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Heavy Metal Contamination in Sediments and Its Potential Ecological Risks in Youtefa Bay, Papua Province, Indonesia

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ABSTRACT

This study aimed to analyze the heavy metal contamination in sediments and their potential ecological risks. The sediment samples were collected using PVC pipes and grab samplers at nine study sites in Youtefa Bay, namely five sites in the mangrove ecosystem, two sites in the estuary, and two sites in the middle of the bay. The heavy metal content was analyzed using Atomic Absorption Spectrophotometry. The results of the analysis of the heavy metal content in the sediment were in the following order: Zn > Cu > Pb > Ni > Cr > Cd > As > Hg (106.077±98.857, 28.553±30.505, 19.798±11.541, 17.665±11.457, 12.103±0.124, 2.996±1.235, 0.149±0.124, and 0.082±0.047 mg kg^{-1}, respectively). Only the Cd content has exceeded the Threshold Effect Level (TEL) at all study sites. On the other hand, the As and Cr content has not exceeded TEL at any study site. The content of Hg, Cr, Pb, Zn, and Ni has exceeded TEL only at a few study sites. The heavy metal content in estuary sites is higher than in mid-bay and mangrove sites, which can provide the information on the sources of heavy metal contaminants. There is a significant correlation for the content of Cu, As, Pb, Cd, Zn, and Ni which can indicate that the sources of these heavy metals are relatively the same (r = 0.569 to r = 0.950). The CF and I_{geo} values indicate that there has been contamination of several heavy metals studied. Further analysis (E_{RI}) showed that the heavy metal content in the sediments poses a potentially serious ecological risk. Most of the potential ecological risks are the contribution of Cd and Hg which have high toxicity factors and this should receive special attention from local governments and stakeholders to prevent higher contamination.

Keywords: ecological risk, pollution load index, geo-accumulation index, contamination factor, threshold effect level, Youtefa Bay.

INTRODUCTION

Environmental pollution occurs when the existing pollutants have exceeded the threshold and cause negative impacts on the environment and living things [Mohammed et al., 2011]. One of the most dangerous pollutants are heavy metals. Currently, the heavy metal pollution has been a problem in most aquatic environments around the world. Heavy metal contamination can have a negative ecological effect on the environment because it cannot be degraded, undergoes bioaccumulation [Saher and Siddiqui, 2019], biomagnification [Vandecasteele et al., 2004], and becomes toxic if it exceeds certain threshold [Rosado et al., 2016]. Heavy metal contamination in aquatic environments can occur in water bodies [Boran and Altinok, 2010; Ali et al., 2016; Tanjung et al., 2019a; Hamuna and Tanjung, 2021], sediments [Salem et al., 2014; Effendi et al., 2016; Ali et al., 2016; Tanjung et al., 2019b; Harmesa and Cordova, 2021], and aquatic organisms [Boran and Altinok, 2010; Ouali et al., 2018; Alrabie et al., 2019].

Heavy metals are difficult to dissolve in water, so most of them are absorbed and bound to organic matter or suspended particles which then settle

on the bottom of the water as sediment [Yang et al., 2014; Baran et al., 2019]. Hence, sediments are a place for accumulation of various pollutants that reach the aquatic environment from various sources [Ridgway and Shimmield, 2002; Luna et al., 2016], as well as a source of endogenous contaminants in the aquatic environment [Ciutat et al., 2007]. The anthropogenic sources that enter the aquatic environment will accumulate in the sediment through the process of adsorption, precipitation, co-precipitation, and biological effects [Peng et al., 2018] so that the concentration of heavy metals in sediments is higher than in water bodies. When there is a physicochemical change in the environment, heavy metals will dissolve into water bodies and enter the food chain so that they can harm the environment and aquatic biota [Fu et al., 2013]. The accumulation of heavy metals in sediments for a long time can be an appropriate method to determine the pollution status in the aquatic environment [Marchand et al., 2006; Saher and Siddiqui, 2016].

The data and information on the content and contamination of heavy metals in sediments from Youtefa Bay are not available to date. On the other hand, the assessment and evaluation of the level of heavy metal contamination in waters is a very important study. The content of heavy metals in sediments can provide original evidence of the status and sources of pollution in the aquatic environment. Therefore, this study aimed to determine the content of heavy metals (Hg, As, Cr, Cu, Pb, Cd, and Zn) in the sediments in Youtefa Bay. Furthermore, a comprehensive analysis was carried out to estimate the contamination status of these heavy metals and their potential ecological risks.

METHODS

Description of the study area

Youtefa Bay is a closed water area located in Jayapura City, Papua Province, Indonesia. The bay is flanked by two headlands, namely Pie cape and Tanjung Saweri which are only separated by a small strait (Tobati Strait) with a width of about 300 m [Dinas Kebudayaan dan Pariwisata Provinsi Papua, 2017]. Currently, Youtefa Bay is one of the Nature Tourism Parks in Papua Province. Youtefa Bay was designated as a Tourist Park based on the Decree of the Minister of Agriculture No. 372/Kpts/Um/1978 with an area of 1,650 ha, then designated as a Nature Tourism Park based on the Decree of the Minister of Forestry No. 714/Kpts-II/1996 with an area of 1,675 ha [Balai Konservasi Sumber Daya Alam, 2007]. There are mangrove and seagrass ecosystems in Youtefa Bay which are often used by local people as a place to find fish, shellfish, and crabs [Rumahorbo et al., 2019, 2020]. The high level of development activities and community activities in the Youtefa Bay area cause mangrove degradation. The area of mangroves is estimated to be only 233.12 ha in 2017 and continues to experience degradation until now [Hamuna and Tanjung, 2018]. Moreover, Youtefa Bay has a high potential for demersal fisheries [Hamuna et al., 2020], and it is estimated that at least 79 fish species have been identified in Youtefa Bay [Tebaiy et al., 2014].

The Youtefa Bay bathymetry is dominated by shallow water (3 to 5 m) and some of the shallow waters will appear at sea level during the lowest tide [Alfons, 2018]. There are two rivers (about 20 m wide) flowing into Youtefa Bay, namely the Acai River and the Entrop River. The two rivers have a great influence on the quality of the waters, because they carry various types of domestic waste from housing, shops, and small industries to Youtefa Bay. The ranges of values for water parameters such as water pH, total suspended solids, dissolved oxygen, biochemical oxygen demand, nitrate, ammonia, and phosphate are 7.0–8.5, 89.0–267.5 mg L^{-1}, 2.13–5.79 mg L^{-1}, 8.06–24.5 mg L^{-1}, 0.004–0.03 mg L^{-1}, 0.03–0.24 mg L^{-1}, and 0.02–1.65 mg L^{-1}, respectively [Manalu et al., 2011].

