Interdisciplinary Studies on Environmental Chemistry—Environmental Pollution and Ecotoxicology, Eds., M. Kawaguchi, K. Misaki, H. Sato, T. Yokokawa, T. Itai, T. M. Nguyen, J. Ono and S. Tanabe, pp. 141–150.

Spatial Profile of Trace Elements in Marine Sediments from Jakarta Bay, Indonesia

Adi Slamet RIYADI[1], Takaaki ITAI[1], Tomohiko ISOBE[1], Muhammad ILYAS[1], Agus SUDARYANTO[2], Iwan Eka SETIAWAN[2], Shin TAKAHASHI[1] and Shinsuke TANABE[1]

[1]*Center for Marine Environmental Studies (CMES), Ehime University, Bunkyo-cho 2-5, Matsuyama 790-8577, Japan*
[2]*Technology Centre for Marine Survey, Agency for the Assessment and Application of Technology (BPPT), Jl. MH. Thamrin 8, Jakarta, Indonesia*

(Received 29 November 2011; accepted 13 December 2011)

Abstract—Jakarta city has the largest urban population in Indonesia. The rapid expansion of industrial activity and chemical pollution of Jakarta Bay is a matter of concern. We studied the spatial and temporal variations of trace elements contamination in the Bay by analyzing nineteen surface sediment samples from Jakarta Bay using handy type X-ray fluorescence analyzer (XRF). Influences of different anthropogenic activities on the composition of the sediments were also evaluated. Degree of heavy metals contamination such as Zn, Cu and Pb were generally higher in coastal sites than offshore. Enrichment factors (EFs) defined as the ratio of metal levels in coastal sites to offshore were higher in coastal sites. This result agreed with geoaccumulation index, which reflects the degree of anthropogenic contamination of the metals, indicating that the sediments in Jakarta Bay can be classified as uncontaminated to moderately contaminated. Apparent anthropogenic impact on metal levels does exist in the Jakarta Bay though the degree of contamination is still moderate.

Keywords: spatial profile, trace elements, marine sediments, Jakarta Bay

INTRODUCTION

Jakarta city, the capital of Indonesia has the largest concentration of urban population in the country with approximately 9 million residents in an area of 662 km^2 (Hosono *et al.*, 2011). Thirteen rivers which are significantly affected by contamination from domestic waste waters, urban runoff and industrial effluents are discharging into the Jakarta Bay. The contaminants from anthropogenic and natural sources accumulate in coastal marine sediments and often record natural and anthropogenic events that occur in drainage basins, local and regional air masses, or several other factors that are forced upon the aquatic system (Callender, 2005). As a result of the rapid expansion of industrial activity in this area, chemical pollution of Jakarta Bay is a matter of concern.

The aim of this study was to determine the spatial and temporal variations of

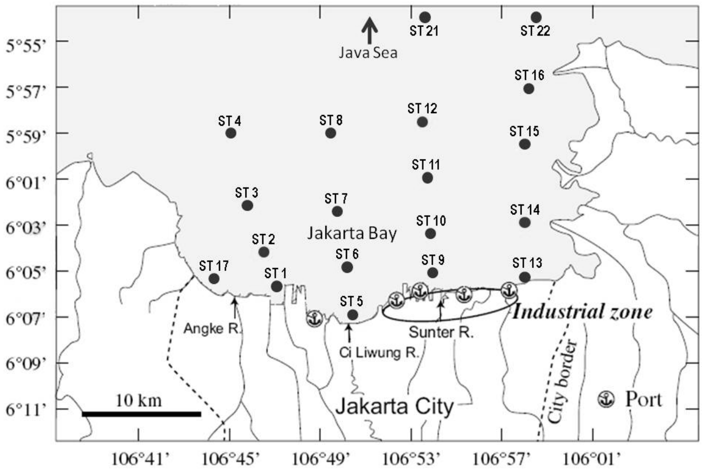

Fig. 1. Sampling locations (map adopted from Hosono *et al.*, 2011).

trace metal contamination in the Bay. We also evaluated the influence of anthropogenic activity on the composition of the surface sediments using enrichment factor (EF) and geoaccumulation index (I_{geo}) of the metals.

MATERIALS AND METHODS

Sampling

Sediment samples were collected from Jakarta Bay during August 2010 using an Ekman Grab. Nineteen samples, from coastal regions to offshore were collected (Fig. 1). The sediments were immediately packed in plastic bag. After they were brought to Japan, all the samples were stored in the Environmental Specimen Bank (*es*-BANK) of Ehime University, Japan (Tanabe, 2006).

