



## Study of water and sediment surface quality on defilement of heavy metals Pb & Cd at a downstream section of Musi River, South Sumatera, Indonesia

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### ABSTRACT

This research (1) analyzed the content of Pb and Cd in water and sediment; (2) analyzed physical and chemical parameters in water; (3) determined the enrichment factor and accumulation index of Pb and Cd in sediments; and (4) to identified water quality based on the Pollution Index (IP) and STORET. The analysis was carried out using PCA (Principal Component Analysis) and Pearson's correlation, and was conducted in the downstream section of the Musi River, Palembang, using a random sampling technique. Based on the analysis, it was found that the content of Pb and Cd in the waters had surpassed the quality standard whereas the contents of both heavy metals found in the sediment still met the quality standard. It was also found that several variables of the physical and chemical parameters did not meet the criteria. Based on the Enrichment Factor (EF) and the Accumulation Index ( $I_{geo}$ ) of Pb and Cd, the river had not been defiled. The pollution index values of both IP and STORET indicated that the water had been heavily polluted. Based on the PCA, three factors which affected the quality of the river water were found.

**Keywords:** abiotic, defilement, evaluation, index, mud, quality.

### Estudo analítico da qualidade da água e das superfícies de sedimentos em contaminantes de metal pesado Pb e Cd na seção a jusante do rio Musi, Sumatra do Sul, Indonésia

### RESUMO

A pesquisa teve como objetivos (1) analisar o conteúdo de Pb e Cd na água e no sedimento; (2) analisar os parâmetros físicos e químicos da água; (3) determinar o fator de enriquecimento e o índice de acumulação de Pb e Cd nos sedimentos; e (4) identificar a qualidade da água com base no Índice de Poluição (IP) e STORET. A análise foi realizada por meio de técnicas estatísticas: PCA (Análise de Componentes Principais) e correlação de Pearson. A pesquisa foi conduzida na seção a jusante do rio Musi, Palembang, usando a técnica de amostragem



aleatória. Com base na análise, constatou-se que o teor de Pb e Cd nas águas superou o padrão de qualidade, enquanto o teor de ambos os metais pesados encontrados no sedimento ainda atendia ao padrão de qualidade. Verificou-se também que diversas variáveis dos parâmetros físicos e químicos não atendiam aos critérios. Com base no Fator de Enriquecimento (EF) e no Índice de Acumulação ( $I_{geo}$ ) de Pb e Cd, o rio não havia sido contaminado. Os valores do índice de poluição de IP e STORET indicaram que a água estava altamente poluída. Com base no PCA foram encontrados três fatores que afetam a qualidade da água do rio.

**Palavras-chave:** abiótico, avaliação, contaminação, índice, lama, qualidade.

## 1. INTRODUCTION

Indonesia has many rivers that are scattered in various regions and act as transportation routes and support the economy of the local community. One such river is the Musi River of South Sumatera (Hartanto *et al.*, 2019). One of the drinking water sources is the Ogan River, whose water is still assumed to be safe for drinking purposes (Rosyidah, 2017). The pollution found in the Musi River was caused by two factors: domestic and industrial activities. The domestic activity was said to affect more than the industries. This condition could be seen from the organic decomposition caused by household waste which was dominated by iron ranging from 288 to 453 mg L<sup>-1</sup> (Setianto and Fahritsani, 2019).

Downstream, in Gandus sub-district, it was found that 86% of the environment was in poor conditions where people were not aware that the river's cleanliness impacted on the environment and their own health as they had been using the river as a garbage dump and public toilet (Putri *et al.*, 2019a). People's habits such as using the river as a garbage dump, and unavailability of Wastewater Treatment Plant facilities around Sekanak River, a tributary of the Musi River, also contributed to the decline in Musi River's water quality (Kospa and Rahmadi, 2019).

The average Pb content found in the muscle of Seluang fish (*Rasbora sp.*/such endemic small fish) was 157.5 µg Kg<sup>-1</sup>, while in mullet fish (*Mugil chepalus*) it was 201.5 µg Kg<sup>-1</sup>. Thus, the metal content was still within the safe limits for consumption purposes (Putri *et al.*, 2016). The presence of this heavy metal had affected Selar fish (*Alepes vari*) and Gulamo fish (*Johnius belangerii*) found in the river's estuaries. It was found that the content of Pb was higher in *Gulamo* fish than in *Selar* fish. The heavy metal affected the fish's organs and had surpassed the safe limits for consumption (Agustriani *et al.*, 2019). Surely this will cause concern for the health of the people who consume it.

The presence of Coliform bacteria indicated that pathogens had contaminated the environment. In the downstream section, starting from Ogan River estuary to Kemaro Island (a small island in the middle of the Musi River, with several erected buildings), Coliform bacteria ranged from 5,000-13,000 CFU 100 mL<sup>-1</sup>. It means that the land use would affect the abundance of these bacteria as the domestic waste was disposed into the river (Genisa and Auliandari, 2018).

This study: (1) analyzed the content of Pb and Cd in water and sediment; (2) examined content of Coliform bacteria in water; (3) identified the physical and chemical parameters of water; (4) determined the enrichment factor and accumulation index of Pb and Cd metals in sediments; (5) determined the river's water quality based on Pollution Index (IP) and STORET; and, (6) analyzed the physical and chemical variables of the waters using Pearson correlation and PCA (Principal Component Analysis).

