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SEYEDEH BELIN TAVAKOLY SANY*, AISHAH SALLEH*, ABDUL HALIM SULAIMAN*, A. SASEKUMAR*, GHAZALEHMONAZAMI TEHRANI*, MAJID REZAYI**, ***

DISTRIBUTION CHARACTERISTICS AND ECOLOGICAL RISK OF HEAVY METALS IN SURFACE SEDIMENTS OF WEST PORT, MALAYSIA

Surface sediments at West Port on the west coast of Peninsular Malaysia were monitored to evaluate the spatial distribution of heavy metals: As, Cu, Cd, Cr, Hg, Pb and Zn. Sediment samples were collected from 10 stations, at three month intervals from November 2009 to October 2010. The degree of sediment contamination and ecological risk factor were estimated to assess contamination status and adverse biological effects. The ecological risk assessment indicates that living organisms are at high risk of Cd and Hg exposure and this is considered a critical environmental issue. Spatial distribution maps of heavy metals would facilitate identification of pollution sources and vulnerable sites.

1. INTRODUCTION

United States Environmental Protection Agency (USEPA) in 1998 defined ecological risk assessment as *a process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors*. Ecological risk assessment is a process of evaluation of the likelihood of adverse effects on the marine biological community [1]. The purpose of ecological risk assessment is to assess ecological effects of human activities through scientifically credible evaluation (chemical assessment and individual bioassay) to protect and manage the environment [2–4].

*Institute of Biological Sciences University of Malaya, 50603 Kuala Lumpur, Malaysia; corresponding author S.B.T. Sany, e-mail: belintavakoli332@gmail.com

**School of Chemical Sciences and Food Technology, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor D.E., Malaysia.

***Food Science and Technology Research Institute, ACECR Mashhad Branch, Mashhad, Iran.

In recent decades, many researchers have focused their attention on the potential threat of heavy metals in the environment [5–9] because of their toxicity and ability to accumulate in the food chain [10, 11]. Despite attempts to control anthropogenic sources, metal concentrations increase in the marine environment and are a serious threat to living organisms and human health [5, 12, 13]. The majority of trace elements originate from igneous rock. These concentrations can be used as background concentrations or concentrations that are unaffected by anthropogenic sources. This information can help to discriminate between the proportion of metals due to anthropogenic sources or natural sources in environment. In the marine environment, anthropogenic sources are influenced from several sources such as river discharge, deposition from the atmosphere, industrial waste input and shipping activities [14, 15]. There have been many studies on the toxic effects of essential and non-essential (toxin) heavy metals. These studies show that the optimal concentration of heavy metals in the environment causes optimal function (reproduction and growth) of organisms and humans, and the variation of optimal concentrations leads to a decrease in optimal functioning and eventual death [16, 17].

At least twenty heavy metals have been identified as essential elements to the health of both humans and organisms at low quantities but toxic at slightly higher quantities. These include iron, chromium, nickel, manganese, copper and zinc. Lead, cadmium, mercury and arsenic are known as toxic metals and are considered the top twenty hazardous substances in the priority list prepared by US Environmental Protection Agency [18].

Ecological risk assessment in costal water of the West Port is a difficult task because this area is greatly influenced by non-point sources of pollution such as shipping activities, port development and land discharge. Strong hydrodynamic turbulence due to the northeast monsoon is another influential factor because it causes significant variation in contamination, a temporal scale probably brought about by dispersion of sediments. To reduce the limitations effect, the stations were selected on three parallels transect (lines) with three distances (100, 500, 1000 m, respectively) from the coastline or berth line (cf. Fig. 1). This selection led to better understanding of distribution pattern of contaminants, and helped to select vulnerable station. Moreover, the field working was done fourfold during one year (two times in northeast monsoon and two times in southwest monsoon).

The objectives of the present study are the following: (i) estimating heavy metal concentrations (As, Cd, Cr, Cu, Hg, Pb, Zn) and to evaluate their contamination level in surface sediments, (ii) describing the distribution pattern of heavy metals in surface sediments and identifying vulnerable stations, and (iii) evaluating ecological risk and assessing adverse biological effects on marine animals. In view of the importance of West Port as an international shipping port and an industrial centre located in a mangrove environment, it is necessary to study sediment chemistry in order to evaluate environmental quality to control pollution and protect living resources.

2. EXPERIMENTAL

Area of study. West Port is one of the Malaysia's principal gateways and the busiest port with 22 berths. West Port has been developed along the Klang Strait and it is well sheltered by several mangrove islands and mudflats forming a natural enclosure. The study area was restricted to a narrow channel between Klang Island and Che Mat Zin Island on the west of the Indah island, nine stations were selected from three transects parallel to the coastline at three different distances (Fig. 1 and Table 1) as well as one station as control point was selected 21 km away in a remote area from the West Port. The study area lies within the humid tropics where the rainy season prevails during the northeast monsoon (November to March) and dry season during the southwest monsoon (April to October). Heavy rainfall is normally experienced during the early part of the monsoon while dry spells occur during the later part. At West Port, sea water had the following characteristics: the average salinity 30.25 ± 1.36‰, average temperature 30.04 ± 0.62 °C, average surface dissolved oxygen (DO) 5.38 ± 0.17 mg/dm^3, and monthly average surface and bottom pH values are between 7.85 and 8.25 [19].