Analytical method

The surface sediment samples for trace element determination ($n = 19$) were freeze-dried for 24 hours, sieved (<250 μm) and homogenized. Identification and quantification of trace elements were performed by Innov X-ray-Fluorescence analyzer 6500 series manufactured by Innov-X-System, Inc., Woburn, MA. This instrument is a non-destructive inspection device that can be used to measure the element levels directly in samples packed in plastic film. Accuracy and precision of the method was preliminarily evaluated using 19 certified geological materials distributed by the Geological Society of Japan.

Data analysis

Data were visualized using the program Surfer® version 8.05 to provide

Table 1. Enrichment level.

EF score	Enrichment level
<2	Deficiency to minimal enrichment
2–5	Moderate enrichment
5–20	Significant enrichment
20–40	Very high enrichment
>40	Extremely high enrichment

Table 2. Intensity of geoaccumulation index.

Class	Value	Contamination intensity
0	$I_{geo} \leq 0$	Practically uncontaminated
1	$0 < I_{geo} < 1$	Uncontaminated to moderate
2	$1 < I_{geo} < 2$	Moderate
3	$2 < I_{geo} < 3$	Moderate to strong
4	$3 < I_{geo} < 4$	Strong
5	$4 < I_{geo} < 5$	Strong to very strong
6	$5 < I_{geo}$	Very strong

spatial profiles of trace elements. Enrichment factor (EF) was used to evaluate the spatial variation of trace element levels. The EF values were calculated using the following equation (Loska *et al.*, 1997; Çevik *et al.*, 2009).

$$EF = (C_{sample}/Ti_{sample})/(C_{offshore}/Ti_{offshore})$$

where C_{sample} represents concentration of the given element in the sediments, Ti_{sample} represents concentration of the reference element in the sediments, while $C_{offshore}$ and $Ti_{offshore}$ is that of offshore sediments. In this study, titanium has been used as a conservative tracer to differentiate natural from anthropogenic components (Loring, 1991). Titanium is a very conservative element that is associated with crustal rock sources. Normalization with respect to *Ti* compensates for the relative percentage of various diluents (non-crustal rock sources) and allows one to see more clearly metal enrichment due to anthropogenic inputs (Callender, 2005). The levels of elements in offshore sediments (site 21) was considered as those from reference environment. The enrichment level is classified as per defined by Loska *et al.* (1997) (Table 1).

Geoaccumulation index (I_{geo}) was employed to assess the degree of anthropogenic contamination. This index allows us the evaluation of contamination level by comparing present concentrations with background levels. The values of I_{geo} were computed by the following equation (Forstner *et al.*, 1993; Lokeshwari and Chandrappa, 2006).