Collection and treatment of sediment samples

Sediment sampling was carried out in December 2020 at nine sites in Youtefa Bay, consisting of mangrove sediment samples (five sites; M1–M5), estuary sediments (two sites; E1–E2), and sediments in the middle of the bay (two sites; T1–T2) (Fig. 1). Sampling of sediments was performed using PVC pipe (diameter 8 cm) and grab sampler (size 20 × 20 cm). PVC pipes were used to collect the mangrove sediment samples, namely the surface and bottom sediments (1 m from the surface), respectively. Meanwhile, the grab sampler was used to collect the surface sediment samples in the estuary and the middle of the bay. In each site, sediment sampling was carried out at three points with a distance of 5

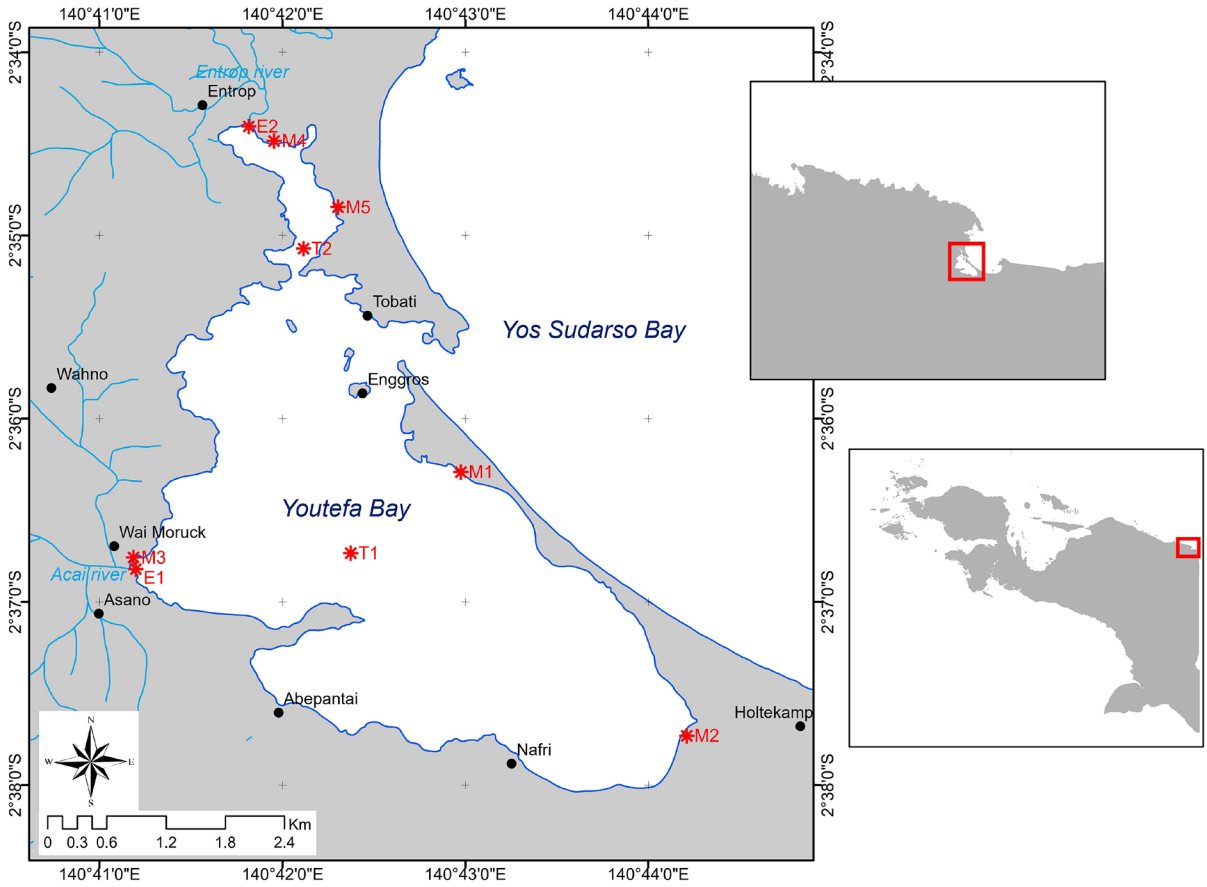

Figure 1. Map of sediment sampling sites in Youtefa Bay, Indonesia. M1-M5 are mangrove sites; E1-E2 are estuary sites; T1-T2 are sites in the middle of the bay

m at each point. The three sediment samples were mixed and as much as 200 g was placed in polyethylene plastic which had been given two drops of 4% formalin. Furthermore, the sediment samples were stored in a cool box for the analysis of the heavy metal content in the laboratory.

Sediment samples analysis

The sediment samples were analyzed at the Laboratory of Productivity and Aquatic Environment (Laboratorium Produktivitas dan Lingkungan Perairan), IPB University. The laboratory has been accredited by the National Accreditation Committee (Komite Akreditasi Nasional) as a testing laboratory (LP-425-IDN). The analysis of the heavy metal content was carried out using Atomic Absorption Spectrophotometry (AAS). The limitations of AAS detection and analysis methods for the content of each heavy metal are presented in Table 1.

Table 1. Summary of analysis methods for the heavy metal content

Heavy metal	Limit detection	Analytical methods	Standard, threshold effect level (mg kg^{-1})
Hg	0.004	APHA, 3112-B,3030-H, 2017	0.13[a]
As	0.003	APHA, 3114-B,3030-H, 2017	7.24[a]
Cr	0.09	APHA, 3111-B,3030-H, 2017	52.3[a]
Cu	1.20	APHA, 3111-B,3030-H, 2017	18.7[a]
Pb	0.23	APHA, 3111-B,3030-H, 2017	30.2[a]
Cd	0.40	APHA, 3111-B,3030-H, 2017	0.7[a]
Zn	0.67	APHA, 3111-B,3030-H, 2017	124[a]
Ni	2.60	APHA, 3111-B,3030-H, 2017	15.9[b]

Remarks: [a]Canadian environmental quality guidelines; [b]National Oceanic and Atmospheric Administration

Data analysis

The assessment of the heavy metal content was carried out descriptively, namely comparing the heavy metal content of the AAS detection results with the standard or threshold for heavy metal content in marine sediments. Until now, the standard for the heavy metal content in marine sediments in Indonesia has not been established, so it refers to the standards set by other countries. The standard for the heavy metal content of Hg, As, Cr, Cu, Pb, Cd, and Zn refers to the Threshold Effect Level (TEL) for aquatic life set by the Canadian Environmental Quality Guidelines [Canadian Council of Ministers of the Environment, 2001], while the content of Ni in sediments refers to the standards set by the National Oceanic and Atmospheric Administration [Buchman, 2008] (Table 1).

Assessment and evaluation of the heavy metal contamination in sediments can be done by analyzing contamination factor (*CF*), geo-accumulation index (I_{geo}), pollution load index (*PLI*), and potential ecological risk (E_{RI}) [Wojciechowska et al., 2019]. *CF* is an indicator to evaluate the level of contamination of toxic substances (heavy metals) in sediments in aquatic environments [Hakanson, 1980; Tomlinson et al., 1980]. *CF* can be determined based on the equation [Turekian and Wedepohl, 1961]:

$$CF = \frac{C_{metal}}{C_{background}} \quad (1)$$

where: C_{metal} is the concentration of the heavy metal analyzed, $C_{background}$ is the reference metal value (average shale metal). $C_{background}$ for Hg, As, Cr, Cu, Pb, Cd, Zn, and Ni are 0.4, 13, 90, 45, 20, 0.3, 95, and 68, respectively [Turekian and Wedepohl, 1961]. According to Hakanson [1980], four categories of *CF*, namely low contamination (class 1; $CF < 1$), moderate contamination (class 2; $1 \geq CF < 3$), significant contamination (class 3; $3 \geq CF < 6$), and very high contamination (grade 4; $CF \geq 6$).