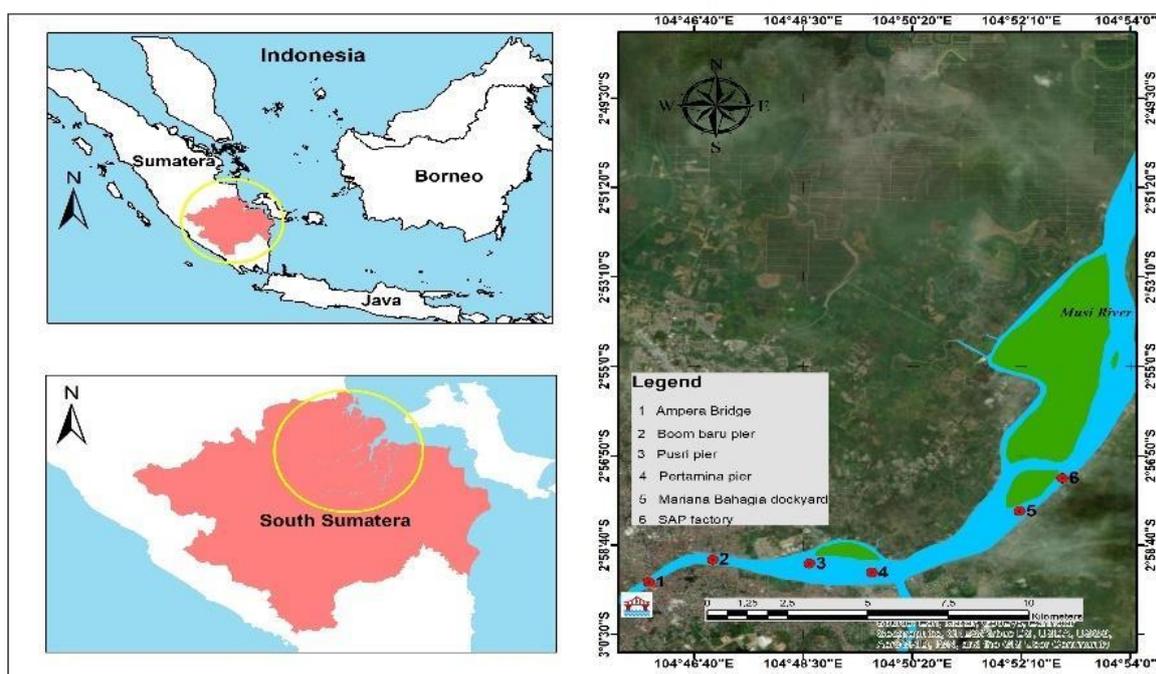
## 2. MATERIAL AND METHODS

### 2.1. Description of the study area

The study was conducted from July to September 2019 during high tide, starting from the

upstream section around Ampera Bridge to the downstream of Musi River, Palembang, South Sumatera Province, Indonesia. The waters were mixed, single dominant tides; there were two high and two low tides within 24 hours. The lowest tide reached 1.2 m and the highest was 3.25m. During the high tide, the flow rate ranged from 0.023 to 0.256 m sec<sup>-1</sup> (Sari *et al.*, 2019).

In this research, random sampling was applied at six observation points: (1) the first point, at Ampera Bridge (02°59'25" S, 104°45'55" E); (2) the second point located at Boom Baru Port (02°58'55" S, 104°46'44" E); the third point, at Pupuk Sriwijaya Company (Pusri), a fertilizer factory (02°59'05" S, 104°47'46" E); (4) the fourth point, in Pertamina's refinery jetty (02°59'21" S, 104°50'03" E); (5) the fifth point, in a the shipyard owned by Mariana Bahagia Company (02°58'02" S, 104°52'12" E); and (6) the sixth point, in the shrimp processing area and PT SAP palm oil mill (02°57'30" S, 104°52'44" E) (Figure 1).



**Figure 1.** Research site.

## 2.2. Research parameters

The samples were then analyzed in terms of temperature, TDS, salinity, TSS, nitrite, nitrate, pH, phosphate, BOD, DO, Pb, Cd, MPN Coliform 100 mL<sup>-1</sup>. The in-situ data included temperature, salinity, and pH whereas the ex-situ data consisted of the primary data obtained from laboratory results including TDS, TSS, nitrite, nitrate, phosphate, BOD, DO, Pb, Cd and MPN Coliform 100 mL<sup>-1</sup>. In-situ measurements were also conducted in order to analyze the level of turbidity, flow rate, and river depth. Moreover, samples of sediment were also obtained to analyze the content of Pb and Cd metal.

## 2.3. Data analysis

### 2.3.1. Stipulation of heavy metals (Pb, Cd) in water

In this research, 18 samples were obtained. Each sample was put into a 100 mL erlenmeyer flask. Five mL of concentrated HNO<sub>3</sub> was then added. Next, it was covered with a watch glass and heated at 105-120°C so that the rest volume became 15-20 mL. After the test sample became clear, it was put into a 50 ml volumetric flask and filtered on 42 µm Whatman paper. Some free-mineral water was then added and tested using AAS (Atomic Absorption Spectrophotometer) (Ginting *et al.*, 2019; SNI, 2009a; 2009b).

### 2.3.2. Stipulation of heavy metal (Pb, Cd) in sediment

In order to determine the level of Pb and Cd, 18 samples were collected. 50 g of each sample was taken and then dried in an oven at 150°C for 24 hours. 5 g of sample was added with 10 ml of HNO<sub>3</sub>. The sample was then heated using a water bath at 150°C for 30 minutes, filtered on 0.45 µm Whatman paper, stored in a sample bottle that had been filled with 15 mL of distilled water. The content of Pb and Cd in sediment was analyzed using AAS.

#### 2.3.2.1. Stipulation of the content of Coliform bacteria in river water

In this research, 18 samples were taken from the river. The water sample was put into sterilized bottles and given a flame at the bottle mouth. The bottles were then closed and put into an icebox. Next, the sample bottles were taken to the laboratory. There were four stages in examining Coliform bacteria (Adrianto, 2018; SNI, 1996).

#### 2.3.2.2. Preliminary Test

In order to perform the preliminary test, 9 mL of LB (Lactose Broth) was put into test tubes with a Durham tube inside. The tubes were then autoclaved at 121°C for 15 minutes. The sample was diluted by adding 9 mL of sterile distilled water as a 10-1 dilution occurred. The dilution was obtained from 0.1 mL, 0.01 mL, 0.001 mL and was then put into three tubes of LB. The tubes were stored in an incubator at 37°C for 24-48 hours. Coliform bacteria were identified by the presence of gas, acid, or discoloration.

#### 2.3.2.3. Confirmation Test

The 1-2 positive suspensions were inoculated into tubes containing BGLBB (Brilliant Green Lactose Bile Broth). The tubes were incubated at 37°C in 24-48 hours. If some gas, acid, or color changes form, it showed that Coliform bacteria existed. Last, MPN was performed.

#### 2.3.2.4. Complementary Test

The media which were positive in the confirmation test were then inoculated. One inoculation loop of the sample was added into Eosin Methylene Blue (EMB) agar and then incubated at 37°C. If a metallic, blackish green colony grew after 3-4 days of incubation, a biochemical test and gram stain were then performed.

### 2.3.3. Stipulation of Water Quality using Pollution Index Method

In this research, the pollution Index method was used to stipulate the relative rating of pollution toward the water quality parameters, using the following formula Equation 1 (Indonesia, 2003; Nemerow and Sumitomo, 1970):

$$PI_j = \sqrt{\frac{\left(\frac{C_i}{L_{ij}}\right)_M^2 + \left(\frac{C_i}{L_{ij}}\right)_A^2}{2}} \quad (1)$$

Where  $PI_j$  = pollution index of j,  $C_i$  = water quality contents i,  $L_{ij}$  = quality parameters listed in criteria of water j, M = maximum, A = average. It finds four stipulations of the pollution: (a)  $0 \leq IP \leq 1.0$  means meets the threshold, (b)  $1.0 \leq IP \leq 5.0$  means slight polluted, (c)  $5.0 \leq IP \leq 10$  means medium polluted, and (d)  $IP \geq 10$  means heavy polluted.