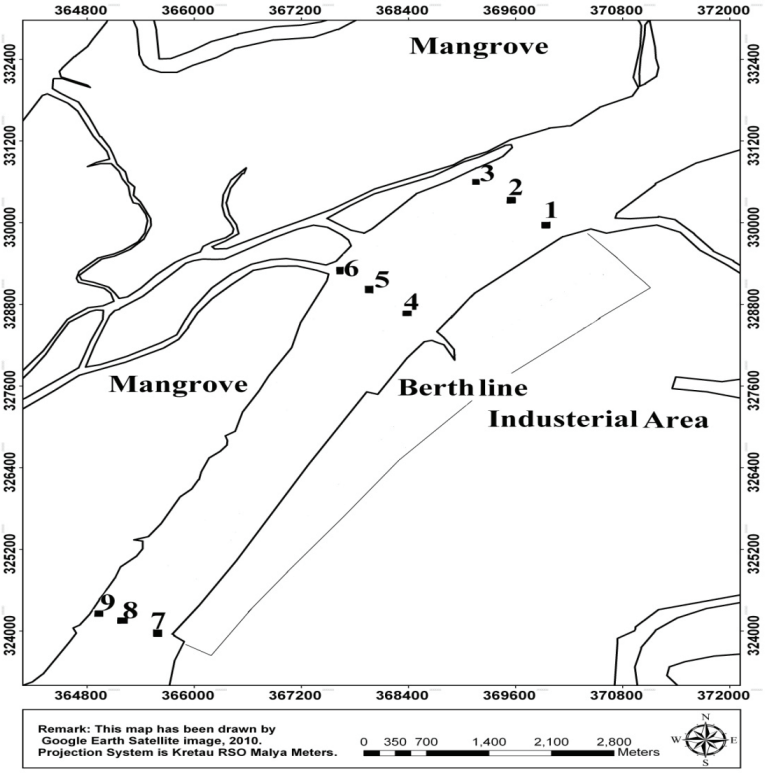

Fig. 1. Location of the sampling stations in West Port, Malaysia

Table 1

Physical and chemical description of sampling stations

Station	Code	Description	Fine sediment [%]	Sand [%]	TOC [%]	Depth [m]
100 m after cement berth	1-WC100	coastline	53.57	46.42	10.24	12.5
500 m after cement berth	2-WC500	remote area	45.96	54.03	7.74	19.5
1000 m after cement berth	3-WC1000	mangrove	63.42	36.57	11.98	7.8
100 m after liquid berth	4-WL100	coastline	56.33	43.66	9.14	13.3
500 m after liquid berth	5-WL500	remote area	41.10	58.89	7.55	20.3
1000 m after liquid berth	6-WL1000	mangrove	70.81	29.18	12.76	8.8
100 m after container berth	7-WT100	coastline	52.31	47.68	10.63	15.5
500 m after container berth	8-WT500	remote area	50.69	49.30	10.15	21.11
1000 m after container berth	9-WT1000	mangrove	70.36	29.63	15.49	6.8
21 km from the Port	10-CP	remote area	51.60	48.39	10.46	17.5

Sampling and experimental methods. Sediment samples were dried at 105 °C) in an oven, and passed through a 2 mm mesh sieve to remove coarser particles. A multi-wavelength particle size analyzer (Beckman Coulter Company, model LS 13 320) was used to analyse the sediment granules. The percentages of the three fractions of grain sizes were measured: Clay (<4 μm), silt (2–64 μm) and sand (>64 μm). A carbon analyzer (Horbia Model 8210) was used to estimate the total organic carbon (TOC) and their specific procedure was described by Fang and Hong [20].

About 2 g of the sediment used for metal analysis was treated with 2 cm^3 of 48% hydrofluoric acid (HF) and 2 cm^3 of 65% nitric acid (HNO_3), heated to dryness, and allowed to cool down. 0.5 g of 99.99% boric acid was added to the cooled solution and the resulting suspensions was centrifuged. The decanted solution from the centrifugal operation was filtered using Whatman No. 40 filter paper and the volume made up to 50 cm^3 with demonized water for measurement of total concentration of heavy metals [21]. Plasma mass spectrometry (ICP/MS) was used to analyze the following suite of metals: As, Cu, Cd, Cr, Hg, Pb and Zn. Stock reference solutions of 1000 mg/dm^3 were diluted to prepare working standards and the matrix matched with similar acidity, both important for various concentration ranges. The entire chemical compound used had the highest purity and Milliq and Ellix quality water and soap were applied to wash and rinse the crystal material and Teflon bottles prior to analysis. Laboratory blanks, field duplicates, and standard reference materials (SRM) 2702 were applied to improve quality assurance during laboratory analyses. SRM 2702 is a natural standard reference of inorganic material collected from marine sediment with the licensed concentration.