I_{geo} analysis can be applied to evaluate the degree of heavy metal contamination in the sediments in Youtefa Bay. I_{geo} can be calculated based on the equation [Müller, 1979]:

$$I_{geo} = log_2\left(\frac{C_{metal}}{1.5 \times C_{background}}\right) \quad (2)$$

where: the value 1.5 is used to minimize the effect of variations from the background values that may be associated with the lithogenic effect. On the basis of the I_{geo} value, the degree of heavy metal contamination can be grouped into seven categories, namely practically uncontaminated (class 1; $I_{geo} < 0$), uncontaminated to moderately contaminated (class 2; $0 < I_{geo} < 1$), moderately contaminated (class 3; $1 < I_{geo} < 2$), moderately to heavily contaminated (class 4; $2 < I_{geo} < 3$), heavily contaminated (class 5; $3 < I_{geo} < 4$), heavily to extremely contaminated (class 6; $4 < I_{geo} < 5$), and extremely contaminated (class 7; $I_{geo} > 5$) [Müller, 1979; Ali et al., 2016; Xia et al., 2018].

PLI for each study site can be determined based on the equation [Tomlinson et al., 1980]:

$$PLI = (CF_1 \times CF_2 \times \ldots \times CF_n)^{1/n} \quad (3)$$

There are three categories of *PLI* values, namely $PLI < 1$ indicates perfect sediment quality, $PLI = 1$ indicates only ground-level pollutants, and $PLI > 1$ indicates a decrease in site quality or has been heavily polluted [Tomlinson et al., 1980; Mohiuddin et al., 2010].

In order to assess the potential ecological risk (E_{RI}) of the heavy metal contamination in sediments, E_{RI} can be applied by referring to the equation [Hakanson, 1980]:

$$E_{RI} = \sum E_i \quad (4)$$

$$E_i = T_i \times CF_i \quad (5)$$

where: E_i is the monomial potential ecological risk factor for each heavy metal, T_i is a heavy metal toxic response factor (Hg = 40, As = 10, Cr = 2, Cu = Pb = 5, Cd = 30, Zn = 1, and Ni = 6), and CF_i is the contamination factor for each heavy metal. Referring to Gan et al. [2000], the values of E_i and E_{RI} are grouped into five categories, namely low risk (kelas 1; $E_i < 30$; $E_{RI} < 100$), moderate risk (kelas 2; $30 < E_i < 50$; E_i $100 < E_{RI} < 150$), considerable risk (kelas 3; $50 < E_i < 100$; $150 < E_{RI} < 200$), very high risk (kelas 4; $100 < E_i < 150$; $200 < E_{RI} < 300$), and disastrous risk (kelas 5; $E_i > 150$; $E_{RI} > 300$).

Statistical analysis

SPSS version 17.0 software was used for statistical analysis of *t*-Student's test and Pearson correlation analysis. The *t*-Student test at the 5% significance level was carried out to determine the differences in the heavy metal content in the

surface and bottom sediments at mangrove sites, as well as the differences in the heavy metal content between study sites. Meanwhile, Pearson correlation analysis was carried out to determine the relationship between the heavy metal content and aquatic environmental parameters. Correlation coefficient criteria refer to Asuero et al. [2006].

RESULTS

Heavy metal content in sediment

The heavy metal content of Hg, As, Cr, Cu, Pb, Cd, Zn, and Ni in the sediments in Youfeta Bay is presented in Table 2. Overall, the average content of heavy metals in the sediments of Youtefa Bay is in the following order: Zn > Cu > Pb > Ni > Cr > Cd > As > Hg (106.077±98.857, 28.553±30.505, 19.798±11.541, 17.665±11.457, 12.103±0.124, 2.996±1.235, 0.149±0.124, and 0.082±0.047 mg kg^{-1}, respectively). Almost all the average content of heavy metals (Hg, As, Cu, Pb, Cd, Zn, and Ni) is higher at estuary sites than mangrove and mid-bay sites, except that the average content of Cr is higher at mangrove sites. Compared with the standard heavy metal content in the sediments used in this study, the heavy metal content of As and Cr in the sediments has not exceeded TEL in all study sites. On the other hand, the Cd content has exceeded TEL at all study sites. The content of Cd, Cu, Pb, Zn, and Ni has exceeded TEL at all estuary sites, except Hg. The content of some heavy metals in the mangrove sediments has exceeded TEL at several sites, such as Hg at the M3 site (only in surface sediments), Cu and Ni at M3 and M4 sites (only in surface sediments), and Zn at the M3 site.

The average content of Hg, Cr, Cu, Pb, and Zn heavy metals in the surface sediments at mangrove sites (0.079±0.052, 13.352±1.877, 23.202±23.218, 15.412±5.216, and 78.726±46.116 mg kg^{-1}, respectively) was higher than in the case of the bottom sediments (0.066±0.023, 13.050±3.399, 20.942±29.032, 14.760±5.530, and 62.644±42.348 mg kg^{-1}, respectively). In contrast, the average content of As, Cd, and Ni was higher in the bottom sediment (0.110±0.075, 2.660±1.162, and 16.046±10.802 mg kg^{-1}, respectively) than in the surface sediment (0.075±0.069, 2.532±0.757,

Table 2. Heavy metals content in several sediment samples from Youtefa Bay, Papua Province, Indonesia

Sites	Heavy metal content (mg kg^{-1})							
	Hg	As	Cr	Cu	Pb	Cd	Zn	Ni
M1-0	0.043	0.066	12.230	2.750	7.020	1.420	33.380	5.120
M1-1	0.075	0.045	17.360	3.490	9.920	0.830	33.900	7.790
M2-0	0.060	0.179	12.610	9.240	20.610	2.100	66.200	10.030
M2-1	0.063	0.136	13.260	9.240	16.290	2.540	69.820	14.170
M3-0	0.170	0.003	11.540	60.480	16.200	2.880	143.780	24.440
M3-1	0.067	0.213	12.460	72.450	21.950	3.930	132.890	34.830
M4-0	0.055	0.103	16.250	30.410	18.600	3.260	107.040	20.470
M4-1	0.030	0.027	7.960	6.090	17.140	2.690	28.910	10.170
M5-0	0.066	0.026	14.130	13.130	14.630	3.000	43.230	12.940
M5-1	0.093	0.127	14.210	13.440	8.500	3.310	47.700	13.270
Mean	0.072	0.093	13.201	22.072	15.086	2.596	70.685	15.323
±SD	0.038	0.071	2.594	24.811	5.080	0.927	42.592	8.924
E1	0.198	0.242	7.720	88.790	31.330	3.880	257.040	33.360
E2	0.063	0.429	12.750	70.740	52.720	5.990	375.270	41.280
Mean	0.131	0.336	10.235	79.765	42.025	4.935	316.155	37.320
±SD	0.095	0.132	3.557	12.763	15.125	1.492	83.601	5.600
T1	0.110	0.153	5.710	6.480	15.800	2.450	53.670	8.220
T2	0.060	0.342	11.250	13.010	26.460	3.660	92.250	11.220
Mean	0.085	0.248	8.480	9.745	21.130	3.055	72.960	9.720
±SD	0.035	0.134	3.917	4.617	7.538	0.856	27.280	2.121

Remarks: M1-0 to M5-0 are surface sediment in M1 to M5 sites; M1-1 to M5-1 are bottom sediment in M1 to M5 sites

and 14.600±7.823 mg kg^{-1}, respectively). However, the results of the *t*-Student's test analysis showed that there was no significant difference in the mean content of heavy metals of the surface and bottom sediments in the mangrove sites ($P > 0.05$). This shows that there has not been any accumulation of heavy metals in the bottom sediments. Furthermore, the average content of six heavy metals, including Cu, As, Pb, Cd, Zn, and Ni in mangrove sites was significantly different from estuary sites ($P < 0.05$), and only As and Cr were significantly different from mid-bay sites ($P < 0.05$). The average difference in the heavy metal content was also shown between estuary sites and mid-bay sites, where Cu, Zn, and Ni were significantly different ($P < 0.05$), while Hg, As, Cr, Pb, and Cd were not significantly different ($P > 0.05$).