### 2.3.4. Stipulation of water quality using STORET

STORET method utilized parameters that met or surpassed the quality standard. Stipulation of water quality status consisted of 4 grades: (a) Grade A, score 0, is considered as very good that it meets the criterion; (b) Grade B, a score between -1 and -10, is considered as mildly polluted; (c) Grade C, score between -11 and -30, is gratified as moderately polluted;

and (d) Grade D, score  $\geq -31$ , is considered as heavily polluted (US EPA, 1989; Arnop *et al.*, 2019).

### 2.3.5. Stipulation of heavy metals for water

In this study, the stipulation of heavy metal quality was based on four standards. The first was the criterion of seawater standards for marine biota (Indonesia, 2004). The second was on water quality management and water pollution control (Indonesia, 2001). Third, from Australia and New Zealand was used (ANZECC, 2013). Lastly, this study also applied provision from Canada (CCME, 1999).

### 2.3.6. Stipulation of Coliform Bacteria Density

The coliform bacterial density was calculated using the formula as follows Equation 2 (Adrianto, 2018; SNI, 1996):

$$\text{Total bacterial number} \left( \frac{\text{MPN}}{100 \text{ ml}} \right) = \frac{A \times 100}{\sqrt{B \times C}} \quad (2)$$

Where A = number of positive tubes, B = volume of test objects in negative tubes (mL), C = volume of test objects in all tubes (mL).

### 2.3.7. The enrichment level of Pb and Cd metals in sediment

The enrichment factor was employed to determine the grade of heavy metal foulness of Pb and Cd in sediment. The level of enrichment (EF = Enrichment Factor) was calculated using the following formula Equation 3 (Sakan *et al.*, 2009):

$$EF = \frac{[\text{Heavy metal of Pb/Cd}]}{[\frac{\text{Pb}}{\text{Cd}} \text{ standards}]} \quad (3)$$

Where EF = Enrichment Factor, standard of Pb = 12.5 mg Kg<sup>-1</sup>, standard of Cd = 0.2 mg Kg<sup>-1</sup>. EF value < 1 means that it is not contaminated, EF value 1-3 means that the defilement is low, value 3-5 means that the defilement is moderate, 5-10 means severe defilement, and 25-50 means that severe enrichment occurs.

### 2.3.8. Accumulation Index

The accumulation index was aimed to determine the value of the presence and intensity of anthropogenic metal contaminants in sediments. The formula used is as follows Equation 4 (Barbieri, 2016):

$$I_{geo} = \log_2 \frac{[\text{heavy metal}]}{1.5 \times [\text{background}]} \quad (4)$$

Where I<sub>geo</sub> = geoaccumulation index, log<sub>2</sub> = 0.301, 1.5 = constant value, background = metal standard value. The accumulation index is divided into seven grades: (1) I<sub>geo</sub> < 0 meaning there is no defilement, (2) 0 ≤ I<sub>geo</sub> ≤ 1 meaning there is no defilement/low defilement, (3) 1 ≤ I<sub>geo</sub> ≤ 2 meaning that moderate defilement occurs, (4) 2 ≤ I<sub>geo</sub> ≤ 3 meaning that there is moderate/heavy defilement, (5) 3 ≤ I<sub>geo</sub> ≤ 4 meaning that it was heavily contaminated, (6) 4 ≤ I<sub>geo</sub> ≤ 5 meaning that there is heavy/extraordinary defilement, and (6) I<sub>geo</sub> ≥ 5 indicating highly contaminated sediment (Forstner and Muller, 1981).

### 2.3.9. Pearson Correlation

This analysis is used to measure the strength of the relationship between two variables and the direction of a linear relationship between the two. The data involved ratio data and contain real numbers. The r value is used to identify the relationship (Priyatno, 2016; Sujarweni, 2014).

In this research, IBM SPSS version 25 was applied.

### 2.3.10. PCA

This analysis is a statistical technique to convert most of the original variables which are correlated with each other into a new, smaller, and independent variable. The principal component analysis is used to eliminate the original variable which has a small contribution of information (Van Delsen *et al.*, 2017; Priyatno, 2010).

## 3. RESULTS AND DISCUSSION

During the research, the water temperature was not in optimal conditions for biota, ranging from 32 to 38.67°C; the optimal temperature was 28-32°C (Miranda *et al.*, 2018). Other physical parameters, TDS values ranged from 38.9-41.57 mg L<sup>-1</sup> which means that it still met the water criterion of Grade II and III, below 1000 mg L<sup>-1</sup>. Meanwhile, TSS value was also still below the quality standard, below 50 and 400 mg L<sup>-1</sup>. The chemical parameters of this research included nitrite, nitrate, pH, phosphate, BOD and DO content.

Based on the analysis, nitrite content had surpassed the quality standard reaching 0.06 mg L<sup>-1</sup>. Whereas, the average content of nitrate had surpassed the standard threshold at 10 mg L<sup>-1</sup>. The average level of Phosphate content was below the quality standard (0.2 mg L<sup>-1</sup>). However, BOD and DO content had surpassed the quality standard, reaching 3 and 4 mg L<sup>-1</sup>. This also happened to Rewalsar Lake, which experienced a decline in BOD values caused by the many spiritual visits to the lake and the disposal of waste (Kumari and Kumar, 2020) (Table 1).