In this study, the percentage of recovery varied between 91 and 104 The standard methods indicated warning limits for matrix spike recoveries from 87 to 113%; thus, the range of recovery was reasonable in this study [22]. Potential contamination was detected by reagent blanks during the analytical and digestion procedure. Statistical

analysis of nonparametric Kurskal Wallis was applied to better understand metal variation and significant differences between stations. Geo-statistical analysis was done with the Surfer 8 software based on GPS values obtained from stations. This method is a practical tool for better understanding contamination in each location because this provides a comprehensive distribution pattern along a large area.

Ecological risk assessment. Hakanson developed a model to assess ecological risk for toxic compounds in aquatic systems. The model is known as a practical model to evaluate aquatic pollution. It may integrate mutual interactions, toxicity sedimentation character and sensitivity of aquatic systems. The model was described based on the degree of sediment contamination and potential ecological risk index for the basin and given substance [23–25].

The contamination degree is estimated to assess contamination level of contaminants in sediment by concentration of substance and background value [26]

$$C_d = \sum_{i=1}^{n} C_f^i = \sum_{j=1}^{n} \frac{C_{0-1}^n}{C_n^i} \tag{1}$$

where: C_d – the contamination degree, C_f^i – the contamination factor, C_{0-1}^i – the average content of compound in question (i) from surface sediment (0–1 cm) at the accumulation area, C_n^i – background value for the compound estimated from Eq. (2) based on the data of previous studies during [23]:

$$C_n^i = x + s_x \tag{2}$$

where C_n^i is the natural background value, x is is the mean of per-industrial data or old previous studies and s_x is a standard division. Contamination factor was ranged as low ($C_n^i < 1$), moderate ($1 \le C_f^i < 3$), considerable ($3 \le C_f^i < 6$), and very high ($C_f^i \ge 6$). The contamination degree (C_d) is estimated based on the sum of all contamination factors. The contamination degree of sediment may be classified as: low (C_d < 8), moderate ($8 \le C_d < 16$), considerable ($16 \le C_d < 32$), and very high ($C_d \ge 32$).

Potential ecological risk index was defined for the basin and given substance through the toxic response factor (Eq. (4)) [27, 28]. To evaluate the toxic response factor, sediment-logical toxic factor (St^i value) and bio-production (BPI) should be estimated. Hakanson proposed a new concept about the toxic factor based on the abundance principle. He indicated that the potential toxicological effect of an element is proportional to the abundance of this element in nature. Abundance numbers are estimated based on abundance of various elements which were provided at least in 4 different types of biological and geological media such as igneous rocks, soils, fresh

or marine water, land animals and land plants [29]. The information provides beneficial revision of the results given in this background media. The relative abundance of various elements is measured based on the equation:

$$\text{Relative abundance} = \frac{\text{element with high mean concentration}}{\text{mean concentration of other elements}} \tag{3}$$

The abundance number have been obtained, the largest value of relative abundance should be omitted for every element in different media and the sum of these relative numbers has been estimated and divided into the lowest mean value of relative abundance.

The abundance number is not equivalent to the St^i and sink-effect factor and problem of dimension should be measured. The sink-effect factor means the various elements make different "fingerprints" in sediment with different tendencies to be deposited in the sediment. Sink factors have been obtained by comparing the natural background values for water with natural background values for sediments. St^i values are obtained by multiplying the sink factors with the abundance numbers. To reduce dimension between and contamination factor is that, all corrected abundance should be divided to the lowest corrected abundance for making normation between elements. Then to get reliable dimensions, the square root is taken from these figures and the values also rounded to emphasize the accuracy of the method. These values seem to be reliable sedimentological toxic factors for all elements [3, 4].

Hakanson [23] described a specific method to measure the BPI values for aquatic system. He determined the BPI by measuring the ignition loss (the *IG* value) and the nitrogen content (the *N* value) of sediment. The BPI value was then described as the *N* content on the regression line for *IG* = 10%. The N content is given in mg/g ds, the IG content in % ds. Thus, the toxic response factor (Tr^i) was defined according to the sediment logical toxic factor (St^i and the sensitivity requirement (given by the BPl). Tr^i was determined by multiplying the St^i with BPl. Tr^i is an analogue to the contamination factor [29]

$$RI = \sum_{i=1}^{n} Er^i = \sum_{i=1}^{n} Tr^i C_f^i \tag{4}$$

where: Er^i is the potential ecological risk index for the given substance, Tr^i is the toxic response factor for a given compound and C_f^i is equal to the contamination factor, *RI* is the potential ecological risk index for the aquatic area.