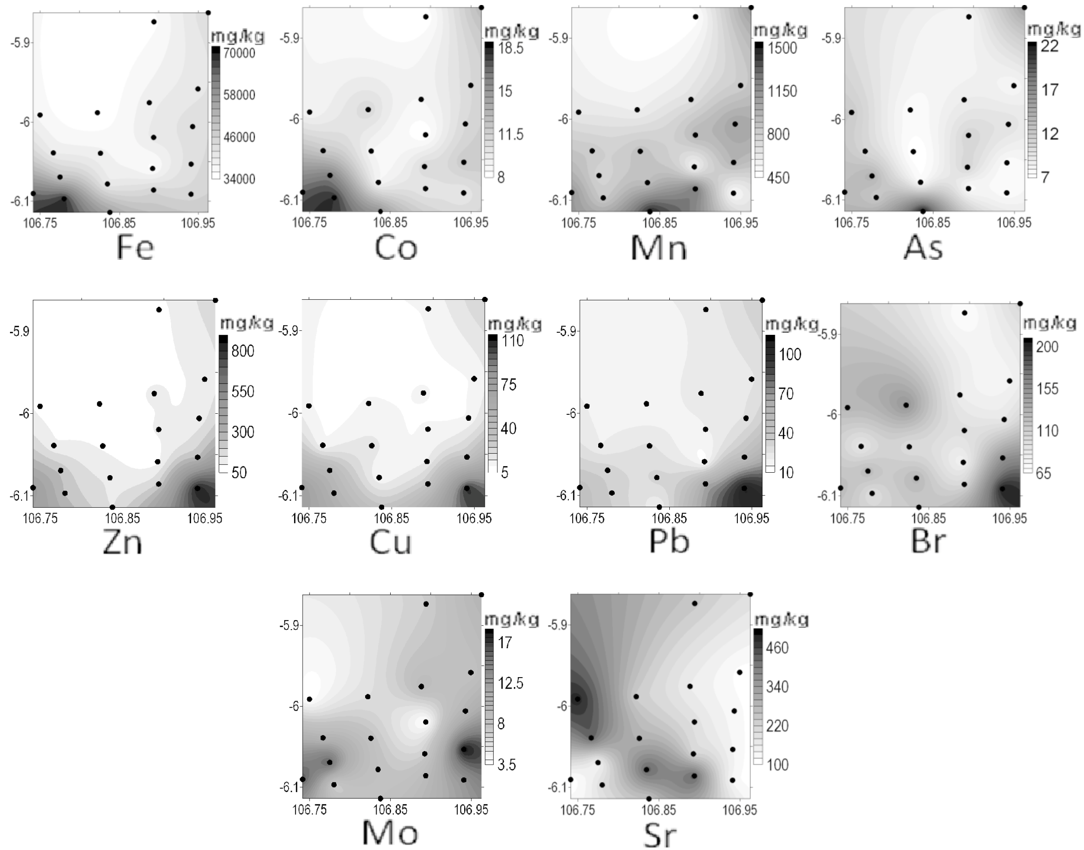

Fig. 2. Spatial profile of trace metal concentrations (mg/kg) in Jakarta Bay—Black dots indicate sampling stations.

$$I_{geo} = \ln(Cn/1.5Bn)$$

where Cn is the concentration of the given element (n) in the sediment, Bn is the geochemical background level of a given element in mudstone, and 1.5 is the background matrix correction factor due to lithogenic effects (Loska *et al.*, 1997). In the present study, elements concentration in site 21 were used as background values, as site 21 was the least affected site by anthropogenic impacts. Contamination levels were distinguished in six classes as shown in Table 2 (Forstner *et al.*, 1993).

RESULTS AND DISCUSSION

Preliminarily measurement using handy X-ray fluorescence analyzer (XRF) indicated that accuracy was within an order of magnitude for common elements. Although fluorescence intensity derived from 38 elements were monitored, it was difficult to quantify the elements lighter than *Ti* due to absorption of fluorescence X-ray by ambient air. Detection limits were generally five to several tens mg kg^{-1}, and the variation of analytical values was influenced by the type of elements and matrix composition. This sensitivity was sufficient to measure the typical metals, but precious metals could not be determined. The elements normally detected from sediment were Ti, Mn, Fe, Co, Cu, Zn, As, Br, Sr, Mo and Pb.

Spatial profiles of trace elements

Spatial profiles of trace elements showed some variation among the sites. Since metals derived from anthropogenic activities are possibly discharged from rivers to Jakarta Bay, heavy metal concentration was found to be higher in coastal sites than offshore. Actually, Fe and Co were higher in the western site of coastal region, whereas Zn, Cu, Pb and Br higher in the eastern coastal site (Fig. 2). Unlike these elements, Mn and As were higher in the central part of coastal site. Only Sr and Mo had different distribution patterns. Molybdenum was found higher in both western and eastern site, while Sr was higher in central and western parts. Hence, it could be presumed that some local pollution sources exist. The variation among the sites might be due to different sources of metals discharged from land through river. A previous water quality study reported that levels of certain trace metals found in some rivers of the region were substantially lower than the levels in Jakarta Bay in this study (Palupi *et al.*, 1995). This is probably because metal concentrations in Jakarta Bay might be increasing including the sediments in line with the rapid economic growth. Continuous monitoring is needed to control the possible increase in trace metal contamination.

Spatial distribution

Variation of EFs indicated that typical heavy metals, such as Zn, Cu and Pb, were higher in coastal sites than offshore suggesting possible anthropogenic impacts on the levels of these metals in rivers (Fig. 3). With EF score ranging from 2 to 5, the enrichment of these metals can be categorized as moderate (Table 1).