On the basis of the Pearson correlation coefficient (Table 3), there was a positive correlation between As and Pb, Cd, Zn, and Ni (r = 0.904, 0.804, 0.768, and 0.569, respectively). Cu has a very strong positive correlation with Ni (r = 0.950), a strong correlation with Zn and Cd (r = 0.854 and r = 0.701, respectively), and a moderate correlation with Pb (r = 0.683). Likewise, Pb was strongly positively correlated with Cd Zn, and Ni (r = 0.921, 0.946, and 0.821, respectively). Cd is positively correlated with Zn and Ni (r = 0.878 and 0.841, respectively), while Zn has a very strong positive correlation with Ni (r = 0.938). In Tab 3, there is a correlation between the heavy metal content and water environmental parameters. Only Cd had a strong positive correlation with temperature, while As and Pb were moderately positive correlations (r = 0.751, 0.608, and 0.542, respectively). In turn, the correlation between Cu and Ni with pH, salinity, and DO (dissolve oxygen), Cd with salinity, and Zn with pH was strongly negative.

Heavy metal contamination assessment

The results of the analysis of CF and I_{geo} of heavy metals are presented in Table 4. The CF values of heavy metals in the sediment are in the following order: Cd > Zn > Pb > Cu > Ni > Hg > Cr > As (10.726±4.440, 1.324±1.221, 1.121±0.666, 0.715±0.738, 0.279±0.184, 0.220±0.121, 0.128±0.033, and 0.014±0.010, respectively). In turn, the I_{geo} values follow the order: Cd > Pb > Zn > Cu > Ni > Hg > Cr > As (2.717±0.659, -0.615±0.779, -0.633±1.161, -1.872±1.682, -2.697±0.931, -2.925±0.680, -3.609±0.448, and -7.088±1.051, respectively).

The results of the *PLI* analysis ranged from 0.158 to 0.786 (Figure 2). The *PLI* values at estuary sites were higher than in mid-bay and mangrove sites, reaching 0.729, 0.309, and 0.299, respectively. These results indicate that the quality of sediment at the nine study sites in Youtefa Bay is classified as perfect sediment quality (unpolluted category; $PLI < 1$).

Table 3. Pearson correlation coefficient between heavy metals and aquatic environmental parameters (temperature, salinity, dissolved oxygen, and water pH)

	Hg	As	Cr	Cu	Pb	Cd	Zn	Ni	Temp	pH	Sal	DO
Hg	1											
As	.071	1										
Cr	-.644	-.203	1									
Cu	.666	.457	-.232	1								
Pb	.131	.904**	-.138	.683*	1							
Cd	.148	.804**	-.099	.701*	.921**	1						
Zn	.345	.768*	-.141	.854**	.946**	.878**	1					
Ni	.434	.569	-.088	.950**	.821**	.841**	.938**	1				
Temp	.032	.608	-.314	.271	.542	.751*	.396	.372	1			
pH	-.224	-.240	-.320	-.795*	-.557	-.662	-.704*	-.856**	-.173	1		
Sal	-.249	-.278	-.017	-.769*	-.587	-.743*	-.677*	-.818**	-.451	.879**	1	
DO	-.397	.018	-.156	-.722*	-.315	-.522	-.527	-.734*	-.192	.889**	.825**	1

Remarks: * Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed)

Table 4. Contamination factor (*CF*) and geo-accumulation index (I_{geo}) of several heavy metals in Youfeta Bay, Indonesia

Heavy metals M1		Sites								
		M2	M3	M4	M5	E1	E2	T1	T2	
Hg	*CF*	0.148	0.154	0.296	0.106	0.199	0.495	0.158	0.275	0.150
	I_{geo}	-3.346	-3.286	-2.340	-3.819	-2.916	-1.599	-3.252	-2.447	-3.322
As	*CF*	0.004	0.012	0.008	0.005	0.006	0.019	0.033	0.012	0.026
	I_{geo}	-8.457	-6.952	-7.496	-8.229	-7.994	-6.332	-5.506	-6.994	-5.833
Cr	*CF*	0.164	0.144	0.133	0.135	0.157	0.086	0.142	0.063	0.125
	I_{geo}	-3.190	-3.384	-3.492	-3.479	-3.252	-4.128	-3.404	-4.563	-3.585
Cu	*CF*	0.069	0.205	1.477	0.406	0.295	1.973	1.572	0.144	0.289
	I_{geo}	-4.435	-2.869	-0.022	-1.887	-2.345	0.396	0.068	-3.381	-2.375
Pb	*CF*	0.424	0.923	0.954	0.894	0.578	1.567	2.636	0.790	1.323
	I_{geo}	-1.825	-0.701	-0.653	-0.747	-1.375	0.063	0.813	-0.925	-0.181
Cd	*CF*	3.750	7.733	11.350	9.917	10.517	12.933	19.967	8.167	12.200
	I_{geo}	1.322	2.366	2.920	2.725	2.810	3.108	3.735	2.445	3.024
Zn	*CF*	0.354	0.716	1.456	0.716	0.479	2.706	3.950	0.565	0.971
	I_{geo}	-2.083	-1.067	-0.043	-1.068	-1.648	0.851	1.397	-1.409	-0.627
Ni	*CF*	0.095	0.178	0.436	0.225	0.193	0.491	0.607	0.121	0.165
	I_{geo}	-3.982	-3.075	-1.783	-2.735	-2.960	-1.612	-1.305	-3.633	-3.184

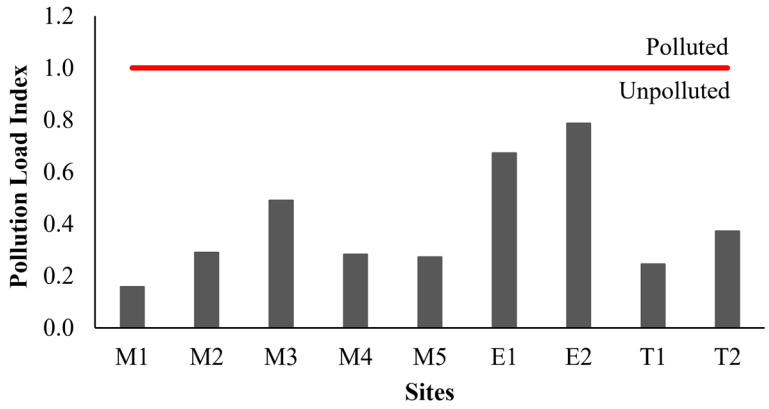

Figure 2. The pollution load index (*PLI*) of heavy metal in sediments in Youfeta Bay, Indonesia

Potential ecological risk

Ecological risk values consist of the ecological risk factor for each heavy metal (E_i) and the potential ecological risk index (E_{RI}) for the study area (Table 5). The potential ecological risks for each heavy metal are in the following order: Cd > Hg > Pb > Cu > Ni > Zn > Cr > As. The potential ecological risk of Cd is already in a serious condition, namely in the disastrous risk category (average E_i = 321.778±133.194). In contrast, the potential ecological risks for the other seven heavy metals (Hg, Pb, Cu, Ni, Zn, Cr, and As) are low risk (E_i < 30).