The following ranges of *RI* values have been accepted: low ecological risk – $RI < 150$, moderate ecological risk – $150 \leq RI < 300$, considerable ecological risk – $150 \leq RI < 300$ and very high ecological risk – $RI > 600$). Er^i value defines the level

of potential risk for investigated toxic factor by the following rank: Low potential ecological risk – $Er^i < 150$, moderate – $40 \leq Er^i < 80$, considerable – $80 \leq Er^i < 160$, high – $160 \leq Er^i < 320$, and very high – $Er^i > 320$ [3, 30, 31].

3. RESULTS AND DISCUSSION

3.1. SPATIAL DISTRIBUTION

The physical and chemical characteristics of surface sediments of the West Port are summarized in Table 1. Analysis of sediment grain size indicated that fine-grained sediment (<64 μm) predominated in almost all stations except of stations WL500 and WC500. The maximum values of fine fractions were estimated at stations close to the mangrove forest, whereas the highest portion of the sand fraction was at stations WC500 (54.03%) and WL500 (58.89%). The TOC content ranged between 7.74% and 15.49% and was synchronous with fine grain size sediment in most parts of the studied areas. According to the Kruskal Wallis test ($\alpha < 0.5$), significant differences existed between distribution of fine grained sediment and TOC at different stations.

Several factors influence the distribution of fine grained sediment in the marine system such as sediment transportation and sedimentary process [24, 32]. In this study, areas with high percentage of fine sediment were found near the mangrove forest. This may be due to the land-based runoff and sedimentary process of mangrove forests. Several studies have shown that mangrove forests can increase the suspended solid deposition by decreasing the water dynamic energy and providing enough time for fine grain size to sink and deposit [33–37].

The distribution of TOC follows the same pattern with fine-grained sediment in most parts of the West Port and the correlation analysis shows the high correlation ($r = 0.76$) between the TOC and fine-grained sediment in this area. The TOC concentration increased when the mean grain size decreased because the fine particle size, particularly the clay colloid, has a high tendency to adsorb TOC [37].

Table 2 shows mean and standard deviation (SD) of heavy metals at various stations. A large value of standard deviation reflected wide variation in metal concentrations in spatial scales [38] which was confirmed by a statistical test. This test indicated a significant difference in metal distribution at all stations and the concentrations of all metals were significantly low at the control point relative to the other sites. Figure 2 shows spatial distribution of heavy metals in surface sediments at West Port. Heavy metal distributions were generally homogenous for Zn, Cr, As, while Pb and Cu showed a similar pattern from a low to a high from north to south direction. There was a higher concentration of Zn and Cr from a south-easterly and east of strait (along the coastline) but Cu and Pb showed a higher concentration in a south-western direction. The lowest concentration of metals (except Hg) was found at station WL500 and there

is significant difference ($\alpha < 0.05$) between this station and others stations. The content of Cd and Hg decreased from mangrove forest to coastline and concentration of Hg peaked at two stations WL1000 and WL500.

