total Cu, Pb(F3), Pb(F4), total Pb, Zn(F3), Zn(F4) and total Zn) were selected on the basis of their high PCA loadings. Again, since all of these nonresistant and resistant parameters are positively loaded with this factor, this factor might represent a mixture of crustal and anthropogenic signatures, the latter could be likely due to land based activities such as industrial and urban wastes, as suggested by Lim and Kiu (1995) and Yap et al. (2002, 2003).

Comparing between offshore and intertidal sediments, one similarity was found in which out of the 20 variables, five factors (Cu(F4), total Cu, Pb(F4), total Pb and total Zn) were selected on the basis of their high loadings as derived by FA in both offshore and intertidal sediments samples. However, by looking at the five selected factors, their potential inclusion in the development of sediment quality guidelines was questionable because of three reasons. First, total metals are inclusive of natural sources

Table 4. Factor loadings rotated matrix for heavy metals and their geochemical fractions, based intertidal sediments of the west coast of Peninsular Malaysia (N= 26).

Parameters	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Cu(F1)	0.71			0.30	
Cu(F2)	0.36				
Cu(F3)	0.68				
Cu(F4)	0.74				
Total Cu	0.71				
Cd(F1)	0.42	0.64		0.36	
Cd(F2)			0.34	0.35	0.79
Cd(F3)	0.81				
Cd(F4)	0.70	0.48		0.36	
Total Cd	0.83	0.41			
Pb(F1)	0.56	0.42	0.49		
Pb(F2)			0.70		0.37
Pb(F3)	0.43		0.48		
Pb(F4)	0.44	0.59			
Total Pb	0.57		0.65		
Zn(F1)	0.48				
Zn(F2)	0.65				
Zn(F3)	0.90				
Zn(F4)	0.83				
Total Zn	0.88				
Eigenvalue	8.17	3.42	2.53	2.20	1.19
Percentages of variance	40.83	17.12	12.63	11.00	5.93

Note: F1= easily, freely, leacheable or exchangeable fraction; F2= acid-reducible fraction; F3= oxidisable-organic fraction; F4= resistant fraction. Total= summation of F1, F2, F3 and F4.
Extraction method: Principal component analysis

of metals and ecotoxicologists are more concerned about the anthropogenic sources. Second, F4 (resistant) is related to natural sources and again those associated with human activities are not selected. Third ecotoxicologists assumed that the selection based on FA are actually performed by principal components in which the principal component was included in the calculations involving the correlation matrix between the different parameters followed by Varimax rotation (Kuppusamy & Giridhar 2006). For example, since Cd are usually low in concentrations and less correlated with Cu, Pb and Zn, the total Cd and their respective Cd geochemical fractions are removed as selected variables. But, Cd is a known toxic metal (Eisler 2000) and its exclusion from the establishment of Malaysian sediment quality sediments is unlikely. Hence, it is thought that the statistical outputs based on the present study using FA cannot be practically acceptable. Only a modification using specific normalizing agents such as the nonresistant fractions (whether F1, F2 and F3), can be tested to know the contribution of anthropogenic sources. Perhaps, the differentiations between the industrial and domestic discharges, such as those developed by Pekey et al. (2004), can be used to identify the probable types of sources of pollution. For example, the normalizing agent can be used if it has high concentration in industrial discharges and very low concentration in sewages, or otherwise. Similarly, other values such as metal geochemical fractions (F1 or F2 or F3) can be employed if these metals were high in industrial discharges and low in domestic discharges. On the other hand, geochemical fractions of metals predominantly discharged from the industries are expected to appear as a separate factor. With these considerations, the FA can be repeated for the data set in future studies. Future studies should focus on what are the geochemical fractions of metals high in industrial discharges and are of very low concentrations in sewages and what are the metals high in sewages and very low in industrial discharges, particularly in Malaysia.

Shin and Lam (2001) used PCA to facilitate translation of the state of marine sediment quality for public information. They developed a pollution index from the results of a routine monitoring program, based on 24 variables at 64 monitoring stations from 1987 to 1997 in Hong Kong using PCA in order to identify the most important parameters that were applied in the index formulation. The application of PCA to identify important variables from a monitoring program would reduce sampling resources, as parameters that did not show significant spatial or temporal variations could be analyzed at a lesser frequency than those that were identified to be more important from the results of PCA. Therefore, ecotoxicologists can use similar PCA as an extraction method in FA to know which geochemical fractions and total metals having high loadings. These identified parameters can be considered to be further used for the establishment of Malaysian Marine Sediment Pollution Index.

FA has been widely used for source identification studies of environmental pollutants. For example, Shukla and Sharma (2010) employed FA based on metals and water soluble ion composition of the particulate matter, for source identification while Uygur et al. (2010) used FA to predict the sources of metal pollution in rainwater. Therefore, ecotoxicologists have a strong basis to use FA for the similar purpose based on the metal data of the sediment samples from Malaysia.

Conclusion

Using FA could be useful in selecting important metals or geochemical fractions of metals to be included in future establishment of Malaysian Marine Sediment Pollution Index. A more comprehensive metal monitoring data should be compiled in addition to the use of FA, before a valid Malaysian Marine Sediment Pollution Index similarly equivalent to Sediment Quality Guidelines, can be proposed to be established. The metal indices should be supported by other evidence such as a significant negative correlation ($P<0.05$) with the benthic species diversity and toxicity of the sediment in order to reflect marine sediment quality effectively.

