APPLICATION OF SEDIMENT QUALITY GUIDELINES IN THE ASSESSMENT OF MANGROVE SURFACE SEDIMENT IN MENGKABONG LAGOON, SABAH, MALAYSIA

[*1]S. M. Praveena, [2]M. Radojevic, [1]M. H. Abdullah, [3]A. Z. Aris

[1]School of Science and Technology, Universiti Malaysia Sabah, Locked Bag 2073, 88999 Kota Kinabalu, Sabah, Malaysia

[2] Faculty of Engineering and Computer Science, University of Nottingham Malaysia Campus, Jalan Broga 43500 Semenyih, Selangor, Malaysia

[3] Faculty of Environmental Studies, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

Received 23 September 2007; revised 5 November 2007; accepted 17 December 2007

ABSTRACT

There have been numerous sediment quality guidelines developed to monitor the sediments. Sediment quality guidelines are very useful to screen sediment contamination by comparing sediment contaminant concentration with the corresponding quality guideline, provide useful tools for screening sediment chemical data to identify pollutants of concern and prioritise problem sites and relatively good predictors of contaminations. However, these guidelines are chemical specific and do not include biological parameters. Aquatic ecosystems, including sediments, must be assessed in multiple components (biological data, toxicity, physicochemistry) by using intregrated approaches in order to establish a complete and comprehensive set of sediment quality guidelines. Numerous sediment quality guidelines Washington Department of Ecology Sediment Quality Guideline, Australian and New Zealand Environment and Conservation Council, Swedish Environmental Sediment Quality, Screening Quick Reference Table, Portuguese Legislation on the Classification of Dredged Materials in Coastal Zones and Interim Sediment Quality Guideline for Hong Kong) have been applied to the Mengkabong lagoon mangrove sediment and discussed. The most appropriate guideline that meets the prioritization criteria consistent with international initiatives and regulations is interim sediment quality values for Hong Kong. The guideline verifies that all the metals are below the Interim Sediment Quality Value-low. However, site-specific, biological testing and ecological analysis of exisiting benthics community structure related to sediment contamination are needed for final decision making in the case of Mengkabong lagoon.

Key words: Mangrove, sediment, sediment quality guidelines

INTRODUCTION

Mangrove sediments were extensively studied all around the world and act as sinks and sources of contaminants in aquatic systems because of their variable physical and chemical properties (Rainey *et al*., 2003; Marchand *et al*., 2006; Pekey, 2006; Karbassi *et al*., 2007).

Trace metals can accumulate in the upper sediment. Such accumulation takes place by biological and geochemical mechanisms and can represent significant environmental concern such as toxic to sediment-dwelling organisms and fish resulting in decreased survival, reduced growth, or impaired reproduction, and lower species diversity (Karbassi and Amirnezhad, 2004; Okafor and Opuene, 2007; Parizanganeh *et al*., 2007). Generally, the primary purposes of sediment quality guidelines (SQGs) are to protect the aquatic biota from the harmful and toxic effects related with sediment-bound contaminants and useful tool for evaluating the potential for contaminants within sediment to induce biological effects (Spencer and Macleod, 2002). These guidelines evaluate the degree to which the sediment-associated chemical status might adversely affect aquatic organisms

*Corresponding author: *smpraveena@gmail.com*
Tel: +601 65169081, Fax: +601 88435324

and are designed to assist sediment assessors and managers responsible for the interpretation of sediment quality (Caeiro *et al.,* 2005). It is also to rank and prioritize the contaminated areas or the chemicals for the further investigation (Farkas *et al*., 2007).

SQGs used in this study were Washington Department of Ecology (WDOE) Sediment Quality Guidelines (1995), Australian and New Zealand Environment and Conservation Council (ANZECC, 1999), Swedish Environmental Sediment Quality Guideline (SQG, 1996), Screening Quick Reference Table (SQUIRT), Portuguese Legislation on the Classification of Dredged Materials in Coastal Zones and Interim Sediment Quality Guideline for Hong Kong. The Washington State Department of Ecology developed biologically based criteria for evaluating contaminated freshwater sediments. As part of this effort, all the sediment guidelines from various United States and Canadian sources were compiled and summarized. The background approach is the simplest and most straightforward of the guideline development methods. Concentrations for each contaminant of interest are determined for sites where the levels are considered to be acceptable (Batts and Cubbage, 1995).

