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Assessment of the Heavy Metals and Nutrients Status in the Seawater, Sediment and Seagrass in Banten Bay, Indonesia and Their Distributional Patterns

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Abstract: This study evaluated the concentrations of heavy metals and nutrients in the seawater, seagrass and sediments of Banten bay, Indonesia and their spatial distributional patterns. Field sampling was conducted on August 24 and 25, 2010; seawater and sediment samples were collected from sixteen stations and seagrass (*Enhalus acoroides*) samples were collected from six stations. The results revealed that in general, the seawater in Banten bay was less polluted than that in Jakarta bay (Indonesia) although, some elements were present at higher concentrations. Most of the heavy metal concentrations in the seawater were below detection limits. All heavy metal concentrations in the sediments were also lower than those found in Jakarta bay. In the seagrass, the concentrations of iron, copper, zinc, mercury, phosphorus, potassium and nitrogen were higher than those found in Jakarta bay, Larymna bay (Turkey) and the Gulf of Mexico (concentrations of cadmium and lead were not). The distribution patterns of elements such as iron, zinc, cadmium, copper, mercury, nitrogen and phosphorus, revealed that they accumulated in the center of the bay as a result of oceanographic processes.

Key words: Banten bay, heavy metals, nutrients, seagrass, seawater, sediment

INTRODUCTION

Banten bay is located Northwest of Java Island, Indonesia, approximately 65 km from Jakarta bay. Space limitations in Jakarta bay have led to the industrialization of Banten bay and Ciujung river. Other human activities such as paddy farming, aquaculture, settlements and capture fisheries also occur in the bay. Hence, the bay is very susceptible to heavy metal and nutrient contamination. Large areas of seagrass, coral reefs and mangroves in Banten bay collectively provide suitable breeding, nursery grounds and shelter for hundreds of demersal and pelagic fish species (Kiswara *et al*., 1991). Marine flora and fauna including seagrass, fish and bivalves have the capacity to absorb heavy metals and nutrients from both sediments and seawater (Nicolaidou and Nott, 1998; Stapel *et al*., 1996). Therefore, the assessment of heavy metals and nutrients is very important to ensure ecosystem sustainability in Banten bay. Banten bay is a dynamic estuary where seasonal monsoons and water currents play important roles in shaping coastlines (Kesumajaya, 2010), protecting coral reefs (Hoitink and Hoekstra, 2003) and distributing sediments (Hoitink and Hoekstra, 2005).

The objectives of this study were to evaluate heavy metal and nutrient concentrations in the seawater, seagrass and sediments from field experiments data and to understand the distributional patterns of these concentrations in Banten bay using Geographic Information Systems (GIS) technology.

MATERIALS AND METHODS

Study site and data sampling: Sampling was performed on August 24 and 25, 2010 in Banten bay (Fig. 1). Seawater and sediment samples were collected from sixteen stations and seagrass samples were collected from six stations. The seawater and sediment samples were taken from the surface water (<10 cm depth) and surface sediments (<10 cm depth), respectively whereas the seagrass samples of *Enhalus acoroides* were taken by snorkeling.

Chemical data analyses: Chemical analyses were performed at the soil and plant laboratory of the Southeast Asian Regional Centre for Tropical Biology (SEAMEO-BIOTROP), Bogor, Indonesia. Table 1 shows the heavy metals and nutrients and the corresponding analytical methods used in this study.