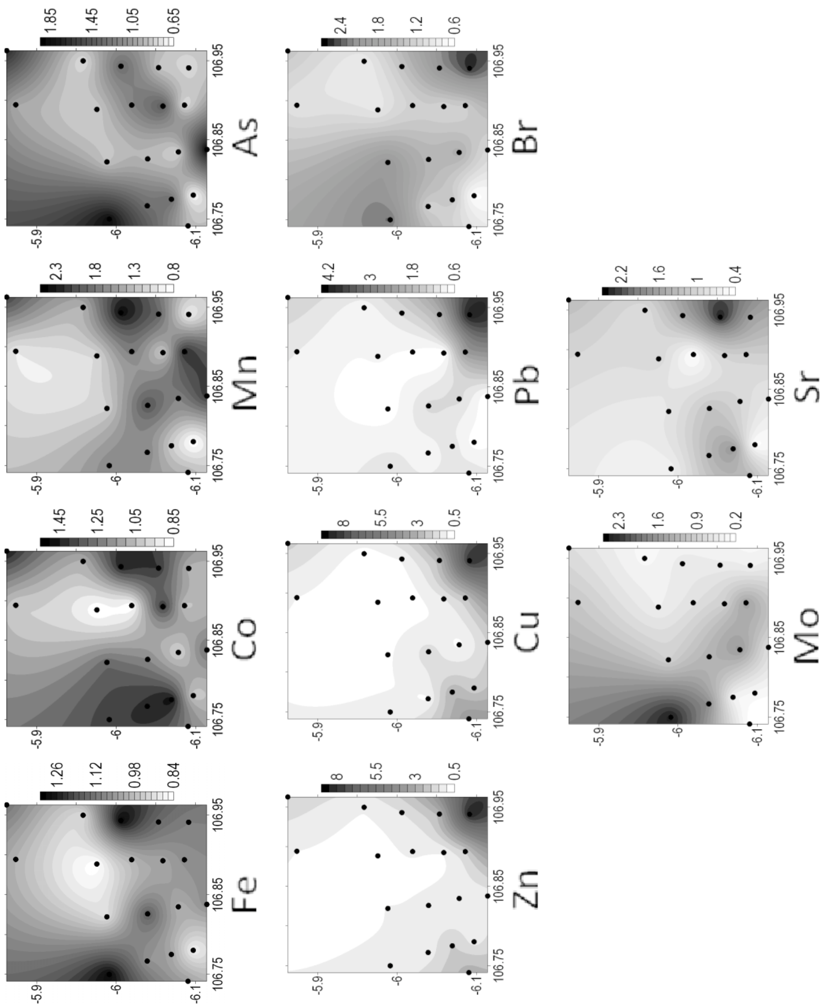

Fig. 3. Distribution of enrichment factor (EF) of trace metals in Jakarta Bay.

Table 3. Geoaccumulation indexes of selected metals from surface sediments.

Site	Station	Cu	Zn	Pb
Coastal Western	ST 1	1.13	0.64	0.03
	ST 2	1.00	0.61	0
	ST 3	–0.41	–0.17	–0.50
	ST 4	–0.41	–0.42	–0.50
	ST 5	0.68	0.14	–0.50
	ST 6	–0.41	0.12	–0.03
	ST 17	1.53	1.19	0.26
	min	–0.41	–0.42	–0.50
	max	1.53	1.19	0.26
	median	0.68	0.14	–0.03
	mean	0.45	0.30	–0.18
Coastal Eastern	ST 9	0.65	0.46	0.66
	ST 10	–0.08	–0.39	–0.93
	ST 13	1.89	1.88	1.17
	ST 14	0.68	0.65	0.33
	ST 15	–0.41	–0.06	–0.24
	ST 16	–0.41	–0.12	–0.32
	ST 22	0.47	0.37	0.06
	min	–0.41	–0.39	–0.93
	max	1.89	1.88	1.17
	median	0.47	0.37	0.06
	mean	0.40	0.40	0.10
Offshore	ST 7	0.11	–0.32	–0.24
	ST 8	–0.41	–0.33	–0.72
	ST 11	–0.41	–0.17	–0.50
	ST 12	–0.41	–0.19	–0.32
	min	–0.41	–0.33	–0.72
	max	0.47	0.37	0.06
	median	–0.41	–0.19	–0.32
	mean	–0.13	–0.13	–0.34

Other elements such as Mn, Fe, Co, As, Br, Sr and Mo can be categorized as deficient to minimal enrichment level in the offshore sites but still enriched in coastal region. One of the potential pathways of enrichment in Jakarta Bay is the discharge of domestic waste. Further, various factories have been built in Jakarta and surrounding regions, so discharge of industrial wastes could also be a cause of metals enrichment in the Jakarta Bay.