The E_{RI} values indicate that the potential ecological risk at the nine study sites is included in the moderate risk category to disastrous risk. Six sites were included in the disastrous risk category, two sites in the very high-risk category, and one site in the moderate risk category. The potential ecological risks for each study site are in the following order: E2 > E1 > T2 > M3 > M5 > M4 > T1 > M2 > M1. The mangrove sites are in the very high-risk category (average E_{RI} = 275.505±96.564), while the estuary and mid-bay sites are in the disastrous risk category (average E_{RI} = 533.025±143.572 and 322.370±85.086, respectively). Overall, the potential ecological risk in the waters of Youtefa Bay is included in the disastrous risk category (average E_{RI} = 343.146±141.862).

Table 5. Ecological risk factors (E_i) and potential risk index (E_{RI}) based on the content of eight heavy metals

Sites	E_i								E_{RI}
	Hg	As	Cr	Cu	Pb	Cd	Zn	Ni	
M1	5.900	0.043	0.329	0.347	2.118	112.500	0.354	0.570	122.159
M2	6.150	0.121	0.287	1.027	4.613	232.000	0.716	1.068	245.981
M3	11.850	0.083	0.267	7.385	4.769	340.500	1.456	2.615	368.925
M4	4.250	0.050	0.269	2.028	4.468	297.500	0.716	1.352	310.632
M5	7.950	0.059	0.315	1.476	2.891	315.500	0.479	1.156	329.826
E1	19.800	0.186	0.172	9.866	7.833	388.000	2.706	2.944	431.505
E2	6.300	0.330	0.283	7.860	13.180	599.000	3.950	3.642	634.546
T1	11.000	0.118	0.127	0.720	3.950	245.000	0.565	0.725	262.205
T2	6.000	0.263	0.250	1.446	6.615	366.000	0.971	0.990	382.535
Mean	8.800	0.139	0.255	3.573	5.604	321.778	1.324	1.673	343.146
±SD	4.823	0.101	0.066	3.689	3.328	133.194	1.221	1.101	141.862

DISCUSSION

In this study, the content of heavy metals (Hg, As, Cr, Cu, Pb, Cd, Zn, and Ni) in the sediments in Youtefa Bay was detected in various ranges and follows the order: Zn > Cu > Pb > Ni > Cr > Cd > As > Hg. The Zn content will be found in a relatively high range, while the Hg content is the lowest [Forsner and Wittmann, 1983]. Almost all heavy metals, including essential micronutrient metals, can be toxic to aquatic organisms and humans if the concentration is high enough [Laws, 2017]. Hg, Pb, Ni, and Cd are the metals that are categorized as dangerous chemical elements [European Commission, 2001] and have a high level of toxic response [Hakanson, 1980].

The content of As and Cr was found to be low and safe for aquatic bota. However, the detected content of some heavy metals has exceeded TEL [Canadian Council of Ministers of the Environment, 2001; Buchman, 2008]. Pb, Ni, Hg, Zn, and Cu have been detected to exceed TEL only at a few study sites and tend to be higher at estuary sites and mangrove sites near estuaries. This can indicate that the heavy metals (Pb, Ni, Hg, Zn, and Cu) are more deposited and accumulated in the estuary and its surroundings. Meanwhile, the Cd content has been detected in all sediment samples with a high content (it has exceeded TEL). This is very dangerous for aquatic biota and humans as consumers [Apeti et al., 2009; Järup and Akesson, 2009], and can affect the coastal and coastal ecosystem [Apeti et al., 2009; Metzger et al., 2007; Maunder et al., 2011]. In this study, the Cd content was lower at the mangrove sites than the estuary and mid-bay sites, where there was a significant difference between the mangrove sites and the estuary sites ($P = 0.046$; $P < 0.05$). This is because the Cd content can be minimized by the mangrove ecosystem, where the mangrove roots will absorb and bind Cd in waters and sediments [Salahuddin et al., 2012].

The Hg, As, and Cr contents in this study area were lower than the Hg content in Gresik waters [Lestari and Budiyanto, 2013] and Banten Bay [Suwandana et al., 2011], the As content in Balikpapan Bay [Sitorus et al., 2020], and the content of As and Cr in the Mahakam Delta [Effendi et al., 2016] (Table 6). The content of Cu, Pb, Cd, Zn, and Ni in the study area was higher than in the port of Tanjung Emas in Semarang (Ni data not available) [Tjahjono et al., 2017], Balikpapan Bay (Zn and Ni data not available) [Sitorus et al., 2020], Kendari Bay (Pb, Cd data not available) [Armid et al., 2017], and Cimanuk estuary, West Java (except Cu) [Harmesa et al., 2020]. The Pb content is higher on the Dumai coast, but the content of other heavy metals is relatively lower [Amin et al., 2009]. Higher levels of Cu, Pb, Zn, and Ni were detected in Jakarta Bay [Budiyanto and Lestari, 2017] and Mahakam Delta [Effendi et al., 2016], as well as Cu and Zn in Gresik waters [Lestari and Budiyanto, 2013]; however, the Cd content in the three waters is lower. The Cd content in this study area is relatively higher than in other waters, as presented in Table 6.

The correlation between the heavy metal contents studied tended to be significantly positive (moderate to very strong correlation; $r = 0.569$ to $r = 0.950$), except for Hg and Cr. This indicates that the sources of Cu, As, Pb, Cd, Zn, and Ni in the study area are relatively the same. A high

Table 6. Comparison of the average content of heavy metals (mg kg^{-1}) in sediments from several studies in Indonesian waters

Location	Hg	As	Cr	Cu	Pb	Cd	Zn	Ni	Reference
Youtefa Bay	0.082	0.149	12.103	28.553	19.798	2.996	106.077	17.665	This study
Banten Bay	0.104	–	–	6.320	5.990	1.420	169.170	–	Suwandana et al., 2011
Gresik waters	0.130	–	–	85.500	4.290	0.640	134.000	–	Lestari and Budiyanto, 2013
Mahakam Delta	–	2.000	47.310	27.660	27.590	1.070	186.610	57.240	Effendi et al., 2016
Balikpapan Bay	–	0.386	–	1.397	2.625	2.530	–	–	Sitorus et al., 2020
Port of Tanjung Emas Semarang	–	–	–	15.830	10.880	1.050	35.050	–	Tjahjono et al., 2017
Coastal of Dumai	–	–	–	6.080	32.340	0.880	53.890	11.480	Amin et al., 2009
Kendari Bay	–	–	–	6.001	–	–	44.927	8.676	Armid et al., 2017
Jakarta Bay	–	–	–	48.350	27.550	0.645	307.000	27.050	Budiyanto and Lestari, 2017
Cimanuk estuary, West Java	–	–	–	28.750	12.240	0.170	74.320	31.170	Harmesa et al., 2020

Remark: – are not available

correlation between heavy metals can provide the information that these heavy metals can come from the same source, are associated with each other, and behave identically during the transport process [Suresh et al., 2012; Salem et al., 2014; Chai et al., 2017; Huang et al., 2020]. Conversely, if there is no correlation, it indicates that the observed heavy metals are not controlled by one factor, but by the geochemical phase combination of the heavy metal content [Suresh et al., 2011; Effendi et al., 2016]. Apart from natural occurrence, heavy metals in waters can be sourced from industrial waste [Sindern et al., 2016; Zhuang and Zhou, 2021], mining waste [Effendi et al., 2016] agricultural activity waste [Zhuang and Zhou, 2021], various maritime activities [Ibrahim et al., 2019], and household waste [Mane et al., 2001; Amin et al., 2009; Sindern et al., 2016]. In the study area, high heavy metal content was detected at the estuary sites. This provides the information on the source of heavy metal contaminants from the mainland carried by the Entrop and Acai rivers to Youtefa Bay. The two rivers greatly affect the quality of the waters of Youtefa Bay [Manalu et al., 2011]. A significant source of heavy metals in the study area is anthropogenic waste, such as small industrial waste, household waste, workshop waste, and urban runoff, and a small part comes from maritime activities. River flow contributes greatly to the anthropogenic enrichment of heavy metals in coastal sediments [Sindern et al., 2016]. Aquatic environmental parameters also play an important role in the distribution and content of heavy metals. In this study, only water temperature has a positive correlation with the heavy metal content in sediments. Meanwhile, salinity, dissolved oxygen, and pH were significantly negatively correlated. The distribution of heavy metals in waters is influenced by several factors, such as the source of heavy metals, current velocity, salinity, pH, and hydrodynamic conditions [Liu et al., 2016].