ANZECC Guidelines for Fresh and Marine Water Quality in 1999 are largely based on biological-effects-based guidelines developed overseas with some modifications to reflect local conditions or more recent information, as were the comparable guidelines in the previous ANZECC Ocean Disposal Guidelines (1998).

Swedish Environmental Protection Agency established the Swedish Environmental Quality in 1999 for marine sediments. The objective of this guideline is to allow local and regional authorities to make accurate assessments of environmental quality, planning and managements (Vallius and Leivouri, 2003).

SQUIRT was developed by NOAA for screening purposes. The guideline values are divided into five increasing categories of observable effects. There are two approaches used in SQV, first it involves matching the sediment chemistry with biological effects and toxicity testing. Second, it is based on combination of water quality criteria to obtain sediment contaminant concentrations. These data are normally normalized to sediment organic carbon concentration to obtain the differences in the bioavailability of contaminants in different samples. Many regulatory authorities apply SQV to surface sediment. It involves comparison of total heavy metal concentration to the probable effects level (Spencer and Macleod, 2002).

In Portugal, coastal morphology and the short availability of suitable landfill sites are key constraints in dredged materials management strategies. The articulate of the present regulations does not consider all the possible approaches to controlling disposal at sea, so some proposals have been under discussion in order to establish a coherent policy (Paixão, 2001).

The interim sediment quality values for Hong Kong (ISQV-low and ISQV-high) were chosen and being most appropriate guideline that meet the prioritization criteria consistent with international initiatives and regulations (Chapman *et al*., 1999a). Based on the guideline, two-sets of values were proposed: ISQV-low which adverse biological effects are unlikely small and ISQV-high which severe adverse biological effects are very likely.

The Mengkabong lagoon in Tuaran District has experienced a 15% decrease from 1991 to 2000. The mangroves covered 12.6km^2 in 1991 while in 2000 it was 10.7km^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). Due to the proximity at KKIP and the increasing development in the area surrounding the mangrove forest, it was decided to assess the current sediment status of the mangrove sediments (Environmental Indicator Report, 2003).

This paper reports the current state of heavy metal concentration in Mengakbong lagoon and six sets of empirically derived SQGs to study the mangrove sediment quality assessment. Finally, the differences when using these sets of SQGs were discussed and the most appropriate guideline that meets the prioritization criteria consistent with international initiatives and regulations was chosen.

MATERIALS AND METHODS

Study area

This study was conducted in Mengkabong lagoon mangrove forest, Tuaran District, West Coast of Sabah which is 40km away from Kota Kinabalu. The total of study area spreads over from latitude 06º06'N to 06º11'N and longitude 116º08'E to 116º13'E (Fig. 1). 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 an industrial area, Kota Kinabalu Industrial Park.