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References

Alves, C.M., Boaventura, R.R.A.R. & Soares, Helena M.V.M. 2009. Evaluation of heavy metals pollution loadings in the sediments of the Ave River Basin (Portugal). *Soil and Sediment Contamination* 18(5): 603-618.

Barona, A. & Romero, F. 1997. Relationships among metals in the solid phase of soils and in wild plants. *Water, Air and Soil Pollution* 95: 59-74.

Brakstad, F. 1992. A comprehensive pollution survey of polychlorinated dibenzo-p-dioxins and dibenzofurans by means of principal component analysis and partial least square regression. *Chemosphere* 25: 1611-1629.

Davies, J.C. & Sampson, R.J. 1973. *Statistics and Data Analysis in Geology*. New York: Wiley.

Eisler, R. 2000. *Handbook of Chemical Risk Assessment: Health Hazards to Human, Plants, Animals*. Vol. 1 (Metals). Albany GA: Lewis Publisher.

Hamzah, A. 1997. *The Straits of Malacca: International co-operation in Trade Funding and Navigational Safety*. Kuala Lumpur: Pelanduk Publication.

Kuppusamy, M.R. & Giridhar, V.V. 2006. Factor analysis of water quality characteristics including trace metal speciation in the coastal environmental system of Chennai Ennore. *Environment International* 32: 174-179.

Lim, P.E. & Kiu, M.Y. 1995. Determination and speciation of heavy metals in sediments of the Juru River, Penang, Malaysia. *Environmental Monitoring and Assessment* 35: 85-95.

Maiz, I., Arambarri, I., Garcia, R. & Millan, E. 2000. Evaluation of heavy metal availability in polluted soils by two sequential extraction procedures using factor analysis. *Environmental Pollution* 110: 3-9.

Panda, U.C., Rath, P., Bramha, C. & Sahu, K.C. 2010. Application of factor analysis in geochemical speciation of heavy metals in the sediments of a lake system—Chilika (India): A case study. *Journal of Coastal Research* 265: 860-868.

Pekey, H., Karakaş, D. & Bakoğlu, M. 2004. Source apportionment of trace metals in surface waters of a polluted stream using multivariate statistical analyses. *Marine Pollution Bulletin* 49(9-10): 809-18.

Pekey, H., Mithat, B. & Pekey, B. 2005. Sources of heavy metals in the Western Bay of Izmit surface sediments. *International Journal of Environmental Analytical Chemistry* 85 (14): 1025-1036.

Shin, P.K. & Lam, W.K. 2001. Development of a marine sediment pollution index. *Environmental Pollution* 113(3): 281-91.

Shukla, S.P. & Sharma, M. 2010. Neutralization of rainwater acidity at Kanpur, India. *Tellus* 62B: 172–180.

Simeonov, V., Massart, D.L., Andreev, G. & Tsakovski, S. 2000. Assessment of metal pollution based on multivariate statistical modeling of 'hot spot' sediments from the Black Sea. *Chemosphere* 41: 1411-1417.

Soares, H.M.V.M., Boaventura, R.A.R., Machado, A.A.S.C. & Esteves da Silva, J.C.G. 1999. Sediments as monitors of heavy metal contamination in the Ave river basin (Portugal): multivariate analysis of data. *Environmental Pollution* 105: 311–323.

Tobias, F.J., Bech, J. & Sanchez, P. 1997. Statistical approach to discriminate background and anthropogenic input of trace elements in soils of Catalonia, Spain. *Water, Air and Soil Pollution* 100: 63-78.

Uygur, N., Karaca, F. & Alagha, A. 2010. Prediction of sources of metal pollution in rainwater in Istanbul, Turkey using factor analysis and long-range transport models. *Atmospheric Research* 95(1): 55-64.

Wenning, R.S. & Erickson, G.A. 1994. Interpretation and analysis of complex environmental data using chemometric methods. *Trends in Analytical Chemistry* 13: 446–457.

Yap, C.K., Ismail, A. Tan, S.G. & Omar, H. 2002. Concentrations of Cu and Pb in the offshore and intertidal sediments of the west coast of Peninsular Malaysia. *Environment International* 28: 467-497.

Yap, C.K., Ismail, A. & Tan, S.G. 2003. Cd and Zn in the straits of Malacca and intertidal sediments of the west coast of Peninsular Malaysia. *Marine Pollution Bulletin* 46: 1348-1353.

Yap, C.K., Ismail, A. & Tan, S.G. 2005. Spatial variation of different geochemical fractions of Zn concentrations in the surface sediments of the Straits of Malacca: Natural or anthropogenic? *Wetland Science* 3(2): 94-103.

Yu, K.C., Tsai, L.J., Chang, C.Y. & Ho, S.T. 2000. Multivariate analyses on heavy metal binding fractions of river sediments in Southern Taiwan. *Water Science and Technology* 42: 7–8, 193–199.

Yu, K.C., Tsai, L.J., Chen, S.H. & Ho, S.T. 2001. Correlation analysis on binding behavior of heavy metals with sediment matrices. *Water Research* 35(10): 2417–2428.

Zar, J.H. 1996. *Biostatistical Analysis*. 3rd Ed. New Jersey: Prentice-Hall International.

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