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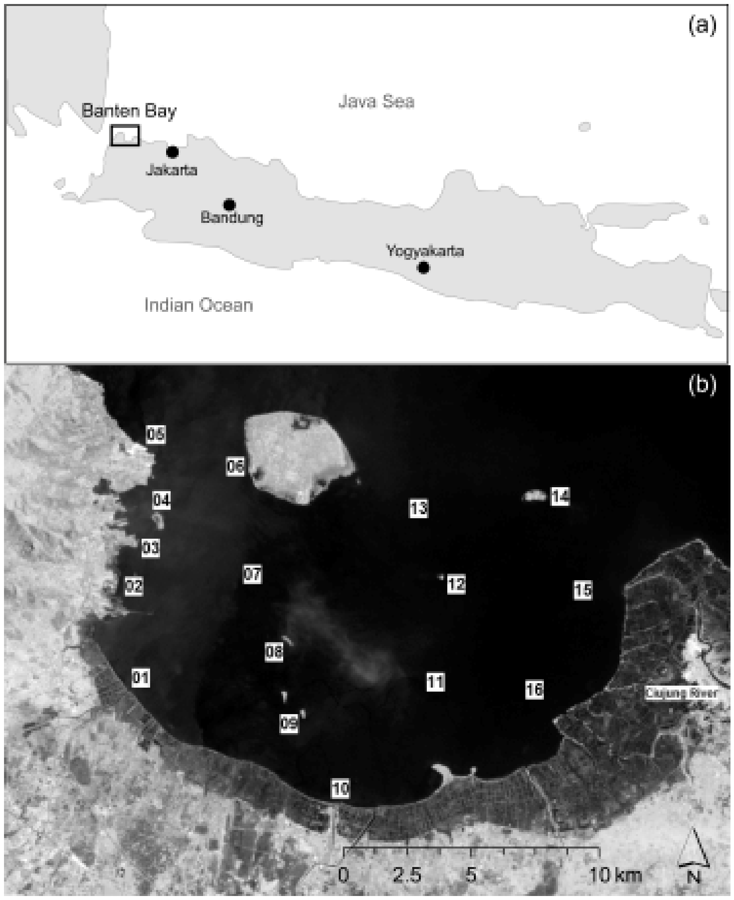

Fig. 1: Location of Banten bay; a) the sampling stations for seawater; b) sediments (station no. 1-16) and seagrass (station no. 2, 3, 4, 6, 8, 9)

Table 1: Analytical methods used for heavy metals and nutrients in seawater, sediments and seagrass (leaves and corms)

	Analytical methods	
Elements	Seawater	Seagrass/sediment
Heavy metals		
Iron (Fe)	APHA 3111-B (AAS)	Extract HNO_3-$HClO_4$ (AAS)
Copper (Cu)	APHA 3111-B (AAS)	Extract HNO_3-$HClO_4$ (AAS)
Zinc (Zn)	APHA 3111-B (AAS)	Extract HNO_3-$HClO_4$ (AAS)
Cadmium (Cd)	APHA 3111-B (AAS)	Extract HNO_3-$HClO_4$ (AAS)
Mercury (Hg)	APHA 3111-B (AAS)	Extract HNO_3-$HClO_4$ (AAS)
Lead (Pb)	APHA 3111-B (AAS)	Extract HNO_3-$HClO_4$ (AAS)
Nutrients		
Potassium (K)	APHA 3111-B (AAS)	Extract HNO_3-$HClO_4$ (flamephotometry)
Phosphorus (P)	APHA 4500-P E	Extract HNO_3-$HClO_4$ (spectrophotometry)
Nitrogen (N)	SNI 06-6989.52-2005	SNI 13-4721-1998

AAS: Atomic Absorption Spectrophotometry

Seawater data: The concentrations of heavy metals including iron (Fe), Copper (Cu), Zinc (Zn), Cadmium (Cd) and lead (Pb) and an alkali metal, potassium (K) in the seawater were determined using the American Public Health Association 3111-B (APHA 3111-B) method (Clesceri *et al.*, 1998). This method could detect the concentrations of these metals in an aliquot portion of stabilized hot acetic acid extract via flame atomic absorption spectrophotometry (AAS; Analytik Jena Type Nova 300, Germany) using acetylene gas (C_2H_2) at 190-870 nm.

