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Evaluation of Heavy Metal Levels in Seawater of Jakarta Bay, Indonesia

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Abstract

Jakarta Bay is located in the north of Jakarta City and has the potential to be contaminated with dangerous chemicals. Research on heavy metal levels in this bay was carried out in March and September 2023, March and August 2021. This research aimed to determine heavy metal levels in the waters of Jakarta Bay which are related to marine organisms, recreation, and port interests. area. Water samples were taken using a water sampler at nineteen stations. All samples were analyzed using an Atomic Absorption Spectrophotometer. The results show that the levels of heavy metals Hg, Pb, Cd, Cu, Zn, Cr, As, and Ni are still within tolerance limits based on seawater quality guidelines set by the Indonesian Ministry of Environment.

Keywords: *Jakarta Bay, seawater, heavy metals, evaluation.*

1. Introduction

Jakarta Bay, which is located in the northern part of DKI Jakarta Province, has the potential for aquatic resources and environmental services. Jakarta Bay waters are included in the category of coastal waters. There is also potential for aquatic resources in Jakarta Bay, including mangrove ecosystems, seagrasses, coral reefs, and marine biota. The environmental services include the industrial sector, trade, transportation, tourism, population, and supporting facilities such as ports (Prihatiningsih 2004). Jakarta Bay is also an estuary of 13 rivers that pass through densely populated settlements and industrial areas in the Bogor, Depok, and Jakarta Bay areas which are classified as water areas that receive input from many regions. Several rivers are associated with Jakarta Bay, such as Cengakreng Drain, Angke, Pesanggarah, Grogol, Krukut, Baru Barat, Ciliwung, Kali Baru, Kali Cipinang, Sunter, Buaran, Jati Kramat, Cakung, Banjar Kanal Timur and Cakung Drain.

Currently, the environmental conditions in the waters of Jakarta Bay are increasingly critical as a result of high human activities around Jakarta Bay. Various human activities result in a decrease in water quality due to the increasing input of waste, both household and industrial waste (Prihatiningsih 2004). The entry of waste into Jakarta Bay through rivers or directly discharged into the bay can cause contamination of sea waters and disruption of biota and the ecosystem as a whole (Zainab 2001).

The seawater quality of Jakarta Bay is greatly influenced by the quality of the river water which originates from Tangerang, Bogor, Bekasi, and Purwakarta, including the headwaters of each river. In principle, the rivers within the city of Jakarta are dominated

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for the disposal of liquid, plastic, and other solid waste. However, some can still be used by the community, especially as raw materials for human needs, such as drinking water, agriculture, fisheries, and industry. During the rainy season, when the water discharge increases, the concentration of pollutants decreases due to dilution (dilution). Meanwhile, during the dry season, when the water discharge drops drastically, there is an increase in pollutant concentrations. Based on this, it is necessary to periodically monitor water quality by looking at the seasonal periods (west and east) in sea waters. The results are expected to provide input to interested parties in the management and utilization of the waters of Jakarta Bay.

2. Methods

2.1 Study area

This research was conducted by the Regional Government of DKI Jakarta in Jakarta Bay, Jakarta Bay in the context of monitoring seawater quality. This research was conducted in March and September 2023 and in March and August 2021. These months are considered to represent the western and eastern seasons. Water samples were taken at nineteen research stations (Fig 1). Determination of station positions was carried out by purposive sampling by the research objectives using GPS.

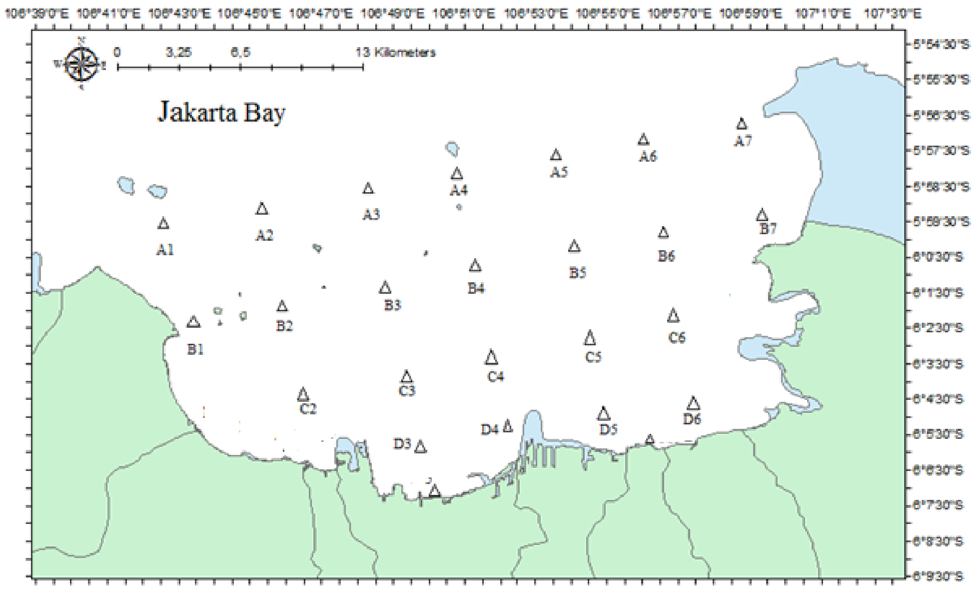

Fig 1. Map of Station Sampling

2.2 Data analysis

Data analysis is secondary data, collected from the final report on the seawater and estuary of Jakarta Bay 2021 and 2023 (Anonymous, 2021, 2023). That data was heavy metals Hg, Pb, Cd, Cu, Zn, As, Cr, and Ni. All parameters were analyzed at the Environmental Productivity Laboratory of the Department of MSP-IPB using an Atomic Absorption Spectrophotometer (AAS). The data were analyzed descriptively by comparing them with the criteria set by the seawater quality standards, and the water quality status was determined using the Stored method (SMERI, 2004).