**Table 1.** Physical and chemical quality conditions of the downstream of Musi River waters.

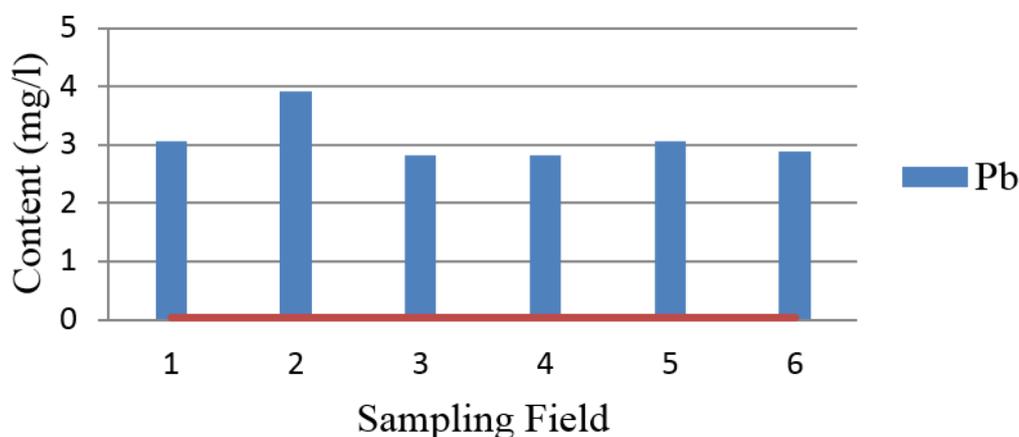
Parameter	Sampling Field						Average
	1	2	3	4	5	6	
Temperature (°C)	32	34	35.27	34.33	38.53	38.67	35.47
TDS (mg L <sup>-1</sup> )	38.5	37.43	37.7	38.9	41.57	41.57	39.28
TSS (mg L <sup>-1</sup> )	0.63	0.27	0.5	0.33	0.3	0.23	0.38
Nitrite (mg L <sup>-1</sup> )	0.16	0.19	0.26	0.11	0.05	0.1	0.15
Nitrate (mg L <sup>-1</sup> )	11.01	4.88	12.5	10.38	10.44	10.8	10
pH	5.12	5.16	5.15	5.22	5.21	5.25	5.19
Phosphate (mg L <sup>-1</sup> )	0.22	0.28	0.15	0.12	0.11	0.1	0.16
BOD (mg L <sup>-1</sup> )	11.67	14.67	11	8.33	10	11	11.11
DO (mg L <sup>-1</sup> )	7.04	7.09	7.01	7.13	7.25	7.25	7.13
Turbidity (NTU)	34.13	24.43	25.77	59.07	24.77	33.6	33.63
Current speed (m sec <sup>-1</sup> )	0.2	0.16	0.17	0.11	0.41	0.28	0.22
Depth (m)	0.14	10.8	0.2	1.1	7.7	6.9	4.47

The turbidity ranged from 24.43 to 59.07 NTU and was identified as high. The high turbidity was due to the presence of mud downstream, which caused suspension and dissolution

(Weliyadi *et al.*, 2020). The water quality was determined by BOD content, which was the key parameter in water quality monitoring. The high content of BOD in the waters was caused by the discharge of inorganic materials (Wanna *et al.*, 2017). The high BOD value was also founding the coastal waters of Bedukang, Bangka Regency, which showed a high content of organic waste (Rema *et al.*, 2019). The high BOD content was also found in the Code River in Yogyakarta. This river water was classified as polluted and the cause was domestic and livestock waste. As a result, a high total Coliform content was found (Hadi *et al.*, 2018). The DO parameter in this water was low. Pollution is considered low if DO content is  $> 5$  ppm (Wulandari *et al.*, 2020). Nitrate is a compound of protein synthesis in plants and animals. The high content of nitrate in the downstream can cause a rapid growth of algae (blooming) (Hamuna *et al.*, 2018).

The average content of Pb found at the six stations was  $3.0933 \text{ mg L}^{-1}$ , ranging from  $2.82$  to  $3.92 \text{ mg L}^{-1}$ . The highest value was found at Boom Baru Port while the lowest was at Pertamina and Pusri Company's ports. Pb content at all stations had surpassed the quality standard  $0.03 \text{ mg L}^{-1}$ . This indicates that river water could no longer be used as a source for drinking water treatment (threshold  $\leq 0.1 \text{ mg L}^{-1}$ ) (Figure 2). The content of Pb in the water indicated that the presence of oil spills resulted from water activities, so it was considered to be correlated with the decrease of macrozoobenthos abundance (Tanjung *et al.*, 2020).

Based on the seawater criterion for biota, the Pb content of  $0.008 \text{ mg L}^{-1}$  was regarded as unsafe for biota. Pb content found in the Musi River was higher than what was found in Tenggang River, Semarang, which ranged from  $0.0755$  to  $0.1425 \text{ mg L}^{-1}$  (Agustina *et al.*, 2019). The average Pb content was higher compared to the previous studies, which ranged from  $0.002$ - $0.004 \text{ mg L}^{-1}$  and  $16.977$ - $61.479 \text{ mg Kg}^{-1}$  in dissolved and suspended conditions (Putri and Purwiyanto, 2016). The presence of Pb in water could affect aquatic organisms such as Cendro fish in the coastal waters of Krueing Raya Aceh Besar (Fadillah *et al.*, 2017).

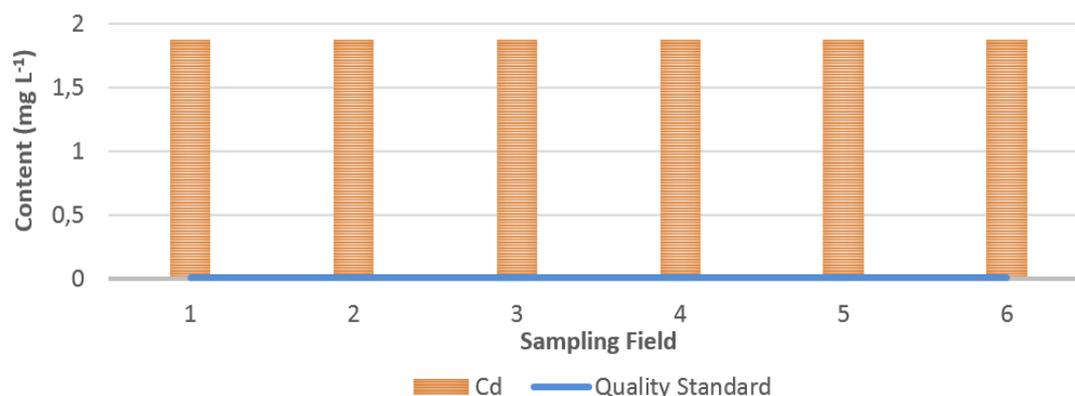


**Figure 2.** The average content of Pb in water.

Based on the analysis, it was found that average Cadmium content in all stations was constant at  $1.88 \text{ mg L}^{-1}$ , which surpassed the quality standard ( $0.01 \text{ mg L}^{-1}$ ) (Figure 3). The presence of this metal indicates the excessive use of fertilizers around the river flow (Rocha *et al.*, 2019). Pearson correlation analysis showed a strong positive significant relationship between temperature and TDS ( $r = 0.732$ ;  $p < 0.01$ ). A similar relationship between TDS and current strength ( $r = 0.654$ ;  $p < 0.01$ ) was also found. However, the relationship between BOD and Pb in the water was categorized as medium ( $r = 0.553$ ,  $p < 0.01$ ).