Phosphorus (P; in orthophosphate-PO_4 form) in the seawater was measured, using the Indonesian National Standard (SNI) method No. 06-6989.31-2005 which was adopted from APHA 4500-PE. Principally, ammonium molybdate and potassium antimonyl tartrate reacted in acid medium with orthophosphate to form a heteropoly acid (i.e., phosphomolybdic acid) which was reduced to intensely colored molybdenum blue by ascorbic acid. The sample was then measured using a spectrophotometer at 880 nm. Dissolved Organic Nitrogen (DON) in the seawater was measured using the SNI method No. 06-6989.52-2005 that utilized macro Kjeldahl coupled with titrimetry. The sample was treated with a digestion mixture of copper sulfate and sulfuric acid. After heating thoroughly, the sample was made alkaline with sodium hydroxide sodium. Ammonia was then distilled from the mixture, trapped in a boric acid-indicator solution and finally titrated with sulfuric acid.

Seagrass and sediment data: Previous studies focusing on heavy metal and nutrient concentrations in seagrass have utilized different units (wet weight or dry weight), sample treatments (cleaned or uncleaned) and sample parts (leaf, root, corm, rhizome and stem). Neinhuis (1986) presented the results in wet weight whereas, most studies have used dry weight. Nicolaidou and Nott (1998) separated the plants into leaves, roots and stems for both cleaned and uncleaned samples whereas other studies handled the samples differently. In this study, the seagrass samples were divided into two parts, leaves and corms, cleaned before analysis and measured in dry-weight units.

Fe, Cu, Zn, Cd, Hg, Pb, P and K concentrations in the seagrass and sediments were determined using the HNO_3-$HClO_4$ extraction method (Burt, 2004; Rayment and Higginson, 1992). A 0.5 mm seagrass sample weighing 1.0 g was put in the digestion flask. After adding 5 mL of 65% HNO_3 and 0.5 mL of 70% $HClO_4$, the sample solution was slowly shaken and stored overnight. Later, the sample solution was placed in a digestion block at 100°C and after the yellow steam disappeared, the temperature was increased to 200°C. The destruction process was ended when white steam appeared and the solution in the flask remained at 0.5 mL. After cooling, the sample was diluted with 0.1 N HNO_3 until a 50 mL volume was obtained. Once, it was homogenous, the sample was filtered using filter paper (Whatman 41 type) to obtain the seagrass extract.

The sediment extract was generated using the previous procedure. The only difference was the utilization of distilled water instead of 0.1 N HNO_3 for diluting the sample solution. The rest of the procedure was unchanged.

After both extracts were obtained, the heavy metals (Fe, Cu, Zn, Cd, Hg and Pb) were measured using hydride-system AAS (Analytik Jena Types Nova 300 and HS 60, Germany), K was measured using flame atomic emission spectrophotometry (flamephotometry) and P was measured using simple spectrophotometry (Cecil CE 1020 scanning, England) at 693 nm.

The Total Nitrogen (T-N) in sediments was measured using SNI method no. 13-4721-1998. Approximately 0.5 g of the 0.5 mm sample was put into a 100 mL Kjeldahl flask and 10 mL of concentrated H_2SO_4 solution was added to the flask. The flask was slowly shaken until the sample was fully soaked with H_2SO_4 and then 0.1 g of a selenium mixture catalyst was added to the flask. The flask was heated at 200°C for 10 min and then the temperature was increased to 340°C and kept constant until complete destruction of the sample was confirmed. After cooling, a few drops of a phenolphthalein indicator were added by dripping. In the Kjeldahl distillation unit (Buchi K-350, Switzerland), 20 mL of 50% NaOH was gradually, added into the sample until it became alkaline. During the distillation process, the distillate was collected in an Erlenmeyer flask containing 10 mL of H_3BO_3 and five drops of conway indicator (0.3 g of bromocresol green +0.2 g of methyl red+20% ethanol) until a volume of 100 mL was obtained. The distillate was titrated with 0.02 N HCl until the solution color changed from green to pink. The blank solution was also titrated.

A similar procedure was applied to measure T-N in the seagrass samples. The only difference was at the step when the sample was cooled down after being heated at 340°C. In this case, the seagrass sample was diluted with 50 mL of distilled water and stirred. When a homogenous solution was obtained, the sample solution was filtered with a filter paper and 10 mL of the concentrated solution was removed by pipette and placed in the distillation flask. From this point onward, the rest of the procedure was unchanged.