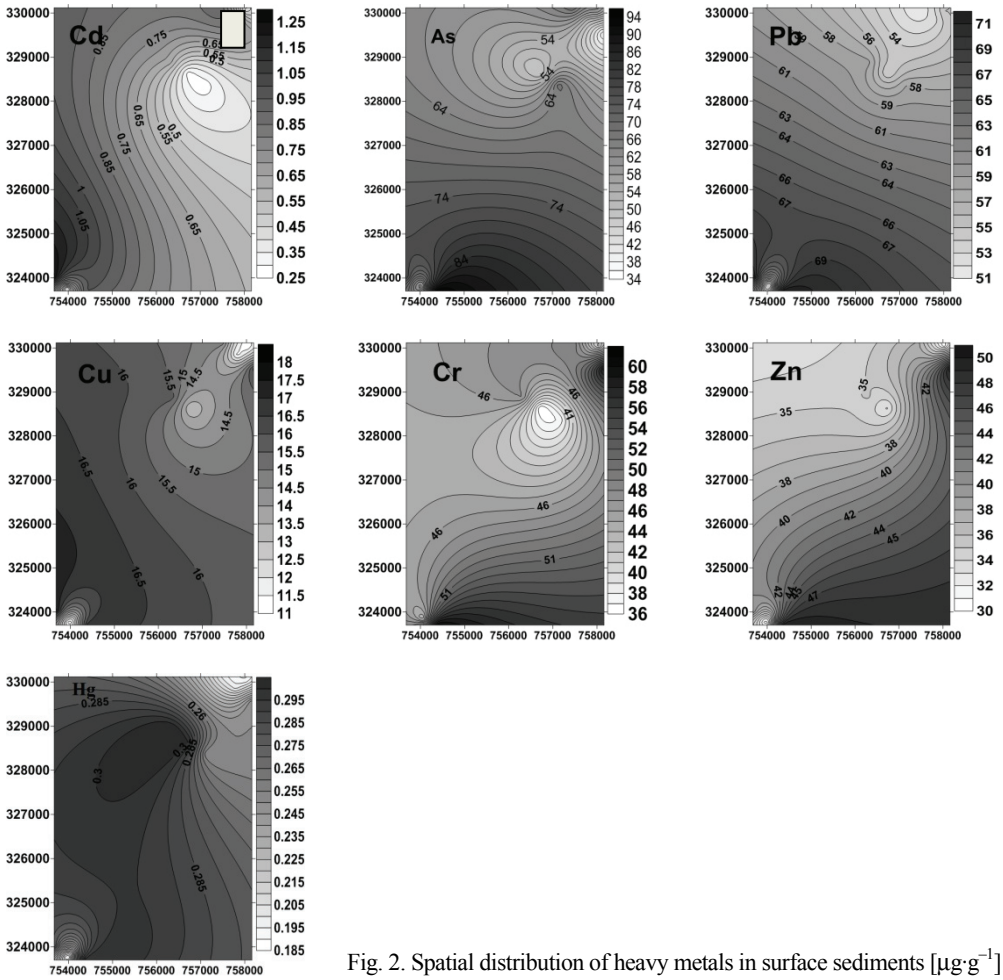

Fig. 2. Spatial distribution of heavy metals in surface sediments [$\mu g \cdot g^{-1}$]

Studies elsewhere indicate that several factors such as erosion, sedimentation, sediment type, water dynamics, urbanisation, industrialisation, river discharge, and geochemical reactions affect the distribution and constitution of heavy metals in coastal and estuarine waters [39–45]. In West Port, most of the metals (Zn, Cr, As, Pb, Cu) showed the same pattern of distribution. High concentrations of these heavy metals were found in stations located in the south of strait (WT100 and WT1000). This result may be due to the large container terminal and the inflow of land runoff in the south of West Port, which may have caused an increase in metal concentration. More-

over, this distribution pattern may be related to particle size of sediment because high percentage of fine particles (silt and clay) was observed in the south of the strait.

Table 2

Average and standard division (SD) of concentrations of heavy metals in surface sediment during sampling periods [$\mu g \cdot g^{-1}$]

Station		As	Cu	Cr	Cd	Pb	Hg	Zn
1-WC100	mean	35.82	16.11	58.64	0.68	54.97	0.25	49.51
	S D	7.92	4.72	6.95	0.33	7.83	0.08	13.33
2-WC500	mean	51.62	11.35	47.06	0.81	52.55	0.20	36.47
	SD	25.48	2.00	12.57	0.33	13.83	0.05	15.05
3-WC1000	mean	68.13	14.72	48.91	0.89	51.31	0.20	37.19
	SD	33.34	2.56	10.24	0.34	5.95	0.05	12.49
4-WL100	mean	67.49	13.96	37.20	0.28	57.71	0.25	37.32
	SD	32.28	1.59	7.16	0.07	7.88	0.09	12.31
5-WL500	mean	47.64	13.00	36.08	0.28	54.07	0.30	32.82
	SD	11.24	2.35	10.88	0.10	7.95	0.08	10.80
6-WL1000	mean	50.31	15.69	47.05	0.62	58.23	0.31	35.11
	SD	5.53	3.79	8.60	0.43	6.72	0.07	11.16
7-WT100	mean	94.24	16.81	60.56	0.95	7.11	0.30	49.87
	SD	37.13	2.64	4.21	0.49	19.89	0.09	20.35
8-WT500	mean	59.07	12.13	42.79	0.73	53.46	0.21	33.00
	SD	14.02	1.67	5.51	0.62	9.64	0.02	12.51
9-WT1000	mean	78.31	17.60	45.98	1.26	71.55	0.28	40.02
	SD	33.67	6.77	5.26	0.57	9.83	0.05	19.61
10-CP	mean	27.57	8.87	18.69	0.05	31.11	0.14	29.52
	SD	7.31	2.38	4.07	0.057	8.09	0.005	5.35

Several researchers reported that sediment particle size is a significant parameter which is able to control heavy metal concentration because fine particles have high ability to adsorb soluble heavy metals and deposit them at the bottom sediment [41, 46, 47]. Spatial maps show that Zn and Cr display high concentrations in stations located in the east side of strait (along coastline). These stations were probably affected by industrial waste which is loaded from the industrial outlets that were located along coastline. The content of Cd and Hg decreased from mangrove line to a coastline which was related to the higher concentration of TOC and fine grain size in mangrove sediment. Many studies show that mangrove sediments act as a trap for chemical contaminants because such sediments contain high percentage of silt and clay that cause an increase in the metals adsorption in these stations [42, 48–50]. Furthermore, the concentration of Hg peaked at two stations WL1000 and WL500 because these stations were influenced by industrial waste flowing from the land.