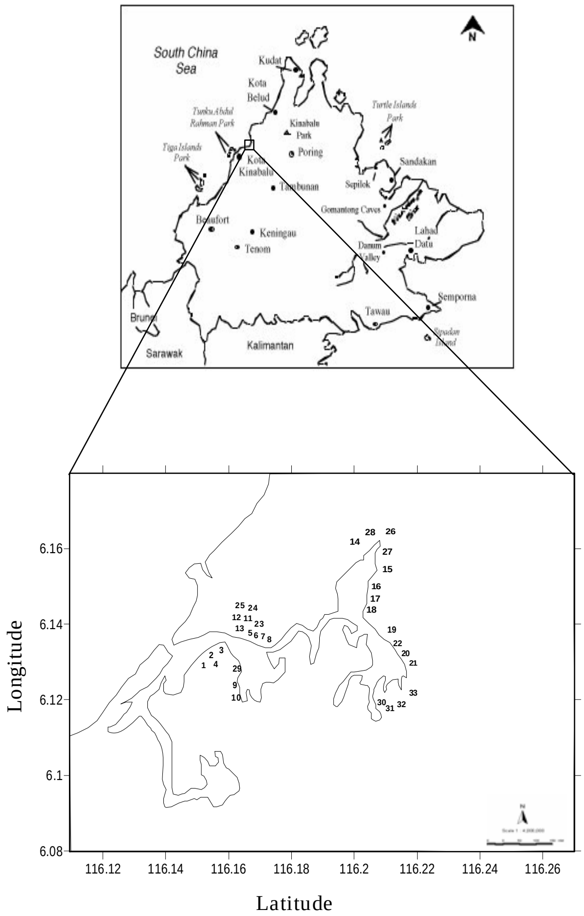

Fig. 1: Location of the sampling stations in Mengkabong lagoon, Sabah

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 (Environmental Impact Assessment, 1992; Town and Regional Planning Department of Sabah, 2003).

Soil sampling and analysis

Mangrove sediments were sampled randomly and taken in triplicates with an auger at 33 stations from March 2006 to November 2006 (Fig. 1) at low and high tide. The exact position of each sampling site was recorded using Global Positioning System (GPS). The sampling sites were selected based on the accessibility to the mangrove forest. Mangrove surface sediments were choosen for this study as this layer controls the exchange of metals between sediments and water (El Nemr *et al*., 2006).

The laboratory apparatus were acid washed and rinsed throughly first with tapwater and then with distilled water to ensure any traces of cleaning reagent were removed before the analysis. Finally, they were dried and stored in a clean place. The sediments were kept cool in an icebox during transportation to the laboratory. The surface sediments were air-dried and after homogenization using pestle and mortar, passed through a 2mm mesh screen and stored in polyethylene bags. The sediment samples were analysed for heavy metal concentrations using aqua regia. Approximately 2g of each sample digested with 15mL of aqua-regia (HCl: HNO_3=1:3) in a Teflon bomb and was heated 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 digestion is safer and adequate for total heavy metals extraction. Heavy metal concentrations of the solution were measured using Atomic Absorption Spectrometry (AAS) with air/acetylene (for Cu, Fe, Pb, Zn) and nitrous oxide-acetylene (for Al) at specific wavelengths (Atomic Absorption Spectrometer, Perkin Elmer 4100).

The metals data from Mengkabong lagoon has been compared with WDOE Sediment Quality Guidelines (1995), Australian and New Zealand Environment and Conservation Council (ANZECC, 1999), Swedish Environmental Sediment Quality Guideline (SQG, 1996), SQUIRT, Portuguese Legislation on the Classification of Dredged Materials in Coastal Zones and Interim Sediment Quality Guideline for Hong Kong.

RESULTS

Descriptive data analysis

All the metals displayed relatively higher concentration at high tide compared to low tide. Table 1 shows the metals distribution at high and low tides. The metal concentrations were generally low and in most cases lower than global average shale value of Turekian and Wedepohl (1961). The concentrations of the metals were compared with several SQGS to evaluate the environmental significance and impact. The SQGSs are WDOE Sediment Quality Guidelines (1995), Australian and New Zealand Environment and Conservation Council (ANZECC, 1999), Swedish Environmental Sediment Quality Guideline (SQG, 1996), SQUIRT, Portuguese Legislation on the Classification of Dredged Materials in Coastal Zones and Interim Sediment Quality Guideline for Hong Kong. Table 2 presents WDOE Sediment Quality Guidelines (1995), Australian and New Zealand Environment and Conservation Council (ANZECC, 1999) and Swedish Environmental Sediment Quality Guideline (SQG, 1996).