These findings showed a linear relationship in which temperature would affect TDS; TDS was influenced by water current meaning that the greater the water current was, the higher TDS would be; the dissolved oxygen content would affect Pb in water. In other words, there was a unidirectional relationship in which the increase of the biological oxygen demand would affect

the content of Pb in water. Any strong relationship between Pb metal and other metals, such as the study in Lake Renuka, namely between Pb-Ni which shows a relationship between sediment enrichment and metal leaching into the lake (Kumar *et al.*, 2019a).



**Figure 3.** The average Cd content in water.

There was a moderately negative correlation between temperature and nitrite ( $r = -0.476$ ;  $p < 0.05$ ), TDS and nitrite ( $r = -0.504$ ;  $p < 0.05$ ), nitrate and nitrite ( $r = -0.523$ ;  $p < 0.05$ ), temperature and water current ( $r = -0.584$ ;  $p < 0.05$ ), phosphate and DO ( $r = -0.567$ ;  $p < 0.05$ ), and BOD and Pb in water ( $r = -0.504$ ;  $p < 0.01$ ). However, a strong negative significant relationship between pH and Pb in water ( $r = -0.647$ ;  $p < 0.01$ ) was also found. The negative relationship, both medium and strong, showed a non-unidirectional relationship. For example, the larger the pH as the dependent variable was, the smaller content of Pb in water as the independent variable would be (Table 2). Research on sediment conducted in the Danjiang River, China showed a moderately significant relationship between Pb-Mn and Pb-Ni ( $p < 0.05$ ) indicating the same source or environmental character (Zhuang *et al.*, 2021). On the other hand, enzymes (alkaline phosphate and urease) – contributed from plant fertilizers – had a significant negative relationship with Pb and Cd ( $r = -0.60$  and  $r = -0.49$ ) in winter in Suez Bay (El-Sikaily *et al.*, 2021).

In this research, there were four water grades which had been determined: Grade I (raw drinking water); Grade II (water recreation infrastructure/facilities, freshwater fish farming, animal husbandry, water for cropping); Grade III (freshwater fish cultivation, animal husbandry, water for agriculture); and Grade IV (agricultural flow) (Indonesia, 2001). Based on the analysis, in Grade I, four parameters did not meet the requirements: pH, BOD, Cd, and Pb. In Grade II and Grade III; five parameters did not meet the requirements: pH, BOD, nitrite, Cd, and Pb. In Grade IV, there were only three parameters that did not meet the requirements: nitrite, Cd, and Pb. Thus, based on the water grade criteria, the water downstream in the Musi River was only suitable for agriculture purposes. Nitrate conditions that have surpassed the standard have made the water in Rewalsar Lake unusable for drinking, which is indicated by the water quality index value which has reached 346.53 in all seasons (Gaury *et al.*, 2018).

The content of Pb in the sediment ranged between 2.48 and 5.28 mg Kg<sup>-1</sup>, whose average reached 4.49 mg Kg<sup>-1</sup>. The highest content was found at Boom Baru Port while the lowest was found at Ampera Bridge. On the other hand, Cd content in the sediment was between 0.18 and 0.41 mg Kg<sup>-1</sup> with an average of 0.31 mg Kg<sup>-1</sup>. The highest finding was found at Boom Baru Port while the lowest was in the Pusri fertilizer factory (Figure 4). The Pb content had increased, between 3.89 and 10.14 mg Kg<sup>-1</sup>, which was found at the Upang Estuary (Sari *et al.*, 2019). The conditions of heavy metals of both Pb and Cd in sediments were in contrast to the condition found at the estuary of Cisadane River in Banten which showed low contents of both (Pb 16.75 mg Kg<sup>-1</sup>, Cd < 0.002 mg Kg<sup>-1</sup>) (Nadia *et al.*, 2017).

**Table 2.** Pearson Correlation between physicochemical parameters.

	T	TDS	TSS	Nitrate	Nitrite	pH	P	BOD	DO	Pb in w	Turb	Pb in s	Cd in s	Current	Depth
T	1														
TDS	<b>0.732*</b>	1													
TSS	-0.334	-0.154	1												
Nitrate	0.16	0.031	-0.132	1											
Nitrite	<b>-0.476*</b>	<b>-0.504*</b>	0.353	<b>-0.524*</b>	1										
pH	0.105	0.07	0.107	-0.329	0.07	1									
P	-0.307	-0.294	0.38	-0.005	0.171	0.058	1								
BOD	0.024	-0.019	-0.033	-0.233	0.033	-0.344	0.105	1							
DO	0.228	0.167	<b>-0.783**</b>	0.262	-0.418	-0.444	<b>-0.567*</b>	0.047	1						
Pb in w	-0.039	-0.115	-0.077	-0.385	-0.05	0.252	0.235	<b>0.553*</b>	-0.23	1					
Turb	-0.233	0.024	0.281	-0.343	0.111	0.23	-0.001	-0.36	-0.182	-0.129	1				
Pb in s	0.133	0.208	-0.223	0.071	-0.065	<b>-0.647**</b>	-0.283	0.131	0.302	-0.185	-0.071	1			
Cd in s	-0.438	0.203	-0.198	-0.155	0.03	-0.332	0.239	-0.036	0.258	-0.002	0.016	0.135	1		
Current	<b>-0.584*</b>	<b>0.654**</b>	-0.088	0.002	-0.397	0.192	-0.231	-0.175	0.209	-0.037	-0.172	-0.112	-0.1	1	
Depth	0.409	0.262	-0.448	-0.341	-0.228	0.093	0.114	0.225	0.222	0.393	-0.261	0.212	0.244	0.359	1

T: Temperature, TDS: Total Dissolved Solids, TSS: Total Suspended Solid, P: Phosphate, BOD: Biological Oxygen Demand, DO: Dissolved Oxygen, Pb in w: Pb in water, Turb: Turbidity, Pb in s: Pb in sediment, Cd in s: Cd in sediment.