3.2. DEGREE OF CONTAMINATION AND ADVERSE BIOLOGICAL EFFECTS

Table 3 shows the concentrations of metals when compared with sediment quality guidelines and background value to assess contamination degree and adverse biological effect. The New York Sediment Criteria and Provincial Sediment Quality Guidelines for metals are divided into low range effect (ISQG-Low) and high effect range (ISQG-High). ISQG-L level indicates the sediment contaminants do not have adverse effects on aquatic organisms in sediment. ISQG-H level indicates that the sediment contaminant certainly have adverse effects on organisms that live in the sediment. Also the level of sediment contamination that is between ISOG-L and ISQG-H shows that the contaminants probably have adverse effects [51]. According to this comparison, the level of Zn, Cu, Ni and Cr are below sediment background values and ISQG-L level (except for Cr) and concentration of As, Cd, Hg and Pb exceeded ISQG-L levels and their sediment background value. In the control station, the concentrations of all metals were lower than the sediment background values and ISQG-L level except for As and Hg which exceeded the background value. This implies that the occasional toxic effects are expected for Hg, Pb and Cd and high adverse effect probably occur for As. Table 4 gives the better view of the sediment situation at all stations, which describe the ranking order based on the contamination factor and contamination degree.

Table 3

Average concentrations of heavy metals obtained in this study with sediment quality guidelines and background value [$\mu g \cdot g^{-1}$]

Subject	Zn	Pb	Cu	Cd	Ni	As	Hg	Cr
Present study	39.15	58.4	14.6	0.79	12.2	62.02	0.25	47.05
Background value in this study	141.22	39.8	23.21	0.186	32.77	18.79	0.08	53.71
New York sediment criteria [61]								
lowest effects range	120	32	16	0.6	16	6	0.15	26
sever effects range	270	110	110	9	50	33	1.3	110
Sediment quality criteria [62, 63]								
lowest effects range (ISQG-low)	120	31	16	0.6	16	6	0.2	26
high effects range (ISQG-high)	220	250	110	10	75	33	2	110

The metal contamination factor (*CF*) was also applied to evaluate the anthropogenic contribution of heavy metals in surface sediments. The C_f values for Cu, Cr, and Zn were lower than 1 and were found at an unpolluted level at all stations, suggesting these metals may have entirely originated from natural processes or crustal materials. The contamination factor for Pb reached moderate value in all stations (except for Cd), indicating that the sediment at West Port had moderate anthropogenic inputs of these heavy metals. Contamination factor for Cd in all stations (except stations WL100,

WL500, CP) was found between high and very high values, coming from anthropogenic sources. Hg and As were between moderately polluted to highly polluted and the sequence of C_f values for metals was Cd > As > Hg > Pb > Cr > Zn > Cu. Contamination degrees for stations WT100 and WT1000 were high, whereas they were moderate in other stations inside the West Port and low at the control point. The results of sediment quality assessment are good evidence to confirm that the surface sediment of the West Port is highly polluted by Cd, Hg and As and it is moderately contaminated with Pb (Table 4); the concentrations of these metals are significantly higher than ISQG-L and their sediment background values.

Table 4

Contamination factor (C_f) and contamination degree (C_d) at all stations

Station	Cu, Cr and Zn	Pb	As	Cd	Hg	$C_d = \sum_{i=1}^{n} C_f^i$
1-WC100	$C_f^i < 1$ unpolluted	$1 \le C_f^i < 3$ moderate	$1 \le C_f^i < 3$ moderate	$3 \le C_f^i < 6$ high	$1 \le C_f^i < 3$ moderate	$8 \le C_d < 16$ moderate
2-WC500						
3-WC1000						
4-WL100				$1 \le C_f^i < 3$ moderate	$3 \le C_f^i < 6$ high	
5-WL500						
6-WL1000				$3 \le C_f^i < 6$ high		
7-WT100			$3 \le C_f^i < 6$ high			
8-WT500						
9-WT1000						$16 \le C_d < 32$ high
Average value inside West Port						$8 \le C_d < 16$ moderate
10-CP		$C_f^i < 1$ unpolluted	$1 \le C_f^i < 3$ moderate	$C_f^i < 1$ unpolluted	$1 \le C_f^i < 3$ moderate	$C_d < 8$ low

The results obtained in his study indicate that heavy metal contamination in sediments of West Port was attributed to both natural processes or logical mineralogy, and human activities (anthropogenic). Furthermore, there was significant anthropogenic input of Cd, Hg and As especially in stations close to berth line (Table 4). Anthropogenic source of metals can be due to disturbances, which changed the associated geochemical concentration ratios, and that the metal concentrations increased from their standard range. The relative concentration ratio of metals exceeds standard variation levels in the sediment when geochemical metal concentrations experience disturbances due to environmental change [52, 53].