Geoaccumulation index

The calculated index of trace metals in Jakarta Bay and their corresponding contamination intensity are summarized in Table 3. The I_{geo} values for the metals indicated that Cu and Zn in western and eastern parts of coastal region were in uncontaminated to moderately contaminated level (Table 2) with their median

Table 4. Comparison of trace metal concentrations of surface sediments at other locations.

Sites	Cu	Zn	Pb	References
Jakarta Bay, 2010, mean (range)	27.7 (10.8–107)	194 (85–845)	32.8 (13–106)	This study
Jakarta Bay 2003	0.79–193.75	71.13–533.59	0.25–77.42	Rochyatun and Rozak, 2007
Jakarta Bay 2004	0.82–74.7	53.87–497.53	3.64–53	Rochyatun and Rozak, 2008
Barcelona coast, Spain	45–392	95–955	20–1046	Lopez-Sanchez *et al*., 1996
Huelva coast, Spain	40–329	144–695	38.3–139	Usero *et al*., 1998
Mediteranian Sea, Italy	2.77–51.34	198–3239	74–772	Caredda *et al*., 1999
Mediteranian Sea, France	14–82.6	20.1–393.6	29.4–509.3	Fernex *et al*., 2001
Harbour and Mytilene coast, Greece	9.39–86.2	38.8–230	30.05–95.0	Aloupi and Angelidis, 2002
Queensland, Australia	19.19	80.02	29.31	Liaghati *et al*., 2003
Northeast coast of Bay of Bengal	4.30–45.29	22.96–204.99	ND*–44.47	Chatterjee *et al*., 2007
Zonguldak, Black Sea, Turkey	30.21	84.6	39.14	Çoban *et al*., 2009
Bohai Bay, China	28.1 (7.2–44)	102.5 (56.3–308.5)	21.2 (5.9–97.0)	Zhan *et al*., 2010
Southern coast of Sfax, Tunisia	15–44	42–391	19–59	Houda *et al*., 2011

*Not detectable.

I_{geo} values being 0.68 and 0.14 (western) and 0.47 and 0.37 (eastern), respectively. Slightly different from these metals, Pb showed similar level only in eastern region with median I_{geo} value being 0.06. Hence, contamination by these metals in the Jakarta Bay can be classified as moderate despite an apparent anthropogenic impact. In offshore, all elements could be classified as practically in uncontaminated level ($I_{geo} < 0$).

Global comparison

Concentrations of Cu, Zn and Pb determined by the present study are higher than in a previous study (Rochyatun and Rozak, 2007, 2008) from Jakarta Bay suggesting a possible increase of these concentrations with time. Meanwhile, levels of these metals are not serious so far when compared with several areas in developed countries (Table 4). However, implemention of regulations in developing countries are very weak relative to developed nations. Hence, continuous monitoring is needed to control the possible increase in trace metal contamination in Jakarta Bay in the future.

CONCLUSION

Trace element concentrations in Jakarta Bay was found to be higher in coastal sites than offshore. Spatial profile of trace element concentration showed variations among the western, central and eastern parts of the coastal site depending on the sources of these element. Meanwhile, both the EF and I_{geo} values revealed moderate anthropogenic influences on the Jakarta Bay sediment, resulting in significant Zn, Cu and Pb enrichment. Although the degree of contamination is still moderate, anthropogenic impact on metal levels is apparent in Jakarta Bay.

Acknowledgments—This study was supported by Grants-in-Aid for Scientific Research (S) (No. 20221003) from Japan Society for the Promotion of Science (JSPS), Japan, Research Grants for Promoting and Developing Sound Material-Cycle Societies (Nos. K2121 and K2129) from Ministry of the Environment, Japan and the Global Center of Excellence (G-COE) Program by the Ministry of Education, Culture, Science & Technology, Japan (MEXT) and JSPS.

REFERENCES

Aloupi, M. and M. O. Angelidis (2002): The significance of coarse sediments in metal pollution studies in the coastal zone. *Water Air Soil Pollut.*, **133**, 121–131.

Callender, E. (2005): Heavy metals in the environment-historical trends. p. 67–105. In *Environmental Geochemistry Vol. 9 Treatise on Geochemistry*, ed. by B. S. Lollar, Elsevier-Pergamon, Oxford.

Caredda, A. M., A. Christini, C. Ferrara, M. F. Lobina and M. Baroli (1999): Distribution of heavy metals in the Piscinas beach sediments (SW Sardinia, Italy). *Environ. Geol.*, **38**, 91–100.