Table 1: Metals distribution at high and low tides (mg/kg)

Metal	High tide (HT)	Low tide (LT)
Cu	28	19
Fe	7670	6805
Pb	52	41
Zn	57	41
Al	14830	9522

Table 2: Average concentration values of five important heavy metals obtained in this study with marine sediment quality guidelines

Sediment quality standards \ Element	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
WDOE, SQG[a] (1995)					
Non-polluted	-	< 25	-	< 40	<90
Moderately polluted	< 25	25-75	-	40-70	90-200
Heavily polluted		>75	-	>70	>200
Interim sediment quality guideline [b] (ISQG)					
ISQG-low	-	65	-	50	200
ISQG- high		270		220	410
Swedish environmental sediment quality guideline (SQG)[c]					
Effects range low	-	34	-	47	150
Effects range medium	-	270	-	218	410

[a] Washington Department of the Environment (WDOE), SQG (1995)
[b]Australian and New Zealand Environment and Conservation Council (ANZECC) (1999)
[c]Mil-Homens *et al.* (2006)

SQUIRT was developed by NOAA divided into five increasing categories of observable effects (Tables 3 and 4). Many regulatory authorities apply SQUIRT to surface sediment. It involves comparison of total heavy metal concentration to the probable effects level (Spencer and Macleod, 2002). Furthermore, the metals were compared with Portuguese Legislation and International SQGs for Hong Kong, developing Interim Sediment Quality Guideline (Tables 5 and 6).

Table 3: Sediment Guidelines and Definitions Used in SQUIRT

Heavy metals	Threshold effects level (TEL)	Effects range low (ERL)	Probable effects level (PEL)	Effects range median (ERM)	Apparent effects threshold (AET)
Cu	18.7	34	108	270	390 (Microtox and Oyster Larvea)
Pb	30.2	46.7	112	218	400 (Bivalve)
Zn	124	150	271	410	410 (Infaunal community)

Table 4: Screening quick reference table for heavy metals in marine sediment. All concentrations in mg/kg (Buchman, 1999)

Sediment Guideline	Descriptions
Threshold effects level	Maximum concentration at which no effects are observed
Effects range level	10th percentile values in effects
Probable effects level	Lower limit of the range of concentrations at which adverse effects are always observed
Effects range median	50th percentile value in effects
Apparent effects threshold	Concentration above which biological indicator affetcs always observed

Table 5: Portuguese legislation on the classification of dredged materials in coastal zones according to Caeiro *et al*., (2005)

Classes/ Contaminants	Cu	Pb	Zn
Class 1: Clean dredged material	<35	<50	<100
Class 2: Trace contaminated dredged material	35-150	50-150	100-600
Class 3: Lightly contaminated dredged material	150-300	150-500	600-1500
Class 4: Contaminated dredged material	300-500	500-1000	1500-5000
Class 5: Highly contaminated dredged material	> 500	>1000	>5000

Table 6: Classification of sediments by the heavy metal concentrations (mg/kg) according to the interim sediment quality guideline for Hong Kong

Metals (mg/kg)	ISQV-low	ISQV-high
Cu	65	270
Pb	75	218
Zn	200	410

DISCUSSION

Evaluation of environmental significance of metals in sediment by comparison with SQGs

From the several SQGs (Table 2) WDOE, SQG (1995) and ANZECC (1999) guideline values showed that Cu, Pb and Zn elements were moderately polluted in the studied area. The mean heavy metals values (Cu, Pb, and Zn) were below than ISQG-L and ISQG-H levels. Even though the surface sediment was still generally well below the SQG-H concentrations where substantial adverse effects on benthic biota could be expected (Abrahim *et al*., 2007). The Swedish Environmental Sediment Quality Guideline (SQG, 1996) is divided to effects range low (ERL) and effects range medium (ERM). ERL indicates the contaminants in sediment are not likely to have adverse effects on animals that live in sediment whereas ERM indicates the contaminants in sediment probably have adverse effects on animals that live in sediment. Cu and Pb values are in ERL range, which indicates a small percentage of the concentration is likely to have adverse effects on animals that live in sediment. Weng *et al*., (2003) studied the stability and relative content of Cu, Pb and Zn in soil and sediment and elobrated that in general, when the relative content ratio of these elements goes beyond their normal variation ranges in soil and sediment. It may be interpreted that their geochemical content is suffering from a disturbance. It indicates to any potential change in anenvironment resulting by human activities.