The assessment of sediment quality is strongly influenced by an accurate comparison of reference values [Chapman, 1995]. The background values for heavy metals in this study area are not available as a reference. Therefore, the reference values for heavy metals generated by [Turekian and Wedepohl, 1961] were used in this study. Nonetheless, the results provide an overview of the level of heavy metal contamination in the study area. The CF and I_{geo} values indicate that there has not been any heavy metal contamination of Hg, As, Cr, and Ni at all sites. The CF value shows that there has been Cd contamination at all sites with a very high level of contamination ($CF \geq 6$; class 4), except at M1 sites which are in the significant contamination category ($3 \geq CF < 6$; class 3). At the same time, the I_{geo} value represents the heavily contaminated category ($3 < I_{geo} < 4$; class 5) at both the estuary site and the T2 site, moderately to heavily contaminated ($2 < I_{geo}$

< 3; class 4) at the T1 site and most mangrove sites, except for M1 sites which are in the moderately contaminated category (1 < I_{geo} <2; class 3). The significant level of Zn contamination at E2 sites (3 ≥ CF < 6; class 3), while at E1 and M3 sites were included in the moderate contamination category (1 ≥ CF <3; class 2). This is in contrast to the I_{geo} value which categorizes Zn as moderately contaminated, uncontaminated to moderately contaminated, and practically uncontaminated at E2, E1, and M3 sites, respectively. On the basis of the CF values at each study site, the *PLI* value for heavy metals is low, which indicates that there has been no pollution in Youtefa Bay. *PLI* is an empirical index that provides a simple and comparative way to assess the level of heavy metal pollution [Khan et al., 2017] and can show trends in environmental changes that can be used as valuable information for decision-makers in environmental pollution management [Mohiuddin et al., 2010]. Although there has been no heavy metal contamination yet, there have been indications of some heavy metal contamination in the study area. If this is allowed to continue, there is a high probability that heavy metal pollution will occur as the input of heavy metal pollutants increases to Youtefa Bay.

Further analysis (E_{RI}) shows that the heavy metals in sediments have the potential to pose serious ecological risks in the Youtefa Bay marine environment, where the average E_{RI} value is in the category of disastrous risk. E_{RI} analysis is a very important tool to determine the potential ecological risks in an aquatic environment based on the sensitivity of the biological community to various heavy metals [Salem et al., 2014]. Although the metal reference value used is not relevant to this study area, the results can provide an idea of the high potential ecological risk posed by the heavy metal contamination in the study area. Where most (around 93.77%) potential ecological risk comes from the contribution of Cd. This could be due to the high Cd heavy metal content at each site. Moreover, the contamination factor and the toxicity factor of heavy metal Cd are high. Hg, which has a higher toxicity factor value, contributed only 2.56%. The substantial and dominant contribution of Cd and Hg in waters can indicate an intense level of human activity [Zhu et al., 2020]. The Pb, Cu, Ni, Zn, Cr, and As heavy metals had very low contribution at 1.63%, 1.04%, 0.49%, 0.39%, 0.07%, and 0.04%, respectively. The potential ecological risk of heavy metals in the mangrove ecosystem is in the very high-risk category. This needs special attention because most of the local Papuan people use the mangrove ecosystem as a place to find fish, shellfish, shrimp, and crab for their daily needs. Thus, it is very worrying if these aquatic biotas are contaminated with heavy metals.

CONCLUSIONS

The study is the first to examine the heavy metal content in the sediments from Youtefa Bay. From the research results, it can be concluded that the content of Cd in the sediments in Youtefa Bay has exceeded the threshold used in this study. Likewise, several other heavy metals (Hg, Cu, Pb, Zn, and Ni) have exceeded the threshold at several study sites. Meanwhile, As and Cr have not exceeded the threshold. The high content of heavy metals in the estuary sites compared to the mid-bay sites and mangrove sites provide the information on the sources of heavy metal contaminants originating from the land carried by the Entrop and Acai rivers to Youtefa Bay. Although the *PLI* value shows that there has been no contamination, the CF and I_{geo} values together indicate that there has been contamination of several heavy metals studied. Furthermore, the heavy metal content in sediments has the potential to pose serious ecological risks based on the E_{RI} analysis, where most of the potential ecological risks are contributed by Cd and Hg which have high toxicity factors. The results of this study have provided the information on the status of heavy metal contamination and its potential ecological risks that should receive special attention from local governments and other stakeholders to prevent higher contamination in Youtefa Bay.

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REFERENCES

1. Alfons A.B. 2018. Kajian pengelolaan lingkungan pada kawasan Taman Wisata Alam Teluk Youtefa. Median: Jurnal Arsitektur dan Planologi 8(1), 1–12. (in Indonesian)