Determination of the status of water quality is based on an analysis of physical and chemical. Water quality is assessed based on the provisions of the stored system which classifies water quality into four classes, namely: 1) Class A: very good, score = 0 (meets the quality standard), 2) Class B: good, score = -1 to -10 (lightly polluted), 3) Class C:

moderate, score = -11 to -30 (moderately polluted), 4) Class D: bad, score > -31 (heavily polluted) (Table 1). Correlation between parameters is determined by using Pearson Correlation (SPSS 19).

Table 1. Determination of the status of water quality value

Samples	Value	Parameter	
		Physic	Chemistry
<10	Minimum	-1	-2
	Maximum	-1	-2
	Average	-3	-6
>10	Minimum	-2	-4
	Maximum	-2	-4
	Average	-6	-12

3. Result and Discussion

The results of measurements of heavy metals content (Hg, Pb, Cd, Cu, Zn, Ni, As, and Cr) in the seawater of Jakarta Bay are presented in Table 2-10. From the table, it can be seen that in March and September 2023, and in March and August 2021, the content of heavy metals is relatively different, this may maybe caused by the different weather conditions at the time of sampling at each station.

Mercury (Hg)

From Table 2, it can be seen that in March 2023 Hg levels varied from 0.0003 to 0.0012 ppm with an average of 0.0005 ppm, and in September 2023 varied from 0.0001 to 0.0007 ppm with an average of 0.0003 ppm. Hg levels in March were higher than in September. In March 2021, Hg levels varied from 0.0002 to 0.0012 ppm with an average of 0.0006 ppm, and in August 2021, Hg levels varied from 0.0004 to 0.0010 ppm with an average of 0.0006 ppm. There is no difference between Hg levels in March and August. The average Hg level in March and August 2021 was higher compared to March and September 2023. This data shows that seawater in March and August 2021 received the same amount of Hg-containing waste input. This Hg level is still lower than the threshold value set by the seawater quality standard for marine biota, tourism, and ports, which is 0.001 ppm (SMERI, 2004) (Okoro et al., 2013).

Table. 2. Hg levels in seawater of Jakarta Bay, ppm

St	March 2023	Sept 2023	March 2021	August 2021
A1	0.0004	0.0003	0.0010	0.0007
A2	0.0005	0.0004	0.0004	0.0004
A3	0.0006	0.0002	0.0002	0.0006
A4	0.0003	0.0003	0.0005	0.0006
A5	0.0003	0.0002	0.0008	0.0007
A6	0.0007	0.0001	0.0008	0.0005
A7	0.0006	0.0002	0.0005	0.0006
B1	0.0005	0.0001	0.0006	0.0008
B2	0.0006	0.0002	0.0009	0.0008

B3	0.0004	0.0007	0.0007	0.0007
B4	0.0003	0.0006	0.0010	0.0006
B5	0.0006	0.0005	0.0006	0.0005
B6	0.0005	0.0004	0.0007	0.0004
B7	0.0004	0.0007	0.0005	0.0006
C2	0.0004	0.0002	0.0006	0.0005
C3	0.0012	0.0002	0.0012	0.0010
C4	0.0004	0.0003	0.0009	0.0009
C5	0.0007	0.0002	0.0004	0.0005
C6	0.0004	0.0002	0.0009	0.0008
D3	0.0004	0.0005	0.0005	0.0006
D4	0.0005	0.0001	0.0004	0.0005
D5	0.0003	0.0001	0.0008	0.0008
D6	0.0008	0.0003	0.0005	0.0006
Min	0,0003	0.0001	0.0002	0.0004
Max	0.0012	0.0007	0.0012	0.0010
Avg	0.0005	0.0003	0.0006	0.0006
SD	0.0002	0.0001	0.0002	0.0001
Threshold value	0.001			

The Hg levels in Jakarta Bay vary from time to time. Yatim et al., (1979) recorded Hg levels in Jakarta Bay, during 1977-1978 varied from 0.0097-0.020 ppm. Razak et al., (1984) in August 1992 varied from 0.006-0.016 ppm, Hutagalung et al., (1988) in the western of Jakarta Bay Hg levels varied from 0.0003-0.0015 ppm with an average of 0.0007 ppm in July 1988 and 0.0001-0.0010 ppm with an average of 0.0006 ppm in September 1988, in the middle varied from 0.0003-0.0005 ppm with an average of 0.0004 ppm in July, and in September varied from 0.0003-0.0011 ppm with an average of 0.0006 ppm. In the eastern varied from 0.0003-0.0034 ppm with an average of 0.0010 ppm in July, and in September from 0.162-0.0309 ppm with an average of 0.0215 ppm. Nurhidayah et al., (2017) recorded Hg levels in Jakarta Bay after reclamation (July, October 2016, and January 2017) varied from 0,0002-0,0015 ppm. Salman (2017), in August-December 2017 recorded Hg levels were not detected (<0.0002 ppm). This variation can be caused by different station locations and sampling times.

Lead (Pb)

In Table 3, Pb levels in March 2023 varied from 0.006 to 0.008 ppm with an average of 0.0065 ppm, and in September from 0.006 to 0.008 ppm with an average of 0.0066 ppm. In March 2021 varied from BL (below limit detection) to 0.007 ppm with an average of 0.004 ppm, and in August, Pb levels also varied from BL to 0.007 ppm with an average of 0.003 ppm. The average Pb level in March and September 2023 is higher than in March and August 2021. This data shows that the seawater in March and September 2023 receives more input of Pb-containing waste. This Pb level is still lower than the threshold values set by the seawater quality standard for the benefit of marine biota, tourism, and ports (SMERI, 2004) namely 0.008 ppm, 0.05 ppm, and 0.05 ppm, while EU, WHO, and EPA (Okoro et al., 2013) set the threshold value of Pb in seawater to be 0.010 ppm.

Table. 3. Pb level in seawater of Jakarta Bay, ppm

St	March 2023	Sept 2023	March 2021	August 2021
A1	0.006	0.007	BL	0.006
A2	0.007	0.007	0.007	0.006
A3	0.006	0.006	0.004	BL
A4	0.006	<0.006	0.007	0.006
A5	0.008	<0.006	0.006	BL
A6	0.007	0.007	BL	BL
A7	0.006	0.007	0.006	BL
B1	0.006	0.006	BL	BL
B2	0.007	0.006	0.006	BL
B3	0.006	0.006	BL	0.006
B4	0.008	<0.006	BL	BL
B5	0.006	<0.006	0.007	BL
B6	<0.006	0.006	0.006	BL
B7	0.007	0.007	BL	0.007
C2	<0.006	0.008	0.006	BL
C3	0.006	0.007	0.005	0.007
C4	0.007	0.006	0.006	BL
C5	0.006	0.007	BL	BL
C6	0.007	0.007	0.006	0.006
D3	0.006	0.007	0.006	0.006
D4	0.006	0.007	0.007	0.006
D5	0.006	0.007	0.007	0.006
D6	0.007	0.006	0.007	0.007
Min	0,006	0.006	BL	BL
Max	0.008	0.008	0.007	0.007
Avg	0.0065	0.0066	0.004	0.003
SD	0.0006	0.0005	0.003	0.003
Threshold value	0.008 (marine biota), 0.005 (Tourism and Ports)			

BL (below detection limit)

Regarding the Pb level of previous studies, some of the data showed the results of this study also varied from time to time. Hutagalung et al., (1988) recorded Pb level varied from 0.0006-0.0096 ppm with an average of 0.0051 ppm in July 1988 in the western of Jakarta Bay and in September varied from 0.0088-0.0529 ppm with an average of 0.0203 ppm, in the middle varied from 0.0006-0.0096 ppm with an average of 0.0078 ppm in July, and in September varied from 0.0088-0.0529 ppm with an average of 0.0265 ppm. In the eastern varied from 0.0006-0.0278 ppm with an average of 0.0119 ppm in July, and in September from 0.162-0.0309 ppm with an average of 0.0215 ppm. KPPL-DKI (1992) recorded Pb levels in Jakarta Bay during 1983-1984, and 1987-1990 varied from not detected to1.15 ppm, William et al., (2000) in June-December 1996 found Pb level varied from not detected to 0.00362 ppm. Razak et al., (2003) recorded the average Pb level in Jakarta Bay (western, middle, and eastern) in June 2003 was 0.007 ppm, 0.009 ppm, and 0.008 ppm, in September 2003 were 0.003 ppm, 0.005 ppm, and 0.003 ppm. Further Rochyatun et al., (2004) found, the average Pb content in May 2004 in Jakarta Bay (western, middle, eastern) was 0.0016 ppm, 0.031 ppm, and 0.024 ppm, in October 2004 were 0.003 ppm, 0048 ppm, and 0.0045 ppm respectively. Permanawati et al., (2013) recorded, Pb level in October-November 2010 in Jakarta Bay varied from 0,005 - 0,011 ppm, and Salman (2017) in August-December 2017, found Pb level was not detected (<0.00086 ppm), furher Nurhidayah et al., (2017) after reclamation (July, October 2016, and January 2017) found Pb level varied from 0,006-0,036 ppm. Pb levels in the open ocean ranged from 0.002-0.07 ppb (Bazzy, 2014). This variation can be caused by different station locations and sampling times.

Cadmium (Cd)

In Table 4, Cd content in March and September 2023 is not detected at all stations (below the detection limit). This condition was also found in March and August 2021. This data shows that there is no difference in Cd levels in March and August. This data shows that seawater in March and August did not receive Cd-containing waste. This Cd level is still lower than the threshold values set by the seawater quality standard for marine biota, tourism, and ports (SMERI, 2004), namely 0.001 ppm, 0.002 ppm, and 0.01 ppm. EU, EPA, and WHO (Okoro et al., 2013) set threshold values for Cd in seawater, respectively 0.005 ppm, 0.01 ppm, and 0.01 ppm. The Cd level of the results of this study was lower than the results of previous studies. Permanawati et al., (2013) reported, Cd levels in Jakarta Bay in October-November 2010 ranged from 0.005-0.015 ppm. Salman (2017) reported in his research from August-December 2017, that Cd levels in Jakarta Bay were not detected (<0.00011 ppm). William et al., (2000) in June-December 1996 from not detected to $0.057.10^{-3}$ ppm.

Table. 4. Cd level in seawater of Jakarta Bay, ppm

St	March 2023	Sept 2023	March 2021	August 2021
A1	BL	BL	BL	BL
A2	BL	BL	BL	BL
A3	BL	BL	BL	BL
A4	BL	BL	BL	BL
A5	BL	BL	BL	BL
A6	BL	BL	BL	BL
A7	BL	BL	BL	BL
B1	BL	BL	BL	BL
B2	BL	BL	BL	BL
B3	BL	BL	BL	BL
B4	BL	BL	BL	BL
B5	BL	BL	BL	BL
B6	BL	BL	BL	BL
B7	BL	BL	BL	BL
C2	BL	BL	BL	BL

C3	BL	BL	BL	BL
C4	BL	BL	BL	BL
C5	BL	BL	BL	BL
C6	BL	BL	BL	BL
D3	BL	BL	BL	BL
D4	BL	BL	BL	BL
D5	BL	BL	BL	BL
D6	BL	BL	BL	BL
Min	BL	BL	BL	BL
Max	BL	BL	BL	BL
Avg	BL	BL	BL	BL
SD	BL	BL	BL	BL
Threshold value	0.001 (marine biota), 0.002 (Tourism), 0.01 (Ports)			

BL (below detection limit)

Hutagalung et al., (1988) recorded that Cd level in the western of Jakarta Bay varied from 0.0001-0.0006 ppm with an average of 0.0005 ppm in July 1988, and in September from 0.0013-0.0030 ppm with an average of 0.0022 ppm. In the middle in July 1988 varied from 0.0001-0.0006 ppm with an average of 0.0004 ppm, and the eastern from 0.0001-0.0052 ppm with an average of 0.0050 ppm, and in September from 0.0013-0.0022 ppm with an average of 0.0019 ppm. KPPL-DKI (1992) recorded, Cd levels in Jakarta Bay during 1983-1984, and 1987-1990 ranged from no detected to 0.015 ppm Another study, Rochyatun et al., (2003) found average Cd levels in Jakarta Bay (western, middle, and eastern) in August ranged from <0.001-<0.001 ppm (BL). Razak et al., (2003) reported, that average Cd levels in Jakarta Bay (western, middle, and eastern) in June 2003 were <0.001 ppm, <0.001 ppm, and <0.001 ppm, in September 2003 were <0.001 ppm, <0.001 ppm, and <0.001 ppm. Rochyatun et al., (2004) reported, that average Cd levels in May 2004 in Jakarta Bay (western, middle, and eastern) were <0.001 ppm, <0.001 ppm, and 0.001 ppm, in Oktober 2004 were 0.0012 ppm, <0.001 ppm, and 0.001 ppm. Cd levels in the open ocean range from 0.02-0.12 ppb, while in coastal waters it ranges from 0.01-0.17 ppb (Bazzy, 2014).

Copper (Cu)

In Table 5, Cu content in March and September 2023 ranged from 0.005 to 0.010 ppm with an average of 0.0073 ppm, and from 0.005 to 0.008 ppm with an average of 0.0065 ppm. This level is not too different from Cu levels in March and August 2021, in March 2021, Cu levels ranged from 0.005-0.011 ppm with an average of 0.007 ppm, and in August, ranged from 0.006-0.008 ppm with an average of 0.007 ppm, The average Cu level in 2023 and 2021 was not too different, namely 0.007 ppm. This data shows that the waters receive the same quantity of waste input containing Cd. This level of Cu is still lower than the threshold value set by the Seawater Quality Standard for marine biota, tourism, and ports (SMERI, 2004), namely <0.06 ppm, 0.05 ppm, and 0.05 ppm.

Table. 5. Cu level in seawater of Jakarta Bay, ppm

St	March 2023	Sept 2023	March 2021	August 2021
A1	0.007	0.007	0.005	0.006
A2	0.005	0.006	0.008	0.008

A3	0.008	0.007	0.006	0.008
A4	0.007	0.007	0.006	0.007
A5	0.007	0.006	0.007	0.008
A6	0.006	0.008	0.006	0.007
A7	0.007	0.006	0.006	0.008
B1	0.008	0.006	0.007	0.008
B2	0.007	0.007	0.007	0.008
B3	0.007	0.006	0.007	0.008
B4	0.008	0.007	0.011	0.006
B5	0.006	0.007	0.007	0.008
B6	0.007	0.007	0.006	0.007
B7	0.007	0.006	0.006	0.007
C2	0.007	0.007	0.009	0.007
C3	0.007	0.005	0.010	0.007
C4	0.007	0.006	0.009	0.007
C5	0.008	0.007	0.005	0.007
C6	0.010	0.006	0.008	0.006
D3	0.009	0.006	0.008	0.006
D4	0.010	0.007	0.008	0.006
D5	0.008	0.007	0.007	0.006
D6	0.007	0.007	0.007	0.008
Min	0,005	0.005	0.005	0.006
Max	0.010	0.008	0.011	0.008
Avg	0.0073	0.0065	0.007	0.007
SD	0.0011	0.0006	0.001	0.0008
Threshold value	<0.006 (marine biota), 0.05 (Tourism), 0.05 (Ports)			

The Cu levels in this study also varied when compared to the results of previous studies. Some of the data indicated that the Cu levels in this study were lower, but some were higher. Hutagalung et al., (1988) from 0.0016-0.0048 ppm with an average of 0.0021 ppm in July 1988 in the western of Jakarta Bay and September from not detected to 0.0029 ppm with an average of 0.0020 ppm, in the middle part from 0.0016-0.0064 ppm with an average of 0.0022 ppm in July, and in September from not detected to 0.0007 ppm with an average of 0.0001 ppm. In the eastern from 0.0016-0.0080 ppm with an average of 0.0026 ppm in July, and in September from not detected to 0.0007 ppm with an average of 0.0001 ppm. KPPL-DKI (1992) recorded Cu levels in Jakarta Bay during 1983-1984, and 1987-1990 ranged from not detected to 2,2 ppm. William et al., (2000) in June-December 1996 from not detected to 4.04 ppb or not detected to 4.04.10-3 ppm. Razak et al., (2003) recorded Cu levels in Jakarta Bay ranged from <0.001-0.005 ppm with an average of 0.002 ppm. Razak et al., (2003) reported, the average Cu level in Jakarta Bay (western, middle, and eastern) in June 2003 were 0.001 ppm, 0.002 ppm, and 0.001 ppm, in September 2003 were <0.001 ppm, 0.002 ppm, and <0.001 ppm. Rochyatun et al.,

(2004) recorded, average Cu levels in May 2004 in Jakarta Bay (western, middle, and eastern) were 0.001 ppm, 0.001 ppm, and 0.001 ppm, in Oktober 2004 were 0.0036 ppm, 0018 ppm, and 0.001 ppm. Rochyatun et al., (2003) found average Cu levels in Jakarta Bay (western, middle, eastern) in August ranged from <0.001-0.006 ppm. Permanawati et al., (2013) found Cu levels in Jakarta Bay in October-November 2010 ranged from 0,005 – 0,005 ppm. Nurhidayah et al., (2017) found Cu level in Jakarta Bay after reclamation (July, October 2016, and January 2017) varied from 0,003-0,007 ppm. Cu levels in the open ocean range from 0.14-0.90 ppb and in coastal waters range from 0.35-0.40 ppb (Bazzy, 2014)

Zinc (Zn)

In Table 6, Zn content in March and September 2023 ranged from 0.019-0.028 ppm with an average of 0.0024 ppm, and from 0.026-0.040 ppm with an average of 0.0318 ppm. These levels are higher than Zn levels in March and August 2021, in March 2021 Zn levels ranged from 0.012-0.023 ppm with an average of 0.017 ppm, and in August from 0.014-0.023 ppm with an average of 0.017 ppm. The average Zn levels in September 2023 are higher than in March 2023. this data shows that the waters in September received a higher quantity of waste input containing Zn. While in March 2021, the average Zn level was not different from August 2021, this data shows that the waters in March and August received the same quantity of waste input containing Zn. This Zn level is higher than the threshold values set by the Seawater Quality Standard for the benefit of marine biota and tourism (SMERI, 2004), namely 0.008 ppm, and 0.005 ppm, but is lower for ports namely 0.05 ppm.

Table. 6. Zn level in seawater of Jakarta Bay, ppm

St	March 2023	Sept 2023	March 2021	August 2021
A1	0.021	0.037	0.020	0.017
A2	0.026	0.034	0.019	0.019
A3	0.028	0.034	0.019	0.016
A4	0.024	0.032	0.017	0.019
A5	0.026	0.032	0.023	0.018
A6	0.023	0.034	0.020	0.019
A7	0.025	0.037	0.017	0.017
B1	0.024	0.031	0.016	0.016
B2	0.027	0.034	0.019	0.018
B3	0.028	0.026	0.019	0.023
B4	0.025	0.027	0.016	0.017
B5	0.026	0.033	0.016	0.019
B6	0.027	0.040	0.017	0.021
B7	0.025	0.028	0.013	0.015
C2	0.026	0.029	0.012	0.014
C3	0.028	0.035	0.013	0.016
C4	0.023	0.027	0.014	0.019
C5	0.024	0.029	0.016	0.019
C6	0.021	0.028	0.019	0.017

D3	0.019	0.029	0.016	0.019
D4	0.021	0.031	0.019	0.017
D5	0.023	0.034	0.018	0.018
D6	0.025	0.031	0.019	0.017
Min	0,019	0.026	0.012	0.014
Max	0.028	0.040	0.023	0.023
Avg	0.0024	0.0318	0.017	0.017
SD	0.0024	0.0036	0.002	0.002
Threshold value	0.008 (marine biota), 0.005 (Tourism), <0.005 (Ports)			

In previous studies, Hutagalung et al., (1988) reported that Zn level varied from 0.0276-0.0501 ppm with an average of 0.0358 ppm in July 1988 in the western of Jakarta Bay and in September from 0.0007-0.0183 ppm with an average of 0.0094 ppm, in the middle varied from 0.0214-0.0501 ppm with an average of 0.0329 ppm in July, and in September from not detected to 0.0071 ppm with an average of 0.0035 ppm. In the east from 0.0286-0.3335 ppm with an average of 0.0758 ppm in July, and in September from 0.014-0.0118 ppm with an average of 0.0042 ppm. William et al., (2000) in June-December 1996 from not detected to 30.1 ppb or not detected to 30.1.10-3 ppm. Rochyatun et al., (2003) found average Zn levels in Jakarta Bay (west, middle, east) in August ranged from 0.003-0.008 ppm. Razak et al., (2003) reported, average Zn levels in Jakarta Bay (west, middle, east) in June 2003 were 0.002 ppm, 0.001 ppm, and 0.002 ppm, in September 2003 were 0.008 ppm, 0.007 ppm, and 0.003 ppm. Permanawati et al., (2013) reported Zn levels in Jakarta Bay in October-November 2010 ranged from 0,005 – 0,007 ppm. Zn levels in the open ocean <1 ppb (<0.001 ppm) and in the open ocean (open ocean) range from 0.03-70 ppb ($0.03.10^{-3}$-70.10^{-3} ppm) (Bazzy, 2014).

Arsenic (As)

In Table 7, Arsenic levels in March and September 2023 ranged from 0.0012-0.0020 ppm with an average of 0.0014 ppm, and from 0.0012-0.0020 ppm with an average of 0.0015 ppm. The average Arsenic levels are not too different between March and September.

Table. 7. As level in seawater of Jakarta Bay, ppm

St	March 2023	Sept 2023	March 2021	August 2021
A1	0.0013	0.0012	0.0023	0.0027
A2	0.0017	0.0018	0.0023	0.0027
A3	0.0012	0.0015	0.0020	0.0024
A4	0.0020	0.0017	0.0021	0.0026
A5	0.0012	0.0013	0.0013	0.0010
A6	0.0014	0.0020	0.0012	0.0014
A7	0.0014	0.0015	0.0014	0.0015
B1	0.0013	0.0016	0.0012	0.0011
B2	0.0015	0.0016	0.0013	0.0012
B3	0.0016	0.0016	0.0011	0.0013
B4	0.0019	0.0019	0.0017	0.0021

B5	0.0013	0.0012	0.0015	0.0012
B6	0.0014	0.0016	0.0013	0.0011
B7	0.0015	0.0014	0.0018	0.0021
C2	0.0013	0.0013	0.0017	0.0020
C3	0.0013	0.0013	0.0011	0.0016
C4	0.0018	0.0016	0.0015	0.0013
C5	0.0013	0.0015	0.0015	0.0013
C6	0.0013	0.0016	0.0017	0.0020
D3	0.0014	0.0012	0.0025	0.0020
D4	0.0013	0.0013	0.0011	0.0013
D5	0.0019	0.0018	0.0024	0.0019
D6	0.0013	0.0018	0.0014	0.0017
Min	0,0012	0.0012	0.0011	0.001
Max	0.0020	0.0020	0.0025	0.0027
Avg	0.0014	0.0015	0.002	0.002
SD	0.0002	0.0002	0.0004	0.0005
Threshold value	0.01 (Marine biota), 0.025 (Tourism), no criteria (Ports)			

Arsenic levels in March and August 2021 ranged from 0.0011-0.0025 ppm with an average of 0.002 ppm, and from 0.0010-0.0027 ppm with an average of 0.002 ppm. The average level of Arsenic in March is not different from August. This data shows that the waters in March and September 2023, and March and August 2021 receive input of waste containing Arsenic in the same quantity. This level of Arsenic is still lower than the threshold values set by the seawater quality standard for the benefit of marine biota, tourism, and ports (SMERI, 2004), namely 0.01 ppm and 0.025 ppm, while there are no criteria for ports. Levels of Arsenic unpolluted seawater ranged from 1-3 ppb (0.001-0.003 ppm) with an average of 1.7 ppb (0.0017 ppm) (Mandal et al., 2022). Arsenic is found in the largest ocean in the world, the mean arsenic concentration in the open ocean region of the Pacific Ocean is approximately 0.001 ppm (Batley et al., 1996).

Nickel (Ni)

In Table 8, Ni levels in March and September 2003 ranged from 0.005-0.009 ppm with an average of 0.0063 ppm, and from 0.004-0.006 ppm with an average of 0.005 ppm. Ni levels in March are higher than in September, this data shows that in March the waters received more inputs of waste containing Ni than in September. Ni levels in March and August 2021 ranged from 0.00 to 0.007 ppm with an average of 0.002 ppm, and from 0.000-0.006 ppm with an average of 0.003 ppm. The average Ni level in March was relatively lower than in August.

Table. 7. Ni level in seawater of Jakarta Bay, ppm

St	March 2023	Sept 2023	March 2021	August 2021
A1	0.006	0.005	0.004	0.005
A2	0.005	0.006	0.003	0.004
A3	0.005	0.004	0.004	0.005

A4	0.006	0.005	0.004	0.005
A5	0.008	0.005	0.004	BL
A6	0.007	0.005	BL	BL
A7	0.006	0.006	BL	0.003
B1	0.006	0.004	0.005	0.006
B2	0.007	0.006	BL	0.003
B3	0.006	0.004	0.004	0.004
B4	0.006	0.004	0.004	0.004
B5	0.007	0.005	0.005	0.003
B6	0.008	0.004	BL	0.003
B7	0.006	0.005	0.004	0.005
C2	0.006	0.005	0.003	0.004
C3	0.006	0.005	BL	BL
C4	0.005	0.005	0.003	0.004
C5	0.007	0.006	0.003	0.003
C6	0.006	0.006	0.007	0.004
D3	0.009	0.005	0.003	0.005
D4	0.005	0.006	BL	0.003
D5	0.005	0.005	BL	0.003
D6	0.008	0.005	0.004	0.005
Min	0,005	0.004	BL	BL
Max	0.009	0.006	0.007	0.006
Avg	0.0063	0.0050	0.002	0.003
SD	0.0011	0.0007	0.002	0.002
Threshold value	0.05 (marine biota), 0.075 (Tourism), no criteria (Ports)			

BL (below detection limit)

This data shows that the waters in August received more inputs of waste containing Ni than in March. This Ni content is still lower than the threshold values set by the seawater quality standard for the benefit of marine biota, tourism, and ports (SMERI, 2004) namely 0.05 ppm and 0.075 ppm, while there are no criteria for Ports. Previous study, William et al., (2000) reported, in June-December 1996 from not detected to 0.637 ppb or not detected to $0.637.10^{-3}$ ppm. Rochyatun et al., (2003) found average Ni levels in Jakarta Bay (western, middle, eastern) in August ranged from <0.001-0.002 ppm. Razak et al., (2003) found Ni levels in Jakarta Bay ranged from 0.001-0.009 ppm with an average of 0.003 ppm. Razak et al., (2003) reported average Ni levels in Jakarta Bay (western, middle, and east) in June 2003 were 0.003 ppm, 0.003 ppm, and 0.003 ppm, in September 2003 were 0.001 ppm, 0.001 ppm, and <0.001 ppm.

Chromium (Cr)

In Table 8, Chromium levels in March and September 2023 are not detected (below of limit detection), this condition was also obtained in March and August 2021. This data shows that there is no input of waste containing Cr to the waters. This Cr level is still lower than the threshold values set by the seawater quality standard for marine biota, tourism, and ports (SMERI, 2004) namely 0.012 ppm and 0.025 ppm, while there are no criteria for ports.

Table. 8. Cr level in seawater of Jakarta Bay, ppm

St	March 2023	Sept 2023	March 2021	August 2021
A1	BL	BL	BL	BL
A2	BL	BL	BL	BL
A3	BL	BL	BL	BL
A4	BL	BL	BL	BL
A5	BL	BL	BL	BL
A6	BL	BL	BL	BL
A7	BL	BL	BL	BL
B1	BL	BL	BL	BL
B2	BL	BL	BL	BL
B3	BL	BL	BL	BL
B4	BL	BL	BL	BL
B5	BL	BL	BL	BL
B6	BL	BL	BL	BL
B7	BL	BL	BL	BL
C2	BL	BL	BL	BL
C3	BL	BL	BL	BL
C4	BL	BL	BL	BL
C5	BL	BL	BL	BL
C6	BL	BL	BL	BL
D3	BL	BL	BL	BL
D4	BL	BL	BL	BL
D5	BL	BL	BL	BL
D6	BL	BL	BL	BL
Min	BL	BL	BL	BL
Max	BL	BL	BL	BL
Avg	BL	BL	BL	BL
SD	BL	BL	BL	BL
Threshold value	0.012 (marine biota), 0.025 (Tourism), no criteria (Ports)			

BL (below detection limit)

In a previous study, Hutagalung et al., (1988) recorded that Cr level varied from 0.0041-0.0157 ppm with an average of 0.0058 ppm in July 1988 in the western of Jakarta Bay and in September from 0.0002-0.0063 ppm with an average of 0.0006 ppm, in the middle from 0.0041-0.0215 ppm with an average of 0.0058 ppm in July, and in September from 0.0002-0.0063 ppm with an average of 0.0008 ppm. In the east from not detected to 0.0099 ppm with an average of 0.0050 ppm in July, and in September from not detected to 0.0063 ppm with an average of rerata 0.0007 ppm. KPPL-DKI (1992) reported, Cr levels in Jakarta Bay during 1983-1984, and 1987-1990 ranged from not detected to 0.22 ppm. William et al., (2000) in June-December 1996 from not detected to 3.98 ppm or not detected to $3.98.10^{-3}$ ppm Permanawati et al., (2013) reported Cr levels in Jakarta Bay in October-November 2010 ranged from 0.001-0.001 ppm. According to Bazzy (2014), Cr levels in the open ocean are around 0.05 ppb (0.00005 ppm).

The average level in March 2023, Cu>Pb>Ni>Zn>As.>Hg>Cd=Cr, September 2023, Zn>Pb>Cu>As>Ni>Hg> Cd =Cr, in March 2021, Zn>Cu>Pb>As=Ni>Hg>Cd=Cr, and in August 2021, Zn>Cu>Pb=Ni>As>Hg>Cd=Cr.

The results of the seawater quality analysis based on heavy metal concentration in Jakarta Bay are presented in Table 9. From the table, it can be seen that the seawater quality score in March and September 2023, and March and August 2021 was 0. This score indicates the quality of seawater in Jakarta Bay is included in category A (very good), and not polluted.

Table 9. Status of seawater quality of Jakarta Bay

No	Parameter	Unit	Seawater quality			March		Average	Score
			Ports	Recreation	Marine organism	Concentration			
						Min	Max		
March 2023									
1	Hg	ppm	0.003	0.003	0.001	0.0003	0.0012	0.0005	0
2	Pb	ppm	0.05	0.05	0.008	0.006	0.008	0.0065	0
3	Cd	ppm	0.01	0.01	0.001	bl	bl	bl	0
4	Cu	ppm	0.05	0.05	0.008	0.005	0.010	0.0073	0
5	Zn	ppm	0.1	0.095	0.05	0.019	0.028	0.0024	0
6	Cr	ppm	-	-	0.005	BL	BL	BL	0
7	As	ppm	-	-	0.012	0.0012	0.0020	0.0014	0
8	Ni	ppm	-	-	0.05	0.005	0.009	0.0063	0
	September 2023							Average	Score
No	Parameter	Unit	Ports	Recreation	Marine organism	Concentration			
						Min	Max		
1	Hg	ppm	0.003	0.003	0.001	0.0001	0.0007	0.0003	0
2	Pb	ppm	0.05	0.05	0.008	0.006	0.008	0.0066	0
3	Cd	ppm	0.01	0.01	0.001	BL	BL	BL	0
4	Cu	ppm	0.05	0.05	0.008	0.005	0.008	0.0065	0
5	Zn	ppm	0.1	0.095	0.05	0.026	0.040	0.0318	0
6	Cr	ppm	-	-	0.005	BL	BL	BL	0

7	As	ppm	-	-	0.012	0.0012	0.0020	0.0015	0
8	Ni	ppm	-	-	0.05	0.004	0.006	0.0050	0
Total Score									0
March 2021									
1	Hg	ppm	0.003	0.003	0.001	0.0002	0.0012	0.0006	0
2	Pb	ppm	0.05	0.05	0.008	0	0.007	0.004	0
3	Cd	ppm	0.01	0.01	0.001	0	0	0	0
4	Cu	ppm	0.05	0.05	0.008	0.005	0.011	0.007	0
5	Zn	ppm	0.1	0.095	0.05	0.012	0.023	0.017	0
6	Cr	ppm	-	-	0.005	0	0	0	0
7	As	ppm	-	-	0.012	0.0011	0.0025	0.0020	0
8	Ni	ppm	-	-	0.05	0	0.007	0.002	0
	August 2021							Average	Score
No	Parameter	Unit	Ports	Recreation	Marine organism	Concentration			
						Min	Max		
1	Hg	ppm	0.003	0.003	0.001	0.0004	0.0010	0.0006	0
2	Pb	ppm	0.05	0.05	0.008	BL	0.007	0.003	0
3	Cd	ppm	0.01	0.01	0.001	BL	BL	BL	0
4	Cu	ppm	0.05	0.05	0.008	0.006	0.008	0.007	0
5	Zn	ppm	0.1	0.095	0.05	0.014	0.023	0.017	0
6	Cr	ppm	-	-	0.005	BL	BL	BL	0
7	As	ppm	-	-	0.012	0.0010	0.0027	0.0020	0
8	Ni	ppm	-	-	0.05	BL	0.006	0.003	0
Total Score									0

BL (below detection limit<0.001)

Correlation between heavy metals parameter

The results of the Bivariate correlation (Pearson) analysis of Hg, Pb, Cd, Cu, Zn, As, and Ni in March and September 2023, and March and August 2021 are presented in Table 4. From the table, it can be seen that in March 2023 there is a negative correlation between Hg and As (r=-0.444), also between Cu and Zn (r = -0.543), while in September 2023 there is no correlation between parameters. Therefore it is estimated that Hg and As come from the same source as Cu and Zn, while for the other there is no correlation, and presumably originate from a different source.

Table 10. Correlation Between Heavy Metals (March 2023)

Correlations

		Hg	Pb	Cu	Zn	As	Ni
Hg	Pearson Correlation	1	.013	-.195	.344	-.444*	.119
	Sig. (2-tailed)		.955	.373	.108	.034	.590
	N	23	23	23	23	23	23
Pb	Pearson Correlation	.013	1	.047	-.199	.188	-.116
	Sig. (2-tailed)	.955		.831	.363	.391	.598
	N	23	23	23	23	23	23
Cu	Pearson Correlation	-.195	.047	1	-.543**	-.172	-.040
	Sig. (2-tailed)	.373	.831		.007	.432	.857
	N	23	23	23	23	23	23
Zn	Pearson Correlation	.344	-.199	-.543**	1	-.046	-.075
	Sig. (2-tailed)	.108	.363	.007		.836	.734
	N	23	23	23	23	23	23
As	Pearson Correlation	-.444*	.188	-.172	-.046	1	-.357
	Sig. (2-tailed)	.034	.391	.432	.836		.094
	N	23	23	23	23	23	23
Ni	Pearson Correlation	.119	-.116	-.040	-.075	-.357	1
	Sig. (2-tailed)	.590	.598	.857	.734	.094	
	N	23	23	23	23	23	23

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

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

Table 11. Correlation Between Heavy Metals (September 2023)

Correlations

		Hg	Pb	Cu	Zn	As	Ni
Hg	Pearson Correlation	1	-.266	-.207	-.371	-.067	-.350
	Sig. (2-tailed)		.220	.344	.081	.761	.101
	N	23	23	23	23	23	23
Pb	Pearson Correlation	-.266	1	-.124	.095	-.038	.280
	Sig. (2-tailed)	.220		.572	.667	.863	.196
	N	23	23	23	23	23	23
Cu	Pearson Correlation	-.207	-.124	1	.194	.338	-.055
	Sig. (2-tailed)	.344	.572		.376	.114	.803
	N	23	23	23	23	23	23

Zn	Pearson Correlation	-.371	.095	.194	1	-.046	.056
	Sig. (2-tailed)	.081	.667	.376		.834	.799
	N	23	23	23	23	23	23
As	Pearson Correlation	-.067	-.038	.338	-.046	1	-.120
	Sig. (2-tailed)	.761	.863	.114	.834		.585
	N	23	23	23	23	23	23
Ni	Pearson Correlation	-.350	.280	-.055	.056	-.120	1
	Sig. (2-tailed)	.101	.196	.803	.799	.585	
	N	23	23	23	23	23	23

In March 2021, there was a positive correlation between Ni and As (r=0.464), and As and Pb (r= 0.479), therefore it is estimated to come from the same sources, while the other does not correlate, and it is estimated to come from different sources. In August 2021 there was a positive correlation between Hg and Cu (r=0.427), while the other metals had no correlations between them.

Table 12. Correlation Between Heavy Metals (March 2021)

Correlations

		Hg	Pb	Cu	Zn	As	Ni
Hg	Pearson Correlation	1	.172	-.078	-.171	-.138	-.101
	Sig. (2-tailed)		.432	.724	.434	.530	.647
	N	23	23	23	23	23	23
Pb	Pearson Correlation	.172	1	-.347	.000	.479*	.214
	Sig. (2-tailed)	.432		.105	1.000	.021	.326
	N	23	23	23	23	23	23
Cu	Pearson Correlation	-.078	-.347	1	.130	-.315	-.053
	Sig. (2-tailed)	.724	.105		.556	.143	.810
	N	23	23	23	23	23	23
Zn	Pearson Correlation	-.171	.000	.130	1	-.287	-.141
	Sig. (2-tailed)	.434	1.000	.556		.184	.522
	N	23	23	23	23	23	23
As	Pearson Correlation	-.138	.479*	-.315	-.287	1	.464*
	Sig. (2-tailed)	.530	.021	.143	.184		.026
	N	23	23	23	23	23	23
Ni	Pearson Correlation	-.101	.214	-.053	-.141	.464*	1
	Sig. (2-tailed)	.647	.326	.810	.522	.026	
	N	23	23	23	23	23	23

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

Table 13. Correlation between heavy metals (August 2021)

Correlations

		Hg	Pb	Cu	Zn	As	Ni
Hg	Pearson Correlation	1	-.142	.427*	-.044	-.198	-.122
	Sig. (2-tailed)		.517	.042	.843	.366	.579
	N	23	23	23	23	23	23
Pb	Pearson Correlation	-.142	1	.207	.059	.148	-.202
	Sig. (2-tailed)	.517		.344	.790	.501	.355
	N	23	23	23	23	23	23
Cu	Pearson Correlation	.427*	.207	1	-.382	-.097	.016
	Sig. (2-tailed)	.042	.344		.072	.659	.943
	N	23	23	23	23	23	23
Zn	Pearson Correlation	-.044	.059	-.382	1	-.010	.028
	Sig. (2-tailed)	.843	.790	.072		.964	.900
	N	23	23	23	23	23	23
As	Pearson Correlation	-.198	.148	-.097	-.010	1	.229
	Sig. (2-tailed)	.366	.501	.659	.964		.293
	N	23	23	23	23	23	23
Ni	Pearson Correlation	-.122	-.202	.016	.028	.229	1
	Sig. (2-tailed)	.579	.355	.943	.900	.293	
	N	23	23	23	23	23	23

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

The absence of this correlation has also been encountered by several researchers, Sun et al., (2019) reported that there was no stronger correlation between the heavy metal elements (Cu, Pb, Zn, Cd, Hg, and As) in seawater, than Mahboob et al., (2021) in Arabia Bay found the negative correlations among Sr and many metals such as Cr, Pb, As Co, Zn, negative correlations between Zn and Be, Cu, As, Cd, Pb, and Co, and negative correlation was also recorded between Pb and Be. Thus it can be assumed that the six heavy metals come from different sources. These sources can come from activities in the waters (ship traffic, ports, docking), from the mainland entering Jakarta Bay through 13 streams (industrial, agricultural, residential waste), and input from the air.

Conclusion

The status of seawater quality in Jakarta Bay is based on heavy metal content metal is still good and is still under its designation, namely ports, marine tourism, and marine biota cultivation, there is no relationship between heavy metals parameters, exception for Hg and As, Cu and Zn, Ni and Cu, Pb and As.

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