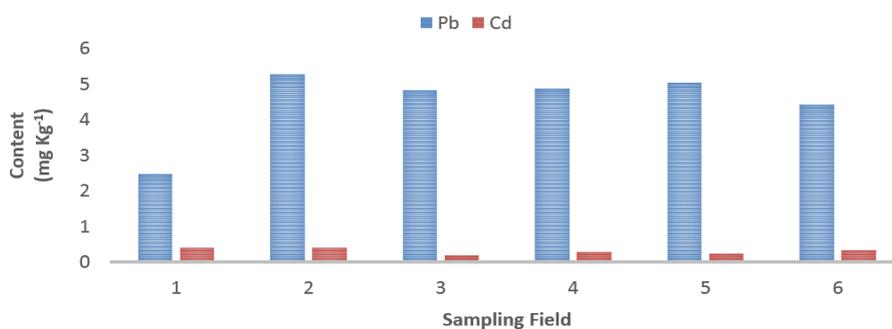
Bold values indicate significant correlations.

\*\*Correlation is significant at the 0.01 level (2-tailed)

\*Correlation is significant at the 0.05 level (2-tailed)

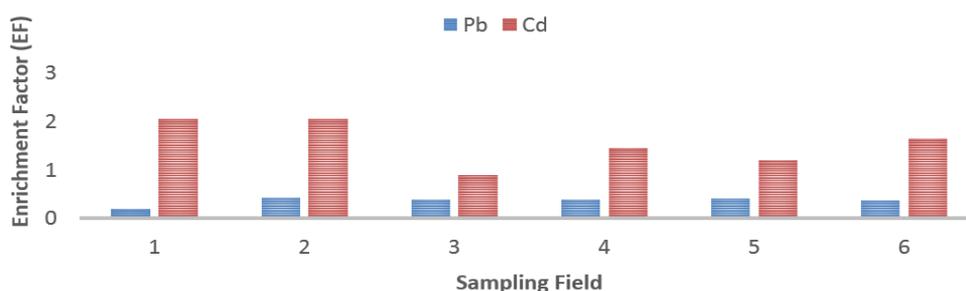
The content of Pb in sediment was greater than its content in water, from 3.0933 to 4.49 mg L<sup>-1</sup>. This finding showed that there had been an enrichment of the metals from water to sediment. The Pb content in sediment was lower than what had been found in the research conducted in Sangihe Islands whose average reached 61.47 mg L<sup>-1</sup>, indicating that this coastal area was heavily polluted even when the heavy metal content in sediment met the quality standard (Mustafa *et al.*, 2021).

It was also found that the criterion of Pb in sediment were 50 and 30.2 mg Kg<sup>-1</sup>. Thus, the content of Pb in sediment was still below the threshold, meaning that it was still safe for biota (ANZECC, 2013; CCME, 1999). The content of Pb was lower than the content found in research conducted at Pakil Bangka River (12.26 mg Kg<sup>-1</sup>). However, the content of Cd was higher (0.53 mg Kg<sup>-1</sup>) (Miranda *et al.*, 2018). The average content of Pb in the estuary water (0.0104 mg L<sup>-1</sup>), the Sungsang waters, had decreased since the waters had been diluting due to the water currents and tides. On the other hand, the average content of Pb in sediment had increased to 24.89 mg Kg<sup>-1</sup> due to the accumulation of sediment carried from upstream (Putri *et al.*, 2019b).



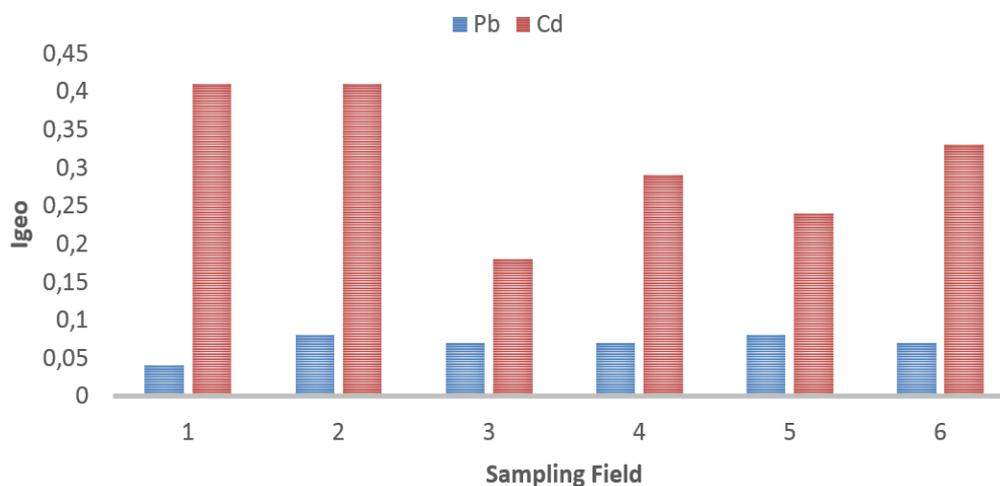
**Figure 4.** Pb and Cd content in sediment.

The enrichment factor for Pb in sediments ranged from 0.2-0.4 and the average reached 0.36. The highest enrichment factor was found in the Pertamina jetty while the lowest finding was at Ampera Bridge. This means that the vessel's activities at Pertamina jetty had caused a high solubility in sediment. The enrichment factors of Pb at all stations did not indicate any defilement. The enrichment factors of Cd ranged from 0.9 to 2.05 with an average of 1.55; the highest value was found at Ampera Bridge and Boom Baru Port, while the smallest was at the Pusri fertilizer factory. Compared to the fertilizer factory whose access was limited only to certain vessels, domestic discharge activities around the KM 16 market and jetty had affected the sediment. The analysis also found that the enrichment factors of Cd in the fertilizer factory area were regarded as not contaminated while the findings at other stations were regarded as lowly contaminated. The average value of Cd enrichment factors was found to be higher than Pb's. This indicates that oil waste from both domestic and aquatic activities was dominant (Figure 5). This enrichment of Pb and Cd would be greater in coastal waters than it was in rivers as found in the research conducted in Bohai and Yellow Seas (Tian *et al.*, 2020).