Spatial distribution maps: Ocean Data View (ODV) software Version 4.2.1 (Alfred-Wegener Institute (AWI) for Polar and Marine Research, Bremerhaven, Germany) was employed to create distribution maps of the examined elements. The maps were produced from data points using the Data-interpolating variational analysis gridding technique.

RESULTS AND DISCUSSION

Heavy metals and nutrient concentrations in seawater: Table 2 shows the heavy metal and nutrient concentrations in the seawater samples from the sixteen stations in Banten bay. Among the heavy metals, the Cd and Pb concentrations were below the sensitivity limits (<0.007 and <0.006 mg L^{-1}, respectively) at all stations. Fe, Zn and Cu were detected only at some stations but the mean concentrations were still below the maximum Permissible Values (PVs) as determined by the Ministry of Environment of Indonesia regulation No. 51/2004 regarding the standard quality of seawater (for marine biota).

Of the nutrients, the P (in PO_4 form) concentrations exceeded the designated PVs at almost all stations. The mean concentration of P was 0.066±0.031 mg L^{-1} which is far above its designated PV (0.015 mg L^{-1}). The oversupply of P in the coastal environment may cause eutrophication that can trigger algal blooms (Bennett *et al*., 2001). Anthropogenic sources of P include fertilizers, wastewater and detergents (Reimann and De Caritat, 1998). The K concentration, although very

Table 2: Heavy metal and nutrient concentrations in the seawater of Banten bay

	Stations																
Elements (mg L^{-1})	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	PV
Fe	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	0.027	0.030	0.016	0.037	0.015	ND
Cu	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	0.009	0.034	<dv	0.008
Zn	0.011	<dv	0.020	<dv	<dv	<dv	0.034	<dv	<dv	<dv	<dv	<dv	<dv	<dv	0.011	<dv	0.050
Cd	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	0.001
Pb	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	0.008
Hg	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.001
PO_4	0.16	0.05	0.05	0.07	0.06	0.04	0.07	0.07	0.04	0.05	0.04	0.10	0.09	0.04	0.05	0.07	0.015
K	554.2	480.5	582.2	591.0	506.0	NA	NA	541.4	515.6	545.3	508.2	514.6	545.1	454.4	540.4	523.6	ND
DON	1.54	1.54	1.54	1.54	0.92	1.23	1.54	0.92	0.92	0.92	0.92	0.92	1.23	0.92	1.85	0.92	ND

PV: Permissible Value, determined based on the ministry of environment of Indonesia regulation No. 51/2004 regarding the standard quality of seawater (for marine biota); ND: Not Determined by the above regulation; NA: Not Analyzed; dv: detectable sensitivity limit: 0.009 mg L^{-1} for Fe; 0.007 mg L^{-1} for Cd; 0.006 mg L^{-1} for Cu and Pb

Table 3: Heavy metal and nutrient concentrations in the seagrass leaves and corms of Banten bay measured in dry weight

		Station no. 2		Station no. 3		Station no. 4		Station no. 6		Station no. 8		Station no. 9	
Elements	Units	Leaves	Corms	Leaves	Corms	Leaves	Corms	Leaves	Corms	Leaves	Corms	Leaves	Corms
Fe-total	(%)	0.12	0.46	0.12	0.31	0.22	0.25	0.07	0.22	0.40	0.26	0.21	0.46
Cu-total	ppm	9.08	10.18	7.12	5.62	8.80	8.59	8.84	6.34	7.07	3.97	5.43	4.91
Zn-total	ppm	195.5	103.4	72.48	57.50	94.06	102.3	98.09	90.12	74.47	76.03	51.85	76.76
Cd-total	ppm	1.05	<dv	0.73	<dv	0.47	<dv	0.28	<dv	0.26	<dv	0.07	<dv
Pb-total	ppm	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv	<dv
Hg-total	ppm	0.027	0.034	0.096	<0.00001	0.027	0.008	0.040	0.028	0.014	0.006	0.102	0.004
P_2O_5-total	(%)	0.25	0.21	0.20	0.14	0.28	0.24	0.26	0.24	0.29	0.17	0.27	0.33
K_2O-total	(%)	4.41	3.13	3.32	2.56	4.19	3.27	3.37	8.53	4.17	2.81	3.05	3.64
N-total	(%)	2.26	1.61	1.92	0.74	2.54	1.84	2.41	1.41	2.33	1.05	2.54	1.22