2. Ali M.M., Ali M.L., Islam Md.S., Rahman Md.Z. 2016. Preliminary assessment of heavy metals in water and sediment of Karnaphuli River, Bangladesh. Environ. Nanotechnol. Monit. Manag. 5, 27–35.
3. Alrabie N.A., Mohamat-Yusuff F., Hashim R., Zulkeflee Z., Arshad A., Amal M.N.A. 2019. Heavy metals concentrations in stormwater and tilapia fish (Oreochromis niloticus) in Kuala Lumpur holding and storage SMART ponds. Pertanika J. Trop. Agric. Sci., 42(1), 225–236.
4. Amin B., Ismail A., Arshad, A., Yap C,K., Kamarudin M.S. 2009. Anthropogenic impacts on heavy metal concentrations in the coastal sediments of Dumai, Indonesia. Environ. Monit. Assess. 148, 291–305.
5. Apeti D.A., Lauensteln G.G., Riedel G.F. 2009. Cadmium distribution in coastal sediments and mollusks of the US. Mar. Pollut. Bull., 58(7), 1016–1024.
6. Armid A., Shinjo R., Sabarwati S.H., Ruslan R. 2017. Pollution assessment of various heavy metals in the surface sediment of Kendari Bay, Indonesia. Nat. Environ. Pollut. Technol., 16(4), 1067–1074.
7. Asuero A.G., Sayago A., González A.G. 2006. The correlation coefficient: an overview. Crit. Rev. Anal. Chem., 36, 41–59.
8. Balai Konservasi Sumber Daya Alam. 2007. Master plan pengelolaan lingkungan Teluk Youtefa. Balai Konservasi Sumber Daya Alam, Jayapura, Indonesia. (in Indonesian)
9. Baran A., Hersztek M.M., Gondek K., Tarnawski M., Szara M., Gorczyca O., Koniarz T. 2019. The influence of the quality of sediment organic matter on the potential mobility and toxicity of trace elements in bottom sediment. Environ. Geochem. Health, 41, 2893–2910.
10. Boran M., Altinok I. 2010. A review of heavy metals in water, sediment and living organisms in the Baltic Sea. Turkish J. Fish. Aquat. Sci., 10, 565–572.
11. Buchman M.F. 2008. NOAA screening quick reference tables, NOAA OR&R report 08-1. Office of Response and Restoriation Division, National Oceanic and Atmospheric Administration, Seattle WA, 34.
12. Budiyanto F., Lestari. 2017. Temporal and spatial distribution of heavy metal in sediment of urban coastal waters: a case study in Jakarta Bay, Indonesia. Bulletin of the Marine Geology, 32(1), 1–10.
13. Canadian Council of Ministers of the Environment. 2001. Canadian sediment quality guidelines for the protection of aquatic life: summary tables. Canadian Council of Ministers of the Environment, Winnipeg, 5.
14. Chai L., Li H., Yang Z., Min X., Liao Q., Liu Y., Men S., Yan Y., Xu J. 2017. Heavy metals and metalloids in the surface sediments of the Xiangjiang River, Hunan, China: distribution, contamination, and ecological risk assessment. Environ. Sci. Pollut. Res., 24, 874–885.
15. Chapman P.M. 1995. Sediment quality assessment: status and outlook. J. Aquat. Ecosyst. Health 4, 183–194.
16. Ciutat A., Gerino M., Boudou A. 2009. Remobilization and bioavailability of cadmium from historically contaminated sediments: influence of bioturbation by tubificids. Ecotoxicol. Environ. Saf., 68, 108–117.
17. Dinas Kebudayaan dan Pariwisata Provinsi Papua, 2017. Wisata Alam Teluk Yotefa Jayapura Papua. https://www.pariwisata.papua.go.id/berita/wisata-alam-teluk-yotefa-jayapura-papua. (in Indonesian)
18. Effendi H., Kawaroe M., Mursalin, Lestari D.F. 2016. Ecological risk assessment of heavy metal pollution in surface sediment of Mahakam Delta, East Kalimantan. Procedia Environ. Sci. 33, 574–582.
19. European Commission, 2001. Commission Regulation (EC) No. 466/2001 of 8 March 2001: setting maximum levels for certain contaminants in foodstuffs. Official Journal of European Communities.
20. Förstner U., Wittmann G.T.W. 1983. Metal pollution in the aquatic environment. Springer-Verlag, Berlin, Heidelberg, New York, Tokyo.
21. Fu J., Hu X., Tao X., Yu H., Zhang Z. 2013. Risk and toxicity assessments of heavy metals in sediments and fishes from the Yangtze River and Taihu Lake, China. Chemosphere, 93(9), 1887–1895.
22. Gan J.L., Jia X.P., Lin Q., Li C.H., Wang Z.H., Zhou G.J., Wang X.P., Cai W.G., Lu X.Y. 2000. A primary study on ecological risk caused by the heavy metals in coastal sediments. J. Fish. China, 24, 533–538 (In Chinese with English abstract)
23. Hakanson L. 1980. An ecological risk index for aquatic pollution control: a sedimentological approach. Water Res., 14(8), 975–1001.
24. Hamuna B., Pujiyati S., Dimara L., Natih N.M.N., Alianto. 2020. Distribution and density of demersal fishes in Youtefa Bay, Papua, Indonesia: a study using hydroacoustic technology. Indian J. Fish. 67(1), 30–35.
25. Hamuna B., Tanjung R.H.R. 2018. Deteksi perubahan luasan mangrove Teluk Youtefa Kota Jayapura menggunakan citra landsat multitemporal. Majalah Geografi Indonesia 32(2), 115–122. (In Indonesian with English abstract)
26. Hamuna B., Tanjung R.H.R. 2021. Heavy metal content and spatial distribution to determine the water pollution index in Depapre waters, Papua, Indonesia. Current Applied Science and Technology, 21(1), 1–11.
27. Harmesa, Cordova M.R. 2021. A preliminary study on heavy metal pollutants chrome (Cr), cadmium (Cd), and lead (Pb) in sediments and beach morning glory vegetation (Ipomoea pes-caprae) from Dasun Estuary, Rembang, Indonesia. Mar. Pollut. Bull. 162, 111819.
28. Harmesa, Lestari, Budiyanto F. 2020. Distribution of heavy metals in seawater and sediments in Cimanuk estuary, West Java, Indonesia. Oseanologi dan Limnologi di Indonesia 5(1), 19–32. (In Indonesian with English abstract)