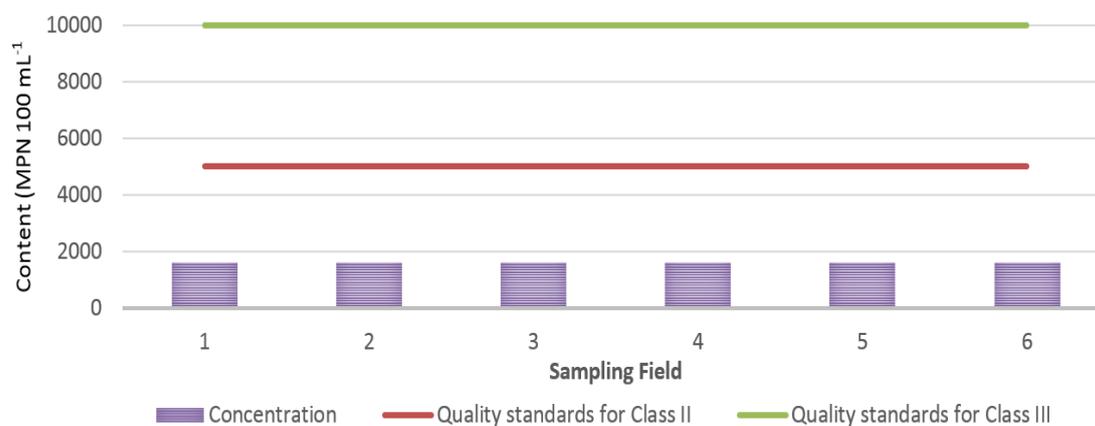
**Figure 5.** Enrichment Factors (EF) of Pb and Cd in sediment.

The accumulation index ( $I_{geo}$ ) for Pb in sediment ranged from 0.04 to 0.08, with an average value of 0.07. The highest value was found at Boom Baru Port. The values at all stations indicated a low defilement. The Cd accumulation index ranged from 0.18 to 0.41 and the average value reached 0.31. The highest value was found at Ampera Bridge and Boom Baru Port.  $I_{geo}$  for Cd at all stations also indicated a low defilement (Figure 6).



**Figure 6.**  $I_{geo}$  for Pb and Cd in sediment.

The content of total Coliform at all stations was 1,600 MPN 100 mL<sup>-1</sup>. It was still below the water quality standard for Grade II and Grade III, which were 5,000 and 10,000 MPN 100 mL<sup>-1</sup>. However, the total Coliform content should be 0 MPN 100 mL<sup>-1</sup>, so the river water was not suitable for drinking purposes (Regulation of the Minister of Health Decree No. 492/MENKES/PER/IV/2010) (Indonesia, 2010) (Figure 7).



**Figure 7.** The Total Coliform content.

The pollution index value according to STORET used Grade II and Grade III of water criterion, whose parameters included TDS, TSS, nitrate, nitrite, pH, Phosphate, BOD, DO, Pb, Cd and Total Coliform, each of which is 1000 mg L<sup>-1</sup>, 50-400 mg L<sup>-1</sup>, 10-20 mg L<sup>-1</sup>, 0.06 mg/liter, 6-9, 0.2-1 mg L<sup>-1</sup>, 3-6 mg L<sup>-1</sup>, 4-3 mg L<sup>-1</sup>, 0.03 mg L<sup>-1</sup>, 0.01 mg L<sup>-1</sup> and 5000-10000 MPN 100 mL<sup>-1</sup>. The highest pollution index was found at Pusri company, the fertilizer factory. The pollution index at all stations was regarded as heavily polluted, exceeding the -31 value (Table 3).

Since the average value reached -126.67, the downstream water of the Musi River could not be used for drinking purposes. A similar condition also occurred in the river of Tanah Abang Dam in East Kutai Regency, East Kalimantan, whose primary, secondary, and tertiary water

were categorized as Grade III and Grade IV due to the high sedimentation rate which was caused by the cultivation of agricultural land (Amprin *et al.*, 2020). Another similar condition was also found in the coastal area of Dumai City, whose water was heavily polluted (STORET value -43.5) (Arifin *et al.*, 2019).

The pollution index at all stations indicated heavy pollution, which surpassed 10. The highest value was found at Boom Baru Port, which was highly influenced by transportation activity. Some factors which influenced defilement included the parameters of BOD, DO, Pb, Cd, and nitrite. The average contents of Pb and Cd in the river reached 3.92 and 1.88 mg L<sup>-1</sup>, indicating that fuel spills caused pollution (Table 4). Activities in urban areas have a direct influence on the quality of river water in the area it passes through (Vargas *et al.*, 2018).

**Table 3.** The parameters values of STORET’s Pollution Index at the stations.

Parameter/Station	1	2	3	4	5	6
TDS	0	0	0	0	0	0
TSS	0	0	0	0	0	0
Nitrate	-16	-4	-16	-4	-8	-16
Nitrite	-20	-20	-20	-16	-4	-16
pH	0	-8	-20	-20	-20	-20
Phosphate	-16	-16	0	0	0	0
BOD	-20	-20	-20	-20	-20	-20
DO	-20	-20	-20	-20	-20	-20
Pb	-20	-20	-20	-20	-20	-20
Cd	-20	-20	-20	-20	-20	-20
Total Coliform	0	0	0	0	0	0
Total Score	-132	-128	-136	-120	-112	-132

**Table 4.** Pollution Index test results.

No.	Parameter	C <sub>imax</sub>						L <sub>ij</sub>	PI <sub>j</sub>						
		1	2	3	4	5	6		1	2	3	4	5	6	
1	TDS	39.9	37.7	38	39	44.4	41.9	1000							
2	TSS	1.2	0.4	0.7	0.6	0.4	0.3	50							
3	Nitrate	13.3	12.29	19.5	16.8	12.1	12	10							
4	Nitrite	5.12	5.36	5.29	5.36	5.39	5.36	9							
5	pH	0.44	0.53	0.19	0.16	0.17	0.13	0.2							
6	Phosphate	14	21	13	17	13	13	3	28.03	33.5	27	26.7	27.4	27	
7	BOD	7.54	7.18	7.09	7.25	7.41	7.43	4							
8	DO	3.37	5.8	2.82	2.82	3.2	3	0.03							
9	Pb	1.88	1.88	1.88	1.88	1.88	1.88	0.01							
10	Cd	0.2	0.25	0.46	0.21	0.07	0.18	0.06							
11	MPN Coliform	1600	1600	1600	1600	1600	1600	5000							

It was also found that the average pollution index downstream of Musi River reached 28.27 and was classified as heavily polluted. This pollution was caused by massive activities including transportation, shipbuilding, palm oil mills, transportation, and domestic waste. The high pollution is also due to the fact that the research samples were taken at the area near the port

and coal mines (Patty *et al.*, 2019; Rois and Andrizal, 2018). The contribution of domestic waste produced from organic and iron substances had also caused the pollution index value in the water of Mahap River in South Kalimantan; it was moderately polluted (average IP 9.5) (Christiana *et al.*, 2020).