dv: detectable sensitivity limit: 0.007 mg L^{-1} for Cd; 0.006 mg L^{-1} for Cu and Pb

high in seawater can be different in each ecosystem. The mean concentration of K in Banten bay was 462.70±183.68 mg L^{-1} which was above its natural concentration (392 mg L^{-1}) at 3.5% salinity (Turekian, 1968).

Fertilizer application is the main anthropogenic source of K (Reimann and De Caritat, 1998) and K evaporites (such as KCl) are extremely soluble and can lead to high K concentrations in brines (Salminen *et al.*, 2006). The mean concentration of DON in the seawater from the study site was 1.21±0.33 mg L^{-1}.

Organic nitrogen including urea, amino acids and proteins is the main source of T-N in the seawater and it is transported to the ocean by river water discharge (Seitzinger and Sanders 1997).

Heavy metal and nutrient concentrations in seagrass: Table 3 shows the results of the heavy metal and nutrient concentrations in the seagrass at the six stations. The concentrations of Pb (leaves and corms) and Cd (corms) were below the limit of detection at all stations. However, the mean concentration of Cd in leaves was 0.48±0.36 ppm which was lower than Cd concentrations found in seagrass leaves of *Cymodocea rotundata* (1.83±1.12 ppm) collected from three islands near Jakarta bay (Kiswara *et al.*, 1990) and seagrass leaves of *C. nodosa* (1.2±0.2 ppm) found in Larymna bay, Turkey (Nicolaidou and Nott 1998). The Cu concentrations in the leaves and corms were 7.72±1.44 and 6.60±2.35 ppm, respectively. These concentrations were higher than those found in *C. rotundata* in Jakarta bay where the mean concentrations in the leaves and corms were 6.17±1.69 and 5.83±1.33 ppm, respectively (Kiswara *et al.*, 1990). The concentrations were also higher than those in found in Larymna bay (5.24±0.4 and 1.10±0.40 ppm in leaves and corms, respectively (Nicolaidou and Nott, 1998). Similarly, the mean concentrations of Zn in the seagrass leaves (97.75±50.72 ppm) and corms (84.30±17.64 ppm) were higher than those in Jakarta bay (Kiswara *et al.*, 1990) and Larymna bay (Nicolaidou and Nott, 1998). Meanwhile, the mean concentrations of Zn were 60.83±29.36 and 40.67±21.95 ppm in the leaves and corms of *C. rotundata* in Jakarta bay and 57.5±6.2 and 23.0±19.5 ppm in the leaves and corms of *C. nodosa* in Larymna bay, respectively. The mean concentrations of Hg were 0.051±0.038 ppm (leaves) and 0.016±0.014 ppm (corms). As a comparison, the average Hg concentration found in two seagrass species from locations near contaminant sources in the Gulf of Mexico was 0.0231 ppm (Lewis and Chancy, 2008). The mean concentrations of Fe at the study site were 0.19±0.12 and 0.33±0.11% in the leaves and corms, respectively. Among nutrients, the T-N and P concentrations play important roles in seagrass ecosystems. Duarte (1990) compiled N and P content measurements from the literature for 27 seagrass species from thirty locations and found that