Çevik, F., M. J. L. Göksu, O. B. Derici and O. Fındık (2009): An assessment of metal pollution in surface sediments of Seyhan dam by using enrichment factor, geoaccumulation index and statistical analyses. *Environ. Monit. Assess.*, **152**, 309–317.

Chatterjee, M., E. V. Silva Filho, S. K. Sarkar, S. M. Sella, A. Bhattacharya, K. K. Satpathy, M. V. R. Prasad, S. Chakraborty and B. D. Bhattacharya (2007): Distribution and possible source of trace elements in the sediment cores of a tropical macrotidal estuary and their ecotoxicological

significance. *Environ. Int.*, **33**, 345–356.
Çoban, B., N. Balkis and A. Aksu (2009): Heavy metal levels in sea water and sediments of Zonguldak, Turkey. *J. Black Sea/Mediterranean Environ.*, **15**, 23–32.
Fernex, F. E., C. Migon and J. R. M. Chisholm. (2001): Entrapment of pollutants in mediterranean sediments and biogeochemical indicators of their impact. *Hydrobiologia*, **49**, 31–46.
Forstner, U., W. Ahlf and W. Calmano (1993): Sediment quality objectives and criteria development in Germany. *Water Sci. Technol.*, **28**, 307–316.
Hosono, T., C. Su, R. Delinom, Y. Umezawa, T. Toyota, S. Kaneko and M. Taniguchi (2011): Decline in heavy metal contamination in marine sediments in Jakarta Bay, Indonesia due to increasing environmental regulations. *Estuar. Coast Shelf Sci.*, **92**, 297–306.
Houda, B., G. Dorra, A. Chafai, A. Emna and M. Khaled (2011): Impact of a mixed "industrial and domestic" wastewater effluent on the southern coastal sediments of Sfax (Tunisia) in the Mediterranean Sea. *Int. J. Environ. Res.*, **5**, 691–704.
Liaghati, T., M. Preda and M. Cox (2003): Heavy metal distribution and controlling factors within coastal plain sediments, Bell Creek catchment, southeast Queensland, Australia. *Environ. Int.*, **29**, 935–948.
Lokeshwari, H. and G. T. Chandrappa (2006): Heavy Metals Content in Water, Water Hyacinth and Sediments of Lalbagh Tank, Bangalore (India). *J. Environ. Sci. Eng.*, **48**, 183–188.
Lopez-Sanchez, J. F., R. Rubio, C. Samitier and G. Rauret (1996): Trace metal partitioning in marine sediments and sludges deposited off the coast of Barcelona (Spain). *Water Res.*, **30**, 153–159.
Loring, D. H. (1991): Normalization of heavy-metal data from estuarine and coastal sediments. *ICES. J. Mar. Sci.* **48**, 101–115.
Loska, K., J. Cebula, J. Pelczar, D. Wiechula and J. Kwapulinski (1997): Use of enrichment, and contamination factors together with geoaccumulation indexes to evaluate the content of Cd, Cu and Ni in the Rybnik water reservoir in Poland. *Water Air Soil Pollut.*, **93**, 347–365.
Palupi, K., S. Sumengen, S. Inswiasri, L. Agustina, S. A. Nunik, W. Sunarya and A. Quraisyn (1995): River water quality study in the vicinity of Jakarta. *Water Sci. Technol.*, **31**, 17–25.
Rochyatun, E. and A. Rozak (2007): Pemantauan kadar logam berat dalam sedimen di perairan teluk Jakarta. *Makara seri sains.*, **11**, 28–36.
Rochyatun, E. and A. Rozak (2008): The distribution of heavy metals in sediment of Jakarta Bay. *Mar. Res. Indones.*, **33**, 101–107.
Tanabe, S. (2006): Environmental specimen bank in ehime university (*es*-BANK), Japan for global monitoring. *J. Environ. Monit.*, **8**, 782–790.
Usero, J., M. Gamero, J. Morillo and I. Garcia (1998): Comparative study of three sequential extraction procedures for metals in marine sediments. *Environ. Int.*, **24**, 487–496.
Zhan, S., S. Peng, C. Liu, Q. Chang and J. Xu (2010): Spatial and temporal variations of heavy metals in surface sediments in Bohai Bay, North China. *Bull. Environ. Contam. Toxicol.*, **84**, 482–487.

A. S. Riyadi (e-mail: w854002b@mails.cc.ehime-u.ac.jp)