Comparison of Mengkabong mangrove forest surface sediment contamination with other mangrove forest elsewhere is discussed below. In Port Jackson estuary (Sydney, Australia), it demonstrated that much higher levels of metal contamination (800µg/g for Cu, 900µg/g for Pb and 1,000µg/g for Zn) in several strongly contaminated inshore areas. While comparison with Tamaka mangrove forest, New Zealand these maximum concentrations are above ISQG-L but below ISQG-H levels (Cu:107µg/g, Pb:121µg/g, Zn:316µg/g).

This emphasized the importance of proactive measurements to manage and mitigate pollution in the catchments surrounding Tamaki Estuary and other estuaries in the Auckland region (Abrahim *et al.*, 2007; Birch and Taylor, 1999).

Wang and Qin (2006) suggests that Cu, Pb and Zn elements coincide with main roads, which suggests these three metals are probably due to vehicular emissions.

The influence of vehicular emissions was characterized by Pb and to lesser extent by Cu and Zn. Besides, the existance of mechanical workshops and factories also may play an important role as an input of Cu, Pb and Zn to soils. Besides, Alloway (1995) stated that agricultural materials, sewage sludge as well as human activities are some of the sources of Cu, Pb and Zn input in soil. Moreover, Department of Town Planning, Sabah (2006) pointed out several pollution sources in Mengkabong area are such as from the household waste that thrown by villagers drifted to the seaside.

Tables 3 and 4 represent the SQUIRT for heavy metals in marine sediment. Total heavy metals concentrations of Cu, Pb and Zn in studied surface sediment (Table 1) were compared to the probable effects level and apparent affects threshold in Table 3. It shows that all the sediments tested lie below PEL and AET. This points out that no adverse biological effects are likely to occur. Previous study done by Speneer and Macleod (2002) indicated that both surface sediment tested from the Medway Estuary and Orlands Estuary (UK) lie below PEL, whilst Pb concentration in Tilbury is higher than 112 mg/kg signifying that any organism living within this sediment could potentially experience adverse effects. Moreover, the Mengkabong mangrove surface sediments were computed according to the Portuguese legislation on the classification of dredged materials (Table 5). According to this legislation, the sediments can be classified into five categories, from clean to highly contaminated sediments. Mengkabong mangrove sediments are catogerized in Class 1, clean dredged material as the mean value of heavy metals (Cu, Pb and Zn) at high and low tides are below the Class 1.

Interim Sediment Quality Guideline for Hong Kong will be improved over time based on region-specific affects and contaminant information. Table 6 shows the Interim Sediment Quality Guideline for Hong Kong and comparison with metals in this study. All the metals are below the ISQV-low. However, site-specific, biological testing and ecological analysis of exisiting benthics community structure related to sediment contamination are needed for final decision making in the case of Mengkabong estuary.

The empirical SQGs are developed from sites where mixtures of toxic contaminants occur, so biological responses at these sites are undoubtedly affected by multiple toxicants. Sediment concentrations are based on total concentrations per dry weight of sediment, and thus do not take into account the bioavailabile fraction (Burton, 2002).

Applied SQGs do not readily describe the inorganic speciation differences, the dynamics of biota and critical of physicochemical characteristics (Burton, 2002; Spencer and Macleod, 2002; Batts and Cubbage, 1995). In addition, the Washingston Department of Environment is designed for freshwater sediments. This guideline will act as screening tool and might not be the best guideline for studied mangrove sediment. Conversely, the application of several SQGs, SQUIRT and Portuguese Legislation to surface sediment alone may under-estimate the risk to organisms if either low sediment accumulation rates or recent inputs of heavy metals to the estuarine system. However, these applications are the primary use initial screening of the surface sediments (Spencer and Macleod, 2002) and decision making tools (Burton, 2002). These approaches can be categorized as empirical and establish the relationship between sediment contamination and toxic response (Burton, 2002). It is recognized that toxicological effects vary with changing physicochemical characteristics in sediments (Spencer and Macleod, 2002).