These disturbances may be related to differential derivation of these contaminations from lithogenic sources and multiple anthropogenic sources. Several studies

described Cd, Pb, Hg and As originate mainly derived from industrial processes including mining, burning of fossil fuels, waste recycling, cement manufacturing, as well as paper and glass production [11, 54–59]. There are several industries in West Port involved in cement manufacturing, palm oil processing and oil/electrical based power generation. Other sources of these metals might be due to atmospheric deposition, terrestrial runoffs, which are the main routes of metal release into the marine environments. In addition, As, Cd and Hg are widely able to enrich sediment through recycling by plants because these metals are easily absorbed by plants and enter the biological cycle [60]. Moreover, the high concentration of Cd and As could have originated from tsunami sediment deposition, ship waste, embarkation activities and anticorrosive paints used on marine vessels [7]. The highest contamination of all heavy metals around the terminal container (WL100 and WL1000) is consistent with observations that this terminal is probably a main source of heavy metal release, especially for Cd and As because of high traffic of shipping in this area.

3.3. ECOLOGICAL RISK ASSESSMENT

Sediment-logical toxic factor (St^i), potential ecological risk factor (Er^i) and ecological risk index (RI) for various heavy metals were estimated according to various methodologies which are summarized in Tables 5 and 6.

Table 5

Determination of the sink-factor and sediment-logical toxic factors

Metal	Abundance number	Background marine water [mg/dm^3]	Sediment background [mg/kg]	Sink factor[a]	Sink factor × abundance number	St^i West Port[b]	St^i Hakanson 1980 [23]	Tr^i [23]
Cd	252	0.0001	0.186	0.53	151.2	43	30	40(5/BPI)
Cr	46.2	0.0005	53.7	0.0008	0.36	2	2	$30(5/BPI)^{1/2}$
Cu	2.9	0.003	23.21	0.129	0.37	2	5	$10(5/BPI)^{1/2}$
Hg	274	0.00003	0.08	0.375	112.7	38	40	$5(5/BPI)^{1/2}$
As	17.7	0.003	18.79	0.16	2.82	6	10	$5(5/BPI)^{1/2}$
Pb	9.8	0.0003	39.8	0.0075	0.073	1	5	$2(5/BPI)^{1/2}$
Zn	1	0.01	141.22	0.07	0.07	1	1	$(5/BPI)^{1/2}$

[a]Sink factor was calculated by dividing natural background value for marine water into background value for marine sediment in this study and multiplied by 1000.

[b]St^i value was calculated by dividing the correct abundance number into element with low correct abundance (Zn = 0.07), taking the square root was and rounding the values.

The amount of BPI measured based on the linear regression between ignition loss (the IG value) and the nitrogen content was equal to 3.8. The potential ecological risk factors for all metals except Hg and Cd were estimated in the low potential risk values

($Er^i < 40$) for all stations (Table 6). Er^i value for Hg and Cd were significantly higher than for other metals and this varied between the moderate and high levels of potential ecological risk in the West Port. In this study, potential risk value for all metals ranked in the following sequence Cd > Hg >As > Cr, Pb > Cu > Zn. Moreover values of *RI* in Table 6 show that all stations are in moderate ecological risk except station WC1000, WT100 and WT1000 which are in high ecological risk.

Table 6

Potential ecological risk (Er^i values) and risk indices (*RI* values) for heavy metals in the West Port (BPI = 3.8)

Station	As	Cu	Cr	Cd	Pb	Hg	Zn	$RI = \sum Er^i$	*RI* value
1-WC100	13	0.6	3	189.5	2	86.64	0.4	295.1	moderate
2-WC500	19	0.5	2	189.2	2	72.2	0.3	285.2	moderate
3-WC1000	25	0.5	2	227.04	1	72.2	0.3	328.04	high
4-WL100	26	0.5	2	70.95	2	86.64	0.3	188.39	moderate
5-WL500	17	0.6	1	70.95	2	109.74	0.3	201.59	moderate
6-WL1000	18	0.4	2	141.9	2	112.63	0.3	277.23	moderate
7-WT100	34	0.4	2	236.5	2	106.85	0.4	382.15	high
8-WT500	21	0.4	2	189.2	2	75.08	0.3	289.9	moderate
9-WT1000	28	0.4	2	316.91	2	98.19	0.3	447.80	high
Average value inside West Port	22.3	0.47	2	181.35	1.88	91	0.32	299	moderate
10-CP	15.4	0.32	2	29.5	1	53.4	0.25	101.87	low

Regarding the Er^i value, the potential problem might have been anticipated, rather with Cd and Hg and there is no concern about other metals because the rest of the metals investigated gave only low potential risk factors. It should be noted that Cd and Hg have rather a sediment logical toxic factor, which only indicates that these two metals can give strong fingerprints in coastal sediments, with a high potential risk factor according to the high abundance principle [29, 64]. Anyway, it does not indicate that Cd and Hg in general terms are relatively harmful environment contaminants.