Research on pollution index conducted at seven sampling points in Batang Merangin River, Jambi, showed that the river was lightly polluted (average IP 1.67) and only one sampling point in Ujung Tanjung was categorized as heavily polluted (Sisca and Marlina, 2019). A similar condition also occurred in the Kampwoker River, an inlet of Lake Sentani, Jayapura. In this river, nine parameters did not meet the requirements that the water was categorized as moderately polluted (IP 6.470 to 7.534) (Walukow *et al.*, 2021). Research conducted at Kalimireng river in Gresik Regency found that the water was lightly polluted (average IP 2.75). The pollution was caused by waste produced from the fish meal (Khoiri *et al.*, 2020). Illegal domestic waste disposal also played a role in causing the Crown Golf Ornamental Lake in North Jakarta to be categorized as lightly to moderately polluted (Widigdo *et al.*, 2020).

In this study, 17 variables were analyzed using PCA. However, 8 variables were excluded since they did not meet the requirements; the MSA (Measure of Sampling Adequacy) value did not meet the criteria ( $< 0.5$ ). KMO and Bartlett's Test value using 9 variables (temperature, TDS, TSS, nitrite, pH, Pb in water, Cd in sediment, current, and depth) reached 0.579 which was  $> 0.5$  meaning that the sampling was adequate. Total Variance explains three out of nine variables tested, with eigenvalues of  $> 1$  reaching 3.114; 1.683; and 1.420. These three factors affected the water quality at 69.08%, while the remaining 30.92% was caused by other factors. Based on the scree plot, it was shown that there were three factors whose eigenvalues were more than one whereas the other six factors were less than one [Figure 8(A)].

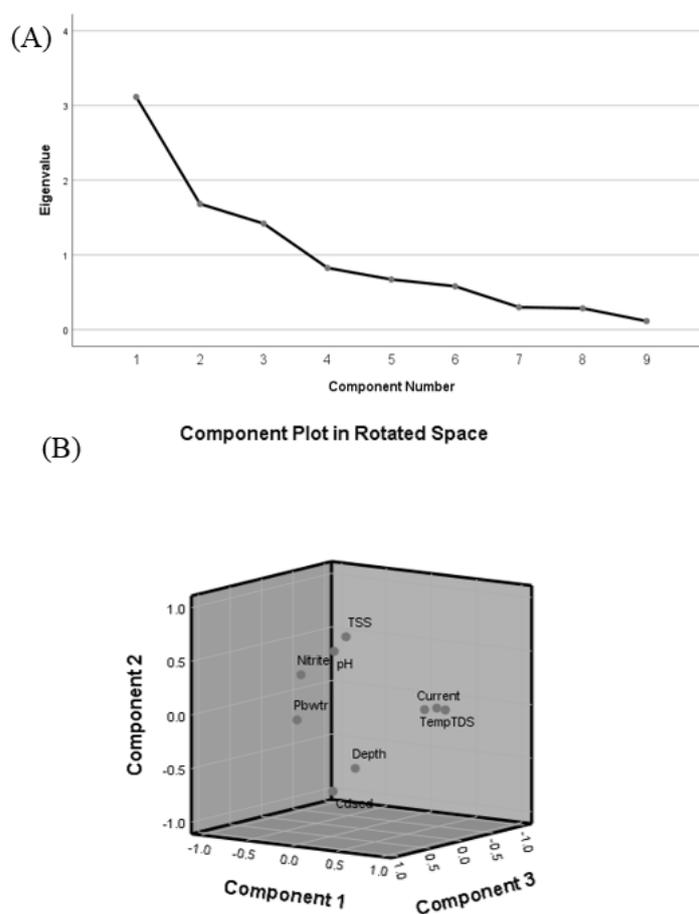


Figure 8. Scree plot (A) and PCA plot (B).

The first factor with 34.60% of the total variance consisted of temperature (0.896), TDS (0.878) and current (0.771) caused by natural factors and anthropogenic activities. The second factor with 18.70% of the total variance involved TSS (0.607), pH (0.630), nitrite (0.256) and Cd in the sediment (-0.785) its called the chemical factor. Last, the third factor with 15.78% of the total variance consisted of Pb in water (0.849) and depth (0.67) caused by community activities. It was also found that within the first factor, temperature, TDS, and current had a strong relationship. In the second factor, TSS and nitrite had a strong relationship, whereas nitrite had a weak relationship. Besides, Cd in sediment had a strong negative relationship; the smaller the Cd in the sediment was, the better the water quality would be. In the third factor, Pb had a very strong correlation while depth had a strong relationship [Figure 8(B)]. Factors affecting water quality can also be caused by the use of chemical fertilizers, causing nutrient enrichment such as in Rewalsar Lake (Kumar and Mahajan, 2020).

In the first factor, temperature and water currents had a strong relationship; the water flow rate would affect the water temperature and the water current would affect the transport of organic matter (Sari and Aprida, 2018). The first factor (26.4% variance), such as TDS, also occurs in Lake Renuka, which is more caused by weathering of rocks than the impact of activities by living organisms (Kumar *et al.*, 2019b). The third factor, heavy metals and depth, had a strong relationship with what research conducted in Parepare Bay had found. This research found that the coastal area was heavily polluted while the outside waters of the bay were moderately polluted (Handiani and Heriati, 2020).

Research on Moro's waters, Karimun, Riau Islands, also found that there were three components that determined the water quality whose influence reached 95.4%; the temperature parameter was the strongest followed by DO and pH (Wiyoto and Effendi, 2020). On the other hand, research conducted in Pazarsuyu River, Turkey, found six factors that affected the water quality: temperature was the second factor, whose contribution reached 14.78% of the total variance, while agricultural drainage factor gave moderate influence (Ustaoglu and Tepe, 2019).

#### 4. CONCLUSIONS

The content of Pb and Cd in waters (3.09 and 1.88 mg L<sup>-1</sup>) had surpassed the quality standard. However, the content of Pb and Cd in sediment still met the quality standard. There were several variables of physicochemical parameters which did not meet the requirements: nitrate, nitrite, phosphate, BOD, and DO. The enrichment factor (EF) and the accumulation index ( $I_{geo}$ ) of Pb and Cd, reaching 0.36 and 0.07, indicating that the downstream waters had not been contaminated. The pollution index value of both IP and STORET showed that it had been heavily polluted. The downstream waters were considered unsuitable for drinking purposes and the river water was classified as Grade IV, which could only be used for agricultural irrigation purposes. The analysis of PCA found that three factors affected the quality of river water whose influence reached 69.08%. The first factor was temperature, whereas TDS and water currents contributed as high as 34.60%. The regional governments and port authorities, both commercial and river port authorities, need to supervise transportation and industrial activities on the river. There is a need for the cooperation of all parties to prevent the pollution that has occurred.

#### 5. ACKNOWLEDGEMENTS

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