Table 4: Heavy metal and nutrient concentrations in the sediments of Banten bay

	Station no.															
Elements	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Fe-total*	6.37	0.96	3.42	0.8	3.69	0.41	5.27	10.58	0.99	6.42	5.11	5.66	5.61	0.71	5.60	6.05
Cu-total	9.82	5.05	6.92	4.48	4.68	4.28	8.47	5.22	4.62	10.44	7.34	8.07	8.72	3.29	6.29	3.44
Zn-total	198.9	152.4	135	94.5	186.1	78.6	224.8	190.1	104.62	233.8	204.4	217.7	232.4	81.8	182.8	188.8
Cd-total	0.27	2.86	1.63	2.82	2.13	3.13	0.43	1.05	2.76	0.43	0.49	0.54	0.47	2.95	0.42	0.30
Pb-total	16.20	17.34	10.36	13.32	10.07	9.87	2.42	4.62	7.09	4.5	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006
Hg-total	0.094	0.039	0.05	0.047	0.051	0.043	0.174	0.201	0.069	0.124	0.150	0.191	0.235	0.056	0.102	0.037
P_2O_5-total	951.3	491.1	715.1	518.7	746.9	410.9	802.7	2.558	676.0	1.109	771.0	1.373	966	606.0	997.0	805.0
K_2O-total*	0.77	0.68	0.56	0.51	0.46	0.38	1.07	1.28	0.53	0.84	1.18	1.10	1.10	1.36	2.67	2.67
N-total*	0.67	0.38	0.64	0.32	0.27	0.24	0.47	0.44	0.36	0.79	0.71	0.66	0.78	0.26	0.27	0.49

All concentrations are given in parts per million (ppm) dry weight, unless specified otherwise.* indicates percentage dry weight

the mean concentrations of N and P in the seagrass leaves were 1.92±0.05 and 0.23±0.01% dry weight, respectively. Meanwhile, the mean concentrations of N and P in the study were 2.33±0.23 and 0.26±0.03% in the leaves and 1.31±0.40 and 0.22±0.07% in the corms, respectively. The mean K concentrations in the seagrass leaves and corms were 3.75±0.57 and 3.99±2.26%, respectively.

Heavy metal and nutrient concentrations in sediments: Table 4 shows the heavy metal and nutrient concentrations in sediment samples from the sixteen stations. The minimum, maximum and the mean±SD concentrations of Cu were 3.29, 10.44 and 6.32±2.27 ppm, respectively. These values are lower than the Threshold Effects Level (TEL) (18.7 ppm) defined in the North Oceanic and Atmospheric Administration (NOAA) screening quick reference tables (Buchman, 2008) and are also lower than values measured in Jakarta bay in 1982 (11.8, 82.9 and 28.59±13.22 ppm, respectively; Marsh, 1992) and 2004 (0.82-74.70 ppm; Rochyatun and Rozak, 2008). The minimum, maximum and the mean±SD concentrations of Pb were <0.006, 17.34 and 5.99±6.17 ppm, respectively and were lower than its TEL (30.2 ppm). These concentrations were also lower than the Pb concentrations measured in Jakarta bay in 1982 (9.0, 438.0 and 41.73±77.77 ppm, respectively; Marsh, 1992) and 2004 (3.64-53.00 ppm; Rochyatun and Rozak, 2008). For Hg, although the concentrations in some stations exceeded the TEL, the mean concentration (0.104±0.067 ppm) was below the TEL (0.13 ppm). This Hg concentration was also lower than that measured in Jakarta bay in 1982 (0.49±0.79 ppm; Marsh, 1992) and that measured in Candarli gulf, Turkey in 2009 (0.2-6.3 ppm) (Pazi, 2010).

The mean concentrations of Zn and Cd were 169.17±54.21 and 1.42±1.15 ppm, respectively. In both cases, these values exceeded their TELs (Zn: 124 and Cd: 0.68 ppm) but were below the concentrations measured in Jakarta bay in 2004 (Zn: 53.87-497.53; Cd: <0.001-40.60 ppm; Rochyatun and Rozak, 2008). However, the concentration of Zn was higher than that measured in the Candarli gulf (55-119 ppm) (Pazi, 2010). Regarding comparisons with other regions, the mean concentrations of Cu, Pb, Hg, Zn and Cd in sediments measured in this study were higher than those measured in Gokova bay, Turkey (Balkis *et al*., 2010) as well as those found in seven seagrass beds in Florida (but excluding the concentrations of Cu and Pb in the seagrass-vegetated area of Little Sabine bay, Florida) (Lewis *et al*., 2007).