The sequence of C_d and Er^i values revealed some differences in the contamination profiles of metals in West Port. The results of sediment contamination degree indicated that surface sediment is highly polluted with As ($3 \leq C_f^i < 6$) but its risk factor is 22.3, which is a low potential risk. The reason for this change is related to the low sediment logical toxic factor (St^i) of As in comparison with Cd and Hg.

Hakanson [23] indicated that the toxic factor gave complex information about the potential transport pathways of toxic metals to humans and to the aquatic ecological system. The main pathway in this model "goes from contamination of water –sediment–biota–fish–man". The risk factor gives a different picture of contamination in comparison with the contamination factor because in the risk model toxicity of ele-

ments, the sink effect and coastal water sensitivity are considered while the contamination factor is estimated only based on the concentration of elements [65].

The results of the present study imply large contamination factors for As, Cd, Hg and Pb which indicates the source of contaminates, but not necessarily the ecological significance of pollution. The potential risk factor analysis has been applied to distinguish which metals should be given more attention in West Port. Hg and Cd should be given high priority while other metals – low priority.

Risk index (*RI*) analysis ranked stations based on the ecological risk on biological communities in West Port. Stations WL100 and WL1000 (close to container terminal) are in high ecological risk and other stations in moderate ecological risk and control station faced rare adverse effect with normal response. The results of risk index were synchronous with results of the degree of contamination.

The initial study of pollution on the west coastal waters of Peninsular Malaysia was carried out by several research organisations in 1981, including the ASEAN (Association of Southeast Asian Nations), DOE Selangor (Department of Environment), Law and Singh [66] and Yasar et al. [67]. Ten specific pollutants (bacteria, phenol, oil and grease contamination and Cd, Hg, As, Pb, Cu, Cr and nutrient concentrations) were studied to assess environmental quality. The high concentration of chemical pollution such as heavy metals in water, sediment and organisms in this area, especially level of the iron and lead were higher than the standard for coastal water as a consequence of the navigation and transportation, land-based pollutants and industrial activities. However, these studies were not sufficient to estimate the degree of contamination or toxicity levels in the sediment. There is no record on the distribution of heavy metals in West Port, and therefore, ecological risk assessment cannot be predicted.

The results of this study are in good agreement with the idea that the sediment quality of West Port in all stations recovered. Contamination levels of most metals (except Hg, As and Cd) from unpolluted to slightly polluted except for stations WL100 and WL1000 which are close to container terminal in West Port. This result was most likely due to wastewater management regulations that were ratified in 1990 and 1997 to control petrogenic and chemical contaminants in coastal waters of Malaysia. These regulations focused on strategies that were based on international agreements to prevent and control pollution from ships, platform draining and industrial inputs (MARPOL 73/78 and OPRC 1990).To some extent these regulations controlled contaminants but were not adequate to completely recover from some toxic metals because contamination level of toxic elements such as Hg, As and Cd were categorized from moderately to highly polluted in most sediment samples. Thus, sediments from the most polluted stations are significant sources of toxic metals. These stations were influenced by shipping activities in terminal containers and industrial outlets in the West Port which may not be under protective regulations.

This research is an initial step forward from earlier studies which only considered metal concentrations in sediments based on experimental analysis, scientific model and indices. As a matter of fact, contamination factor and degree of contamination means that a first step towards a diagnostic tool to assess the level of anthropogenic sources, risk factors and risk indices were used as a second step to establish ecological adverse effects. Due to lack of consumption rate and body level measurements for metals, human risk assessment was not carried out in this study.

4. CONCLUSION

The differential distribution pattern showed that multiple sources contributed to increase the content of heavy metals in sediments along the West Port. These sources include a large scale inputs from the industrial centres such as palm oil, cement and food manufacturers that are located in the vicinity of West Port, vessel-based discharges, land runoff, sedimentation, and siltation. This study also showed that fine grain sized sediments and TOC have synergic effect on the distribution of heavy metals, especially Cd and Hg. In general terms, heavy metal pollution in West Port is moderate but large risk indices were estimated for Hg and Cd. Thus these metals need more attention. Pollution from As, Pb and Cr may be given low priority. High level pollution of Hg and Cd is a serious threat in future because of their accumulation and toxicity effects on marine organisms and the human population. Risk model clarified the vulnerable stations (WT100, WT1000 and WC100) having data to manage and protect West Port coastal waters. This will be of immense value to the Department of Environment of Malaysia in its quest to take corrective measures. The present study emphasizes the importance of proactive measures to manage and control pollution in the West Port coastal waters because there is no recent data on pollutants in this area. Thus the results of this study can be used as background data for future studies. In addition, the results imply that further management policies and mechanisms are needed to ensure the implementation of regulations. Mechanisms may include permit programs, bad actor laws, zoning, enforceable general environmental laws and prohibitions and water quality standards.

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