Chapman *et al*., (1999a; 1999b) recommended a composite of international SQGs for Hong Kong, developing Interim Sediment Quality Guideline. The interim sediment quality values (ISQV-low and ISQV-high) were chosen and are the most appropriate guideline that meets the prioritization criteria consistent with international initiatives and regulations. If the range of concentration of an area has uncertain toxicity, further biological testing was required before the sediment could be classified as a hazard. ISQV-low values were suggested for implementation as part of decision-making process while ISQV-high values are required compreensive data be gathered from biological screening and assessment.

ACKNOWLEDGEMENTS

The primary author sincerely acknowledges her Universiti Malaysia Sabah Scholarship (YTL Foundation) and is thankful to Mr Asram Rasmun and Mr Neldin Jeoffrey for assisting with the field samplings. The authors also thank anonymous reviewer for the helpful comments.

REFERENCES

Alloway, B. J., (1995). Heavy Metals in Soil. 2nd Edition. Chapman and Hall, United Kingdom.

Australian and New Zealand Environment and Conservation Council (ANZECC), Agriculture and Resource Management Council of Australia and New Zealand, (1999). In: Preda, M., Cox, M. E., (2002). Trace Metal Occurrence and Distribution in Sediments and Mangroves, Pumicestone Region, Southeast Quuensland, Austalia. Environ. Int., **28**: 433-449.

Batts, D., Cubbage, J., (1995). Summary of Guidelines for Contaminated Freshwater Sediments. Environmental Investigations and Laboratory Services Program Olympia, Washington 98504-7710. Publication No. 95-308.

Birch, G. F., Taylor, S. E., (1999). Source of Heavy Metals in Sediments of the Port Jackson Estuary, Australia. Sci. Total Environ., **227**: 123–138.

Buchman, M. F., (1999). NOAA Screening Quick Reference Tables. NOAA HAZMAT Report 99-1, Seattle, WA, Coastal Protection and Restoration Division, National Oceanic and Atmospheric Administration. In: Spencer, K. L., Macleod, C. L., (2002). Distribution and Partitioning Of Heavy Metals in Estuarine Sediment Cores and Implications for the Use of Sediment Quality Standards. Hydrol. and Earth System Sci., **6**: 989–998.

Burton, G. A., (2002). Sediment Quality Criteria in Use around the World. J. Limno., **3**: 65-75.

Caeiro, S., Costa, M. H., Ramos, T. B., Fernandes, F., Silveira, N., Coimbra, A., Medeiros, G. Painho, M., (2005). Assessing Heavy Metal Contamination in Sado Estuary Sediment: An Index Analysis Approach. Ecol. Indicators., **5**: 151–169.

Chapman, P. M., Allard, P. J., Vigers, G., (1999a). Development of Sediment Quality Values for Hong Kong Special Administrative Region: A Possible Model for Other Jurisdictions. Marine Poll. Bull., **38**: 161-169.

Chapman, P. M., Allard, P. J., Vigers, G. A., (1999b). Assessing Sediment Contamination in Estuaries. Environ. Toxicol. and Chem., **20**: 3–22.

El Nemr, A., Khaled, A., Sikaily, A. E., (2006). Distribution and Statistical Analysis of Leachable and Total Heavy Metals in the Sediments of the Suez Gulf. Environ. Monit. Assess., **118**: 89-112.

Environmental Impact Assessment, (1992). Proposed Mangrove Paradise Resort Complex on LA 91040377 Tuaran, Sabah, Malaysia. Perunding Sekitar Kota Kinabalu.

Environment Indicator Report, (2003). Environment Protection Department (EPD), Sabah, Malaysia. Wisma Budaya, 1 - 3 Floor, Tunku Abdul Rahman Road, Locked Bag No. 2078, 88999 Kota Kinabalu, Sabah, Malaysia.

Farkas, A., Erratico, C., Vigano, L., (2007). Assessment of the Environmental Significance of Heavy Metal Pollution in Surficial Sediments of the River Po. Chemosphere., **68**: 761-768.