Zn, Cu, Hg, Cd and Pb are very important and widely used in many industrial activities including mining, coal and waste combustion, steel processing and paint, rubber and dry batteries production (Salminen *et al*., 2006), some of those industries are active in Banten bay.

The maximum PV of Fe is not specified in the NOAA table however, the background concentration in the table is 0.99-1.8%. Meanwhile, the mean concentration of Fe in the study site was 4.23±2.85% which was higher than the given background level. It was also higher than that found in the Candarli gulf (1.62-3.60%) (Pazi, 2010).

The mean concentration of total P (P_2O_5) was 906.06±504.17 ppm which was higher than the mean concentrations of 628.1, 676.3 and 682.6 ppm found in the Zhuyuan, Bailonggang (both in Chanjiang Estuary) and Xinghuo outfalls (Hangzhou bay), China, respectively (Li *et al*., 2003).

Steel processing is one of the anthropogenic sources of Fe in the environment (Reimann and De Caritat, 1998). Fertilizers and herbicides may also contain Fe in the form of iron sulfate (Reimann *et al*., 2003). The mean K (K_2O) concentration was 0.963±0.551% which was lower than the median concentration of K_2O (1.71%, N = 4905) found in Japan's coastal sea sediments (Ohta *et al*., 2007). The T-N concentration of the study sites was 0.484±0.196%.

For comparison, the T-N concentration in the surface sediment off the Tokai area in Japan ranges between 0.10 and 0.30% (Maekawa and Komiya, 1999). The uses of N, P and K in fertilizers and detergents are among the most important anthropogenic sources of those elements in the environment (Reimann and De Caritat, 1998).

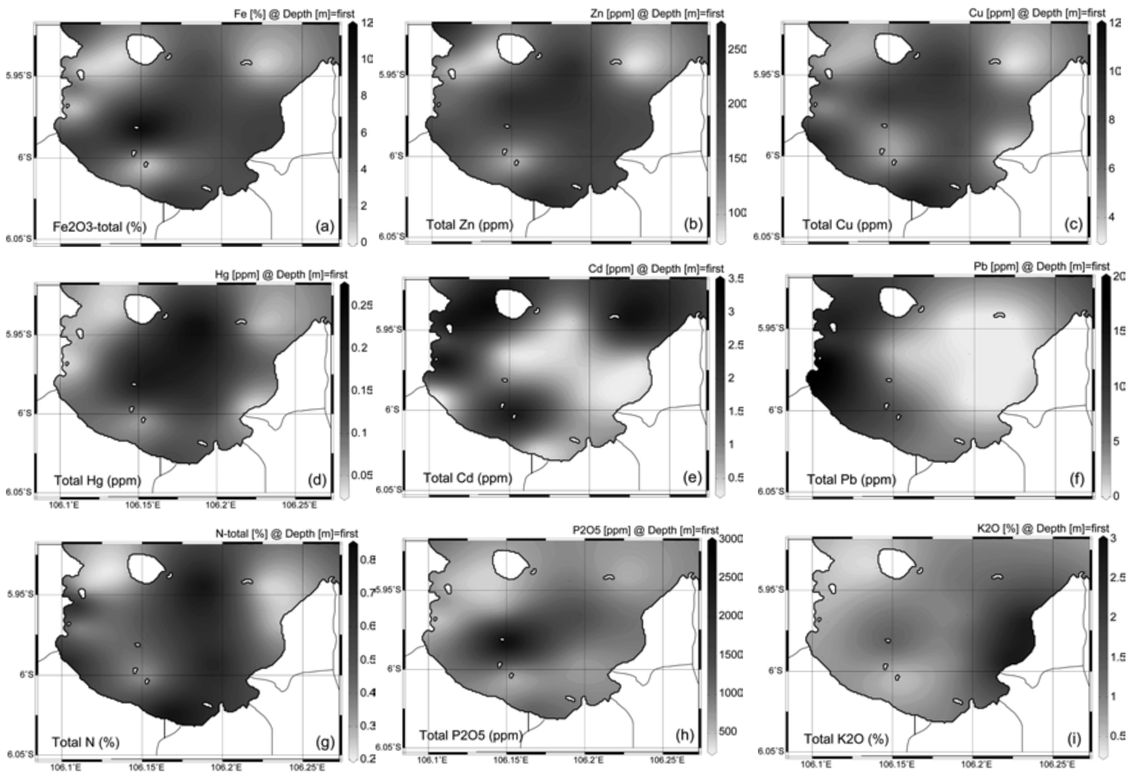

Fig. 2: Spatial distribution patterns of heavy metals and nutrients in Banten bay

Spatial distributional patterns: Spatial distribution maps for heavy metal and nutrient concentrations in the sediment of Banten bay were created (Fig. 2a-i). The spatial distributional patterns demonstrated the tendency of some heavy metals and nutrients (such as total Fe_2O_3, Zn, Cu, Hg, N and P_2O_5) to be deposited in the center of Banten bay. In addition to the center of the bay, high concentrations of some elements (such as total Fe_2O_3, Zn, Cu, P_2O_5 and most prominently T-N) were also found near the river mouths. It was evident that organic and inorganic materials transported by river water were deposited near the river mouths. In turn, the coastal waves and seawater currents dynamically redistributed the pollutants to the middle of the bay.

The fact that high concentrations of heavy metals and nutrients (excluding Cd, Pb and K) were concentrated in the center of the bay was quite interesting. Banten bay is influenced by seasonal variations of the Northwest and Southeast monsoons, combined with bidirectional asymmetric diurnal tidal flows. These seasonal couplings between waves, wind-driven throughflow, river discharge and tidal flows can generate a certain mechanism that leads to sediment deposition in the center of the bay (Hoitink and Hoekstra, 2003). This complex water current mechanism can help explain the distribution patterns of heavy metals and nutrients in Banten bay. A study by Helfinalis also revealed a fluctuative sediment distribution in B anten bay during four observation periods in 2001. The other three elements (i.e., Cd, Pb and K), exhibited different distribution patterns. The highest concentrations of total Cd and Pb were mostly localized near the industrial zone in the western part of the bay. Meanwhile, the highest concentration of K was localized in the eastern part of the bay (close to the mouth of the Ciujung river) in an area where a large part of the land is occupied by paddy farming. Although, more evidence is required, the different distribution patterns exhibited by the privious elements may be related to the sources of pollutants in the surrounding areas.

CONCLUSION

This study investigated concentrations of heavy metals (Fe, Zn, Cu, Cd, Hg and Pb) and nutrients (N, P and K) in the seawater, seagrass (leaves and corms) and sediments of Banten bay and analyzed their spatial distribution patterns in the sediments. The results revealed that the concentrations of heavy metals and nutrients in the seawater samples from the sixteen stations were relatively low, with most concentrations being below the limits of detection. In the sediments, all heavy metal concentrations were lower than those previously reported for Jakarta bay, Indonesia and Gokova bay, Turkey. Excluding total K, the mean concentrations of total P and N were also higher than those found in China and Japan, respectively. With the exclusion of Cd and Pb, the concentrations of other elements in the seagrass were higher than concentrations found in Jakarta bay, Larymna bay (Turkey) and the Gulf of Mexico. The spatial distribution maps of concentrations in the sediments showed that some elements (such as Fe, Zn, Cd, Cu, Hg, N and P) exhibited strong tendencies to accumulate in the center of the bay as a result of oceanographic processes. These results suggest that the combination of the Northwest and Southeast monsoons, bidirectional asymmetric diurnal tidal flows, wind-driven throughflow and river discharge play important roles in sediment distribution in Banten bay.

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