29. Huang Z., Liu C., Zhao X., Dong J., Zheng B. 2020. Risk assessment of heavy metals in the surface sediment at the drinking water source of the Xiangjiang River in South China. Environ. Sci. Eur., 32, 23.
30. Ibrahim M.I.A., Mohamed L.A., Mahmoud M.G., Shaban K.S., Fahmy M.A., Ebeid H.M. 2019. Potential ecological hazards assessment and prediction of sediment heavy metals pollution along the Gulf of Suez, Egypt. Egypt. J. Aquat. Res., 45, 329–335.
31. Järup L., Akesson A. 2009. Current status of cadmium as an environmental health problem. Toxicol. Appl. Pharmacol. 238(3), 201–208.
32. Khan M.Z.H., Hasan M.R., Khan M., Aktar S., Fatema K. 2017. Distribution of heavy metals in surface sediments of the Bay of Bengal Coast. Journal of Toxicology, 2017, 9235764.
33. Laws E.A. 2017. Aquatic pollution: an introductory text. 4th edition. John Willey & Sons Inc., New York, 760.
34. Lestari, Budiyanto F. 2013. Concentration of Hg, Cd, Cu, Pb and Zn in sediment of Gresik waters. Jurnal Ilmu dan Teknologi Kelautan Tropis, 5(1), 182–191. (In Indonesian with English abstract)
35. Liu B., Xu M., Wang J., Wang Z., Zhao L. 2021. Ecological risk assessment and heavy metal contamination in the surface sediments of Haizhou Bay, China. Mar. Pollut. Bull. 163, 111954.
36. Liu R., Men C., Liu Y., Yu W., Xe F., Shen Z. 2016. Baseline: Spatial distribution and pollution evaluation of heavy metals in Yangtze estuary sediments. Mar. Pollut. Bull. 110(5), 564–571.
37. Luna G.M., Quero G.M., Perini L. 2016. Next generation sequencing reveals distinct fecal pollution signatures in aquatic sediments across gradients of anthropogenic influence. Adv. Oceanogr. Limnol. 7(2), 115–124.
38. Manalu J., Nurjaya I.W., Surjono H.S., Kholil. 2011. Analyze of water pollution level in Youtefa Bay Jayapura, Papua using pollution index method. Berita Biologi: Jurnal Ilmu-Ilmu Hayati, 10(6), 749–761. (In Indonesian with English abstract)
39. Mane P.C., Kadam D.D., Chaudhari R.D. 2013. Accumulation of heavy metal ions in water, sediment and aquatic weeds: a case study of Sudha Dam, Bhokar, India. Adv. Appl. Sci. Res., 4(5), 394–400.
40. Marchand C., Lallier-Vergès E., Baltzer F., Albéric P., Cossa D., Baillif P. 2006. Heavy metals distribution in mangrove sediments along the mobile coastline of French Guiana. Mar. Chem. 98, 1–17.
41. Maunder R.J., Buckley J., Val A.L., Sloman K.A. 2011. Accumulation of dietary and aqueous cadmium into the epidermal mucus of the discus fish Symphysodon sp. Aquat. Toxicol., 103(3–4), 205–212.
42. Metzger E., Simonucci C., Viollier E., Sarazin G., Prévot F., Elbaz-Poulichet F., Seidel J-L., Jézéquel D. 2007. Influence of diagenetic processes in Thau Lagoon on cadmium behaviour and benthic fluxes. Estuar. Coast. Shelf Sci. 72(3), 497–510.
43. Mohammed A.S., Kapri A., Goel R. 2011. Heavy Metal Pollution: source, impact and remedies. In: M. Khan, A. Zaidi, R. Goel, and J. Musarrat (eds.), Biomanagement of Metal-Contaminated Soils. Environmental Pollution. Springer, Dordrecht, 20, 1-28.
44. Mohiuddin K.M., Zakir H.M., Otomo K., Sharmin S., Shikazono N. 2010. Geochemical distribution of trace metal pollutants in water and sediments of downstream of an urban river. Int. J. Environ. Sci. Technol., 7, 17–28.
45. Müller G. 1979. Heavy metals in the sediment of Rhine-Changes seity. Umsch. Wiss. Tech. 79, 778–783.
46. Ouali N., Belabed B.E., Zeghdoudi F., Rachedi M. 2018. Assessment of metallic contamination in sediment and mullet fish (Mugil cephalus Linnaeus, 1758) tissues from the East Algerian coast. J. Water Land Dev., 38(3), 115–126.
47. Peng W., Li X., Xiao S., Fan W. 2018. Review of remediation technologies for sediments contaminated by heavy metals. J. Soils Sediments, 18(4), 1701–1719.
48. Ridgway J., Shimmield G. 2002. Estuaries as repositories of historical contamination and their impact on shelf seas. Est. Coast. Shelf Sci., 55, 903–928.
49. Rosado D., Usero J., Morillo J. 2016. Assessment of heavy metals bioavailability and toxicity toward *Vibrio fischeri* in sediment of the Huelva estuary. Chemosphere, 153, 10–17.
50. Rumahorbo B.T., Keiluhu H.J., Hamuna B. 2019. The economic valuation of mangrove ecosystem in Youtefa bay, Jayapura, Indonesia. Ecol. Quest., 30(1), 47–54.
51. Rumahorbo B.T., Hamuna B., Keiluhu H.J. 2020. An assessment of the coastal ecosystem services of Jayapura City, Papua Province, Indonesia. Environ. & Socio-econ. Stud., 8(2), 45–53.
52. Saher N.U., Siddiqui A.S. 2016. Comparison of heavy metal contamination during the last decade along the coastal sediment of Pakistan: multiple pollution indices approach. Mar. Pollut. Bull., 105, 403–410.
53. Saher N.U., Siddiqui A.S. 2019. Occurrence of heavy metals in sediment and their bioaccumulation in sentinel crab (Macrophthalmus depressus) from highly impacted coastal zone. Chemosphere, 221, 89–98.
54. Salahuddin, Fandeli C., Sugiharto E. 2012. Kajian pencemaran lingkungan di Tambak Udang Delta Mahakam. Jurnal TEKNOSAINS, 2(1), 32–47. (In Indonesian with English abstract)
55. Salem D.M.S.A., Khaled A., El-Nemr A., El-Sikaily A. 2014. Comprehensive risk assessment of heavy metals in surface sediments along the Egyptian Red Sea coast. Egypt. J. Aquat. Res. 40, 349–362.
56. Sindern S., Tremöhlen M., Dsikowitzky L., Gronen L., Schwarzbauer J., Siregar T.H., Ariyani F., Irianto

H.E. 2016. Heavy metals in river and coast sediments of the Jakarta Bay region (Indonesia): geogenic versus anthropogenic sources. Mar. Pollut. Bull., 110(2), 624–633.

57. Sitorus S., Ilang Y., Nugroho R.A., 2020. Analisis kadar logam Pb, Cd, Cu, As pada air, sedimen dan bivalvia di pesisir Teluk Balikpapan. Dinamika Lingkungan Indonesia, 7(2) 89–94. (In Indonesian with English abstract)
58. Suresh G., Ramasamy V., Meenakshisundaram V., Venkatachalapathy R., Ponnu-samy V. 2011. Influence of mineralogical and heavy metal composition on natural radionuclide contents in the river sediments. Appl. Radiat. Isot. 69, 1466–1474.
59. Suresh G., Sutharsan P., Ramasamy V., Venkatachalapathy R. 2012. Assessment of spatial distribution and potential ecological risk of the heavy metals in relation to granulometric content of Veeranam lake sediments, India. Ecotoxicol. Environ. Saf. 84, 117–124.
60. Suwandana E., Kawamura K., Soeyanto E. 2011. Assessment of the heavy metal and nutrients status in the seawater, sediment and seagrass in Banten Bay, Indonesia and their distributional patterns. J. Fish. Int., 6(1), 18–25.
61. Tanjung R.H.R., Hamuna B., Alianto. 2019a. Assessment of water quality and pollution index in coastal waters of Mimika, Indonesia. J. Ecol. Eng., 20(1), 87–94.
62. Tanjung R.H.R., Hamuna B., Yonas M.N. 2019b. Assessing heavy metal contamination in marine sediments around the coastal waters of Mimika Regency, Indonesia. J. Ecol. Eng., 20(11), 35–42.
63. Tebaiy S., Yulianda F., Fahrudin A., Muchsin I. 2014. Fish community structure at seagrass beds habitat in Youtefa Bay Jayapura Papua. J. Iktiol. Indones. 14(1), 49–65. (In Indonesian with English abstract)
64. Tjahjono A., Bambang A.N., Anggoro S. 2017. Pollution assessment in surface sediments of trace metal in port of Tanjung Emas Semarang. Adv. Sci. Lett., 23, 2215–2219.
65. Tomlinson D.C., Wilson J.G., Harris C.R., Jeffrey D.W. 1980. Problems in assessment of heavy metals in the estuaries and the formation of pollution index. Helgoländer Meeresuntersuchungen, 33(1), 566–575.
66. 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(2), 175–192.
67. Vandecasteele B., Samyn J., Quataert P., Muys B., Tack F.M.G. 2004. Earthworm biomass as additional information for risk assessment of heavy metal biomagnification: a case study for dredged sediment-derived soils and polluted floodplain soils. Environ. Pollut. 129(3), 363–375.
68. Wojciechowska E., Nawrot N., Walkusz-Miotk J., Matej-Łukowicz K., Pazdro K. 2019. Heavy metals in sediments of urban streams: contamination and health risk assessment of influencing factors. Sustainability, 11, 563.
69. Xia F., Qu L., Wang T., Luo L., Chen H., Dahlgren R.A., Zhang M., Mei K., Huang H. 2018. Distribution and source analysis of heavy metal pollutants in sediments of a rapid developing urban river system. Chemosphere, 207, 218–228.
70. Yang J., Zhang B., Peng X., Wang H., Li Z., Cai W., Fang H. 2014. Sediment quality assessment for heavy metal contamination in the Dongzhai Harbor (Hainan Island, China) with pollution indice approach. Open Chem. Eng. J., 8, 32–37.
71. Zhu A., Liu J., Qiao S., Zhang H. 2020. Distribution and assessment of heavy metals in surface sediments from the Bohai Sea of China. Mar. Pollut. Bull. 153, 110901.
72. Zhuang W., Zhou F. 2021. Distribution, source and pollution assessment of heavy metals in the surface sediments of the Yangtze River Estuary and its adjacent East China Sea. Mar. Pollut. Bull. 164, 112002.