Karbassi, A. R., Nabi-Bidhendi, Gh. R., Bayati, I., (2005). Environmental Geochemistry of Heavy Metals in A Sediment Core Off Bushehr, Persian Gulf. Iran. J. Environ. Health. Sci. Eng., **2**(4): 255-260.

Karbassi, A. R., Amirnezhad, R., (2004). Geochemistry of heavy metals and sedimentation rate in a bay adjacent to the Caspian Sea, Int. J. Environ. Sci. Tech., **1**(3): 191-198.

Marchand, C., Lalliet Verges, E., Baltzer, F., Alberic, P., Cossa, D., Baillif, P., (2006). Heavy Metals Distribution in Mangrove Sediments along the Mobile Coastline of French Guiana. Mar. Chem., **98**: 1-17.

Mil-Homens, M., Stevens, R. L., Abrantes, F., Cato, I. 2006. Heavy Metals Assessment for Surface Sediment from Three Areas of the Portuguese Continental Shelf. Cont. Shelf Res., **26**: 1184-1205.

Okafor, E. C., Opuene, K., (2007). Preliminary assessment of trace metals and polycyclic aromatic hydrocarbons in the sediments. Int. J. Environ. Sci. Tech., **4**(2): 233-240.

Paixão, G., (2001). The Fate of Dredged Material in Portugal: A Perspective. Instituto portuário e dos transportes marítimos, IPTM, Lisbon, Portugal. http://ipimar-iniap.ipimar.pt/ 8 August 2007.

Parizanganeh, A., Lakhan, V. C., Jalalian, H., (2007). A geochemical and statistical approach for assessing heavy metal pollution in sediments from the southern Caspian coast. Int. J. Environ. Sci. Tech., **4** (3): 351-358.

Pekey, H., (2006). Heavy Metals Pollution Assessment in Sediments of the Izmit Bay, Turkey. Environ. Monit. Assess., **123**: 219-231.

Radojevic, M., Bashkin, V. N., (1999). Practical Environmental Analysis. Royal Society of Chemistry, Cambridge.

Rainey, M. P., Tyler, A. N., Gilvear, D. J., Bryant, R. G., Mcdonald, P., (2003). Mapping Intertidal Estuarine Sediment Grain Size Distributions through Airborne Remote Sensing. Remote Sens. Environ., **86**: 480-490.

Spencer, K. L., Macleod, C. L., (2002). Distribution and Partitioning of Heavy Metals in Estuarine Sediment Cores and Implications for the Use of Sediment Quality Standards. Hydrol. and Earth System Sci., **6**: 989-998.

Town and Regional Planning Department (TRPD), (2003). Environmental Local Planning (ELP) Project Sabah. 3rd Floor, Block B, Wisma Tun Fuad Stephens, Karamunsing 88646 Kota Kinabalu, Sabah.

Turekian K. K., Wedepohl K. H., (1961). Distribution of the Elements in Some Major Units of the Earth's Crust. Geol. Soc. Am. Bull., 72:175–92. In: Ntekim, E. E. U., Ekwere, S. J., Ukpong, E. E., (2004). Heavy Metal Distribution in Sediments from Calabar River, Southeastern Nigeria. Environ. Geo., **21**: 237-241.

Vallius, H., Leivouri, M., (2003). Classification of Heavy Metal Contaminated Sediments of the Gulf of Finland. Baltica., **16**: 3-12.

Wang, X., Qin, Y., (2006). Spatial Distribution of Metals in Urban Topsoils of Xuzhou (China): Controlling Factors and Environmental Implications. Environ. Geol., **49**: 905-914.

Washington Department of Ecology, (1995). Sediment Management Standards. Chapter 173–204, Washington Administrative Code, amended December, 1995. In Long E. R., MacDonald, D. D., (1998). Recommended Uses of Empirically Derived, Sediment Quality Guidelines for Marine and Estuarine Ecosystems. HERA., **4**: 1019-1039.

Weng, H., Zhang, X., Chen, X., Wu, N., (2003). The stability of the relative content ratios of Cu, Pb and Zn in soils and sediments. Environ. Geo., 4**5